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Appropriate LRPs for Southwest Pacific Ocean Striped Marlin and Other Billfish

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Stephen Brouwer[1] and Paul Hamer[2]

[1] **Saggitus Consulting**

[2] **Oceanic Fisheries Programme, The Pacific Community (SPC)**

Contents

Executive Summary

This paper represents the report of Scientific Committee Project 104 "LRPs for southwest Pacific Ocean (SWPO) striped marlin and consideration of other billfish species". It reviews the work done on establishing Limit Reference Points (LRPs) within the WCPFC and considers options for a LRP and relevant performance indicators for SWPO striped marlin and other billfish. The paper discusses potential LRPs for stocks assessed with data-rich, medium-data and data-poor assessment methods[1]. For data-rich assessments LRPs measuring the dynamic spawning biomass depletion ($SB/SB_{F=0}$) seem appropriate for SWPO striped marlin and other billfish. Stocks assessed using medium-data assessment methods could use empirical LRPs (e.g., CPUE-based), but these require a reliable index with a reasonable degree of confidence that the index tracks trends in the stock biomass consistently. Stocks assessed using data-poor methods could also use empirical LRPs provided there is an informative signal in the data used to indicate stock abundance, or risk-based fishing mortality benchmarks, derived from life history information, as an interim once off assessment of stock vulnerability. Due to the insufficient knowledge of steepness for WCPO billfish stocks, consistent with the target tuna stocks and the hierarchical approach for tuna LRPs endorsed by WCPFC8, MSY-based reference points for stock biomass are currently not recommended as LRPs for WCPO billfish.

Life history parameters (growth, maximum age, natural mortality, age-at-maturity) of SWPO striped marlin and SWPO swordfish are comparable to the WCPO target tuna species. Therefore, using a depletion based LRP for these stocks would be consistent with the approach applied to target tuna stocks (i.e. 20% $SB/SB_{F=0}$). Prior to the agreement of fishery objectives for these stocks, the LRPs applied to tuna could be used as interim LRPs for SWPO striped marlin and SWPO swordfish. Noting also that striped marlin and swordfish were previously considered in the work by Preece et al. (2011) that guided the choice of the depletion LRP for target tuna. For stocks where biological knowledge is more limited, an extension to the hierarchical approach to developing LRPs defined by Preece et al. (2011) is suggested for WCPO billfish stocks.

The wider review notes that in some settings, fishery managers have considered a more risk prone approach to LRPs for bycatch species if the objectives for those stocks are different to target tuna species. Characterisation of species as bycatch, non-target and target species and the development of alternative objectives for each has not been considered by the WCPFC. Significantly, we note that where the underlying biology of target and bycatch stocks are comparable, there is no clear basis for setting the biological limits, defined by their LRPs, at different levels. The acceptable risk of falling below a LRP is a management decision, however; that risk may be explicitly stated to be different between target and bycatch stocks, and should ideally be determined to support the achievement of fishery objectives for each stock.

The following recommendations are proposed for the SC17 to consider.

1. The WCPFC should develop interim objectives for SWPO striped marlin to guide

[1]**Data-Rich Assessments** = full integrated stock assessment model using multiple sources of data including catch, effort and biological information in a model such as MULTIFAN-CL, Stock Syntheses or similar; **Medium-Data Assessment** = Model that uses catch and effort data with/or without some biological parameters to get an estimate of fishing mortality (F) such as Surplus Production models; **Data-Poor Assessments** = Analyses that estimate a level of risk but do not derive estimates of F.

the appropriate levels for any agreed LRP and the associated maximum risk levels for breaching a LRP.

2. In the interim, a LRP equivalent to 20% $SB/SB_{F=0}$ for SWPO striped marlin could be used, consistent with the logic behind the application to key tuna stocks.
3. For the other WCPO billfish - develop objectives as species groups, by dividing Western and Central Pacific Ocean (WCPO) billfish into: target species (swordfish); data-rich bycatch species (striped and blue marlin); medium information species with moderate levels of catch (black marlin); and data-poor low-catch bycatch (shortbilled spearfish and sailfish).
4. Consider Table 7 as a list of Limit Referent Point metrics that could be used for WCPO billfish.
5. Consider the values presented in Table 9 for SWPO striped marlin and swordfish as potential LRPs for these and other billfish species.
6. Assess the remaining stocks against the proposed LRPs in Table 7 and Table 9 to determine the appropriate LRPs.
7. Any new proposed LRP metrics that are developed in the future, should be assessed against those presented in Table 7.
8. Incorporate these decisions into the Billfish Research Plan that is scheduled to be developed in 2022 and focus that work on developing objectives, assessing LRPs for each species, and determining if a pathway to a higher level of information and knowledge should be developed.
9. The proposed risk-based fishing mortality benchmarks should be defined as dependent variables in the two main assessment platforms used (SS and MFCL) so that statistical uncertainty of the estimates can be calculated.

1 Introduction

Under global commitments to conserve marine biodiversity and ecosystems, fisheries management should aim to conserve both target and non-target or bycatch species (Curtis et al., 2015). Management benchmarks, in the form of reference points, are often used to gauge how well a fish stock is performing relative to fishery management and conservation objectives. The need for reference points within the Western and Central Pacific Fisheries Commission (WCPFC) context arises from Article 6 of the WCPFC Convention text, and Annex II of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the conservation and management of straddling fish stocks and highly migratory fish stocks (referred to here as the UN Fish stocks agreement [UNFSA]). Both the UNFSA and WCPFC Convention Text require the development of reference points, which should be stock-specific and can take socio-economic conditions into consideration. Article 5 of the Convention Text and Annex II of UNFSA also note that Regional Fishery Management Orginisations (RFMOs) should promote objectives for optimal utilisation, and that stocks should be capable of producing the Maximum Sustainable Yield (MSY) and ensure that there should be a low probability of reaching the Limit Reference Point (LRP) where these are specified. In addition, Article 5 (e and f) of the Convention Text indicates that Members shall *. . . adopt measures to minimize waste, discards. . . and protect biodiversity in the marine environment*. The WCPFC is therefore required to consider establishing reference points for exploited stocks in the Commission's convention area. To this extent significant work has gone into developing reference points for the key target tuna stocks Preece et al. (2011) and exploring options for non-target species, specifically elasmobranchs Clarke and Hoyle (2014) and Zhou et al. (2019).

For target species, two main types of reference points are required to gauge stock and fishery performance against management objectives: *Target Reference Points* (TRP) and *Limit Reference Points* (LRP). Caddy (1999) discussed the concept of reference points as a management traffic light system with points to aim for, points when management action is triggered and finally points to avoid. TRPs are typically used to indicate the stock size and/or fishing mortality levels to which management should aspire and LRPs indicate the levels to avoid (Caddy, 2002). Reference points clearly should relate to specified management objectives. However, Pilling et al. (2019) noted that, in the absence of other objectives, the main biological consideration for a TRP is that it should be sufficiently above the LRP so that if the TRP is achieved on average, the risk of breaching the LRP is acceptably low. While objectives for TRPs can often be difficult to develop because they typically relate to social and economic aspirations from a fishery, which can vary among stakeholders, and often require considerable negotiations to agree on. Therefore, objectives for LRPs should be less contentious and directed more by generic objectives for biological sustainability, that is avoiding stock collapse and long-term impairment of recruitment.

The work by Preece et al. (2011) sets a basis for the WCPFC to develop a LRP for biomass depletion for the key tuna species. However, despite the work by Preece et al. (2011), that also specifically considered swordfish and striped marlin no LRPs have been adopted for billfish. Further work was requested by the WCPFC Scientific Committee (SC) to explore options for a LRP for billfish, and specifically, for southwest Pacific Ocean (SWPO) striped marlin, under Project 104.

Depending on the species and fishery, billfish may be viewed as target, non-target or bycatch. This may have implications for determining LRPs, and specifically the risk of falling below those biologically critical levels. Irrespective of their targeting status billfish are apex predators in marine food webs, and managing fishery impacts on billfish is important from an ecological sustainability perspective (Baum and Worm, 2009). Similar to tuna, billfish are thought to be relatively productive and resilient to fishing due to their fast growth and high fecundity, but understanding billfish population trends and responses to fishing pressure is challenging due to data limitations. With the exception of perhaps swordfish and striped marlin, billfish species are often not well recorded in fishery logbooks, have varying levels of historical reporting and retention, and have limited knowledge of biology and life history parameters. Billfish in general therefore lack information to use when developing reference points for conservation and management. However, there are a variety of options for developing LRPs depending on the data availability and life history information. This paper builds on the work of others such as Clarke and Hoyle (2014) and Zhou et al. (2019) who considered LRPs for use within the WCPFC for elasmobranchs. The main aim being to provide the SC Members, Cooperating Non-members and Participating Territories (CCMs) with advice and options on LRPs for SWPO striped marlin, and other billfish.

This work is being undertaken as Project 104 of the WCPFC SC and the following Terms of Reference were provided:

1. Literature review of LRPs used for SWPO striped marlin (and other billfish with similar biological characteristics, e.g., blue marlin, black marlin, swordfish) in other jurisdictions;
2. Meta-analysis to provide insights into the levels of depletion and fishing mortality that may serve as appropriate LRPs for SWPO striped marlin and consider relevance for other billfish;
3. Assess the appropriateness of the WCPFC hierarchical approach for defining LRPs for billfish in the WCPO and, if not appropriate, recommend alternatives;
4. Review the key data requirements and feasibility of potential LRP options considering currently available information for SWPO striped marlin;
5. Estimate candidate LRPs and their associated uncertainties for SWPO striped marlin; and
6. Recommend additional information requirements to improve the estimation of LRPs for SWPO striped marlin and other billfish (i.e., blue marlin, black marlin, swordfish) as either target or non-target species.

Given the volume of work presented here, We first provide a summary of the findings against these Terms of Reference. Subsequent sections provide the discussion and analyses that led to those findings.

2 Response to the Terms of Reference

The detail relating to the Terms of Reference are covered in the following sections. However, a specific response to each is provided here.

1. Literature review of LRPs used for striped marlin (and other billfish with similar biological characteristics, i.e., blue marlin, black marlin, swordfish) in other jurisdictions.

   - There are numerous stock assessments evaluating the status of striped marlin stocks as well as other billfish. Most of them report against MSY based reference points. These "default" metrics are used simply because there are few agreed billfish-specific LRPs. There are also numerous studies providing general guidance on LRPs but not specifically for striped marlin.

   - A number of jurisdictions have recognised LRPs for striped marlin and other billfish as reported in Table 8.

     (a) The Australian Commonwealth Harvest Strategy Policy has a default proxy biomass LRP of 20% B_0 and F-based LRP of $F/F_{MSY} = 1$ which applies to their domestic harvest strategies. These defaults apply to both striped marlin and swordfish (Department of Agriculture and Water Resources, 2018).

     (b) Swordfish in ICCAT (ICCAT, 2017) have a biomass LRP of $0.4*B_{MSY}$.

     (c) Swordfish in IOTC (IOTC, 2015) have a biomass LRP of $0.4*B_{MSY}$ and an F-based LRP of $1.4*F/F_{MSY}$ (i.e. $F/F_{MSY} = 1.4$) Table 8.

     (d) In New Zealand for both swordfish and striped marlin have default LRPs of 20% SB_0 (soft limit) and 10% SB_0 (hard limit) (Fisheries New Zealand, 2020).

     (e) The USA Western Pacific Regional Fishery Management Council uses MFMT[2], MSST[3] and B_{FLAG} (Western Pacific Regional Fishery Management Council, 2009). These estimates are derived from F_{MSY}, B_{MSY} and M. They apply to swordfish, blue marlin and other billfish which we assume to include striped marlin.

2. Meta-analysis to provide insights into the levels of depletion and fishing mortality that may serve as appropriate LRPs for SWPO striped marlin and consider relevance for other billfish.

   - SWPO striped marlin life history parameters that influence productivity and resilience to fishing are similar to most WCPO target tuna stocks (except for skipjack tuna) (Figure 2), which have established LRPs. This implies that, biologically, for SWPO striped marlin any LRP should be at least equivalent to that of the target tuna LRPs (i.e. 20% $SB/SB_{F=0}$).

   - SWPO swordfish are less productive than the target tunas, but not markedly so. This suggests that, biologically, SWPO swordfish should also have a depletion-based LRP that approximates 20% $SB/SB_{F=0}$.

   - To compare the other billfish species, estimates of natural mortality rate and age-at-maturity are required for the WCPO stocks. However, reviewing work conducted elsewhere suggests that blue marlin is likely less productive than

[2]Maximum Fishing Mortality Threshold
[3]Minimum Stock Size Threshold

swordfish; black marlin and sailfish appear similar to striped marlin; and the biology of shortbilled spearfish is poorly understood.

3. Assess the appropriateness of the WCPFC hierarchical approach for defining LRPs for billfish in the WCPO, and if not appropriate recommend alternatives.

   - The hierarchical approach developed by Preece et al. (2011) and endorsed by the WCPFC8 is an appropriate way to guide the choice of potential reference point metrics for all species, not just tuna, as noted in that report.
   - A number of additional metrics could be included in the hierarchy if the WCPFC wishes to expand the utility of the hierarchical approach to account for specific data limited situations, as demonstrated in Table 1. Preece et al. (2011) omitted empirical reference points and risk-based fishing mortality benchmarks.
   - An additional "Level 4" is recommended to be included to account for LRPs based on empirical metrics.
   - Risk-based fishing mortality benchmarks should be included as "Level 5" metrics for data-poor stocks.
   - There would be some value in separating species that are specifically targeted from those that are non-target/bycatch species if these can be objectively defined. While the metrics can be the same the value of each metric could differ when assigning the specific LRP for a species. However, where the biology of species or stocks are comparable, there appears no clear basis for setting the biological limits defined by their LRPs at different levels. Managers may explicitly define different levels of risk of falling below a LRP to reflect the difference between target and non-target/bycatch species.

4. Review the key data requirements and feasibility of potential LRP options considering currently available information for SWPO striped marlin.

   - The metrics are presented in Table 7. They fall within three categories with respect to their data requirements:

     (a) Metrics derived from an integrated stock assessment model - $SB/SB_{F=0}$; $SB/SB_{F=0\ t1-t2}$; $SB/SB_{F=0}$_low; $x\%$ B_0; B_{0t1-t2}; and Biomass_low. These metrics require estimates of growth, maturity, and size composition as well as reliable long-term catch and effort data.

     (b) Empirical reference point metrics - $x\%$ $CPUE_0$, $CPUE_{t1-t2}$ and CPUE_low. These metrics require reliable catch and effort data and a CPUE index that is thought to track stock biomass. For $CPUE_{t1-t2}$ and CPUE_low the index has to have declined to a low undesirable level and then recovered.

     (c) Spawning potential ratio (SPR) and risk-based fishing mortality benchmarks - F/F_{lim}, and F/F_{crash}. These require estimates of natural mortality, growth parameters, the intrinsic population growth rate and selectivity. To monitor these over time would require the ongoing estimation of the current F level and ideally the re-estimation of F_{lim} and F_{crash} as new biological information becomes available.

- It is technically feasible to calculate all of these metrics for SWPO striped marlin. However, not all of these metrics would be useful. The risk-based fishing mortality benchmarks provide a method for assessing relative risk but these would be static, if based solely on biological characteristics. Stocks would still have to be assessed regularly to monitor status against these reference points. The empirical reference points noted above can be calculated, but selecting a suitable CPUE series and deciding on a reference period for determining the LRP would require stakeholder endorsement. The metrics derived from an integrated stock assessment model are likely to be the most useful and should be applied preferentially over the other metrics.

5. Estimate candidate LRPs and their associated uncertainties for SWPO striped marlin.

    - Thirteen options for LRPs for SWPO striped marlin were developed and are compared in Table 6. Those results are presented as examples but CCMs will need to decide on the preferred LRP options, and the years used for any time-bound reference points that are considered.

6. Recommend additional information requirements to improve the estimation of LRPs for SWPO striped marlin and other billfish (i.e. blue marlin, black marlin, swordfish) as either target or non-target species.

    (a) Target species - swordfish: To improve the swordfish estimates higher levels of observer coverage particularly on the high seas vessels targeting swordfish would improve catch estimates, provide length data and verify logsheet catch, all theses would improve the estimates from the stock assessment.

    (b) Bycatch species (data-rich) - SWPO and NP striped marlin and blue marlin: Higher levels of observer coverage particularly on the high seas vessels to provide better estimates of the fate and condition of the catch, collect length composition data and biological samples.

    (c) Bycatch species (medium-data) - black marlin: Higher levels of observer coverage particularly on the high seas vessels to provide better estimates of the fate and condition of the catch; improved length data, WCPO specific growth and maturity estimates are required.

    (d) Bycatch species (data-poor) - sailfish and short-billed spearfish: Higher levels of observer coverage particularly on the high seas vessels to provide better estimates of the fate and condition of the catch; improved biological data including length, growth and maturity estimates are required.

    (e) For all species, increased reporting of gear covariates in logbooks (such as light stick use/bait type/float line depth/branch line depth/etc. . .) would be useful to augment CPUE standardization efforts and support more representative indices of abundance.

3 Developing Limit Reference Points

A broad review of all qualitative and semi-quantitative information on both the fishery and life history information is important to inform the development of LRPs. Caddy (1999) proposed qualitative or semi-quantitative estimates be incorporated into reference point setting and that a range of reference points can be considered simultaneously (i.e., using multiple lines of evidence) and if most concur, then any of them could potentially be used as a management reference point. Limit Reference Points (LRPs) should ideally be based on biological parameters that can be estimated from existing data and models; should be straight-forward and easy to explain and understand; and create strong incentives to reduce mortality as they are approached. Finally, they should be defensible and robust to uncertainty in a species' biology and the estimation approaches (Curtis et al., 2015). The metrics and levels of the LRP also need to be considered in the context of the fisheries management objectives (Curtis et al., 2015). The first step, therefore, should be deciding on the objectives for the species/stock. We note that objectives for guiding development of LRPs for billfish have not been explicitly stated. However, without objectives, the metrics may be considered, and LRPs will almost always be measures of population status and fishing mortality. The actual values and risk tolerance, however, should be relevant to meeting stated objectives, and while some options can be proposed, the choice of LRP levels will require additional consideration by the WCPFC.

Ideally some level of risk should be incorporated into the process of defining LRPs. This would include consideration of the acceptable risk of breaching the LRP as well as the uncertainty of estimating the reference point. There are clear advantages to incorporating risk, in the form of uncertainty, explicitly into LRP estimators. There are two aspects of uncertainty that will need to be considered: 1) uncertainty in how effective a chosen LRP level will be at meeting the management objective for the stock; 2) uncertainty in estimating the LRP, i.e., what is the uncertainty of being above or below the LRP. Applying the precautionary principle where there is less certainty in either of these aspects, the risk tolerance should be lower.

Once the LRP metric, value and risk tolerance are defined, management action can be structured in response to the LRP. Risk tolerance might depend on a population's current status (Moore et al., 2013), productivity, or other information, where management responses can be more risk averse for less productive species. Zhou and Griffiths (2008) suggested that for unprotected species of low economic or cultural value, depletion to lower abundance or accepting higher levels of risk that a LRP may be breached might be acceptable, as the consequences of breaching the LRP may be considered less severe. This poses the questions of whether different LRPs should be considered for target species (i.e. with associated social and economic importance) and non-target/bycatch or secondary species in a fishery, irrespective of the species' biology. However, Zhou et al. (2019) noted the distinction between target and non-target or bycatch species is a result of human values and utilisation, rather than one of biology or ecology. As such they argued that there is no biological basis for bycatch and target species to have different LRPs. We note that the risk of falling below the LRP is a management decision. Managers can explicitly state their specific risk tolerance for target and non-target species falling below the LRP using this mechanism.

For non-target species, fishing mortality will be primarily influenced by the effort directed towards the target species, as such, low catch rates (and low abundance) of non-target species will not necessarily lead to reduced fishing pressure on them. If the non-target species have different biology; vulnerability to gear; and are generally less resilient to fishing than the target species, they can be at higher risk of being severely depleted if the fishing effort is managed solely on considerations for the target species. Without management arrangements that consider both target and non-target species, the non-target species could be overfished while the target is sustainably exploited. This question has not been addressed at the WCPFC and is perhaps problematic in an overall RFMO (Regional Fisheries Management Organisation) context. Some member countries, or fleets, will consider a species a target species while others will consider it non-target of low value, and yet others may consider it as a valuable by-product species. Swordfish aside, other billfish species including SWPO striped marlin likely fall somewhere in the non-target species category, and are therefore vulnerable to the scenario discussed above in the absence of specific formal LRPs.

True target species are typically the focus of data collection, biological research and stock assessment, and therefore generally have more information available for developing and estimating informative reference points. Conversely, developing reference points for non-target or true bycatch species that have lower socio-economic value is challenging because of a general lack of data, especially over the longer-term. Billfish suffer from this issue to varying degrees depending on the species/stock. Considerable work has occurred worldwide to deal with these data challenges and develop the most appropriate reference points for non-target or low data species. Within the WCPFC the most notable work has been that of Davies and Polacheck (2007); Davies and Basson (2008); Norris (2009); Harley et al. (2009); Clarke and Hoyle (2014); Pilling et al. (2019); Zhou et al. (2019) and Neubauer et al. (2019). While biomass, biomass depletion and fishing mortality based LRPs are typically determined through stock assessment modelling using a range of data, alternative metrics such as empirical reference points based on CPUE, or risk-based fishing mortality benchmarks derived from life-history information can be used to develop LRPs where data is limited (Zhou et al., 2019). While such metrics are yet to be adopted as a basis for LRPs by the WCPFC, in this paper we consider a range of options for developing LRPs for SWPO striped marlin and other billfish, that encompass data-rich biomass and fishing mortality based LRPs applied to the key tuna species, to risk based metrics considered for the data-poor elasmobranchs.

There is guidance for decisions on developing LRPs in Preece et al. (2011). They developed a hierarchical approach to developing LRPs (Table 1), that was endorsed by WCPFC8. The hierarchical approach provides guidance for choosing LRP metrics and is also a useful guide to removing metrics that are inappropriate or can not be supported by the data available or for those stocks with uncertain assumptions. Acknowledging the differences in stock status reporting for the north and south Pacific stocks, we note that the Preece et al. (2011) hierarchical approach is a legitimate starting point for considering LRPs for WCPO billfish stocks, including SWPO striped marlin. As the level of knowledge about stock status and biology for a number of Western and Central Pacific Ocean (WCPO) billfish is limited, a single LRP metric may not be possible or appropriate for all WCPO billfish. To guide LRP development for lower information non-target species under a structured process we recommend revisiting Preece's hierarchical table in light of the work on elasmobranchs Zhou et al. (2019) and now billfish. We have suggested additional levels in Table 1 as a starting point for enhancing the hierarchical process. Specifically, we note that within the WCPFC, for South Pacific albacore, CPUE has been used as a basis for identifying benchmark years to guide the determination of a spawning biomass depletion TRP, but empirical biomass proxies such as CPUE are currently not included as reference point options in the hierarchical approach of Preece et al. (2011). Risk based indicators are also suggested by Zhou et al. (2019). Therefore, CPUE biomass proxies could be added as a Level 4 category and other risk-based fishing mortality benchmarks, could be added as Level 5.

4 Conceptual Limit Reference Points

The most recent billfish stock assessments in the WCPFC have been carried out on striped marlin in the southwest (Ducharme-Barth et al., 2019) and northwest (ISC, 2019) Pacific; swordfish in the southwest (Takeuchi et al., 2017) and northwest (ISC, 2018) Pacific; and Pacific blue marlin (ISC, 2016). In addition, Pacific blue marlin and south west Pacific swordfish are scheduled for assessments in 2021 (WCPFC, 2020). These assessments are all "integrated assessments" implemented in either MULTFAN-CL (MFCL) or Stock Synthesis (SS), and provide various model derived management quantities for biomass and fishing mortality. The options for LRPs for these billfish therefore encompass most LRPs considered here. Although LRPs for billfish are not formally stated in WCPFC conservation and management measures for southern or northern stocks, MSY is entrenched in reporting as it is referenced in the WCPFC Convention Text. It is notable that the reporting of reference points varies across the north and south Pacific billfish stocks, with the status of North Pacific stocks being reported against MSY based reference points typically summarised in a Kobe plot (F/F_{MSY} and SB/SB_{MSY}), whereas for the South Pacific stocks, stock status reporting places stronger emphasis on dynamic spawning biomass depletion ($SB_{recent}/SB_{F=0}$), while also reporting F/F_{MSY} (and SB/SB_{MSY}) summarised in both Majuro and Kobe plots. The main difference between the Kobe and the Majuro plot is that for the Kobe plot a stock is classified overfished when the spawning biomass is estimated to be less than the spawning biomass expected to deliver the MSY (i.e., SB/SB_{MSY1} <1), whereas for the Majuro plot a stock is classified overfished when the spawning biomass is estimated to be less than 20% of the spawning biomass that would be expected if no fishing had occurred over a recent period (i.e., $SB/SB_{F=0} < 0.2$), referred to as the "dynamic spawning biomass depletion" (for descriptions of all metrics used in this report please see Appendix I). Both imply that overfishing is occurring when the current F is greater than that which would maintain the stock at SB_{MSY} (i.e., F/F_{MSY} >1).

Based on the standard MSY and spawning biomass depletion reference points in the respective Kobe and Majuro plots of recently available assessments, both WCPFC swordfish stocks would not be considered overfished and overfishing is not taking place; striped marlin in the north Pacific would be considered overfished and overfishing is taking place; southwest Pacific striped marlin would be considered likely to be overfished and close to experiencing overfishing; and the stock status of black marlin, sailfish and shortbilled spearfish are unknown (Table 2). Despite the reporting against these standard stock status and fishing mortality metrics none of the WCPFC billfish stocks have formally agreed LRPs for management advice. This creates ambiguity, as B_{MSY} as an overfishing reference point is designed for an MSY objective, whereas spawning biomass depletion ($SB/SB_{F=0}$) is not directly linked to a MSY objective, but is more focussed on ensuring a certain level of spawning biomass is maintained. It is possible that for a given stock size, one biomass reference point could indicate an overfished state and the other not. Further, SB_{MSY} is a more conservative biomass reference point than the spawning biomass depletion $SB/SB_{F=0} = 0.2$ currently applied as a LRP for the target tuna species in the WCPO.

Besides the standard reference points for biomass and F, many other reference points are reported in WCPFC billfish stock assessments. A review of reported reference point metrics across the recent WCPO billfish assessments indicated that 26 reference point metrics have been used (Table 3). Of these nine are F-based (including three that relate to spawning potential ratio [SPR]), 14 are biomass based, and three are catch or yield based. The list in Table 3 provides a considerable range of options for managers and stakeholders to digest and understand, and the origins or reasons for many reference points being included are unclear, but no doubt relate to various requests from CCMs over time to include them in reporting. While the list of reference points might grow even further, in relation to developing formal LRPs, the key reference points need to be identified and standardised across assessments and separated out from all the other reference points of interest to various groups. Ideally for a LRP, a specific metric and level is chosen for biomass status and another for fishing mortality status. Although multiple metrics and LRPs could be developed, this risks creating confusion in managers and stakeholders. Where conventional metrics can not be estimated alternatives will need to be considered.

5 MSY as a basis for LRPs

5.1 MSY

As the concept of MSY is omnipresent in the development of fisheries management strategies and reference points, it requires some focused discussion within the context of a LRP for SWPO swordfish and other billfish. MSY is the largest long-term average yield or catch that can be taken from a stock under prevailing fishery selectivity, ecological and environmental conditions, without impairing its ability to maintain the population through natural growth and reproduction. For many quota managed stocks, the total allowable catch is set at a level that either moves the stock towards or maintains the stock at or above a biomass level that can support MSY. In other words, the biomass that produces MSY (i.e., B_{MSY}) is often considered the ideal place for a stock to be maintained over the long-term (see below). If the sole objective is to maximize yield, achieving MSY is often the target of fishery managers, rather than a limit. However, under some circumstances, in order to reduce the risk of fishing past MSY, managers may set a more precautionary catch at below the estimated MSY. This is often the case when the estimation of MSY is more uncertain, and the precautionary principle is applied.

MSY is a useful concept and valid objective for management if it can be estimated accurately, and ensuring the catch remains at or below the estimated MSY could be considered as a basis for a catch based LRP. MSY is not a measure of stock status or fishing mortality, and as such is not considered in the context of a LRP for stock status. Achieving MSY is also not typically a management objective for non-target or bycatch species.

MSY is difficult to predict with high certainty without fishing the stock to levels below

B_{MSY} and then observing it rebuild. As such determining MSY with any degree of certainty requires a long time series of information with a strong contrast in the observed trends. Further, MSY reference points are based on equilibrium assumptions, whereas in reality MSY is not constant through time due to changes in productivity of the stock, e.g., recruitment variation, regime shifts (Nishijima et al., 2021) and potentially changes in size-at-capture (selectivity) (Tremblay-Boyer et al., 2017; Vincent et al., 2020) (Figure 1). The recent WCPFC yellowfin tuna assessment conducted by Vincent et al. (2020) demonstrated clearly the impact that changes in fishery selectivity have on MSY. Figure 1 shows that in around 1970, the MSY level halves as a result of the introduction of data from new "miscellaneous" fisheries that catch very small fish. For these reasons MSY is not considered a useful metric as a LRP.

5.2 F_{MSY}

F_{MSY} is the fishing mortality (F), under the current selectivity regime, and biological productivity assumptions, that if applied over the long-term would maintain the stock on average at the biomass that produces MSY (B_{MSY}). Where achieving MSY is a management objective, LRPs can potentially be set for F so it is maintained at some level in relation to F_{MSY}, i.e. x% F/F_{MSY}.

5.3 B_{MSY}

B_{MSY} is the biomass that under the current selectivity regime and biological productivity assumptions should produce the MSY on average. Clearly where achieving MSY is a management objective, the stock should be maintained at or above B_{MSY} if this can be calculated with confidence. The question often arises as to whether B_{MSY} should be considered a TRP or a LRP, and if it is the basis for a LRP, is the LRP equal to B_{MSY} or some fraction of B_{MSY}?

Given the high profile of MSY in fisheries management, there has been a large focus on estimating MSY and MSY based reference points for data-rich stocks and estimating equivalent values for medium-data and data-poor stocks[4]. WCPFC discussions on LRPs for bycatch species have often focused on MSY and developing reliable MSY proxies.

MSY is a concept developed around maximising yield, rather than preserving a critical level of spawning biomass, and its relevance to non-target species, and in relation to defining LRPs is questionable. To this end, explicitly defining the conservation and management objectives for billfish stocks is important to underpin the choice of LRPs and assess whether MSY based reference points are suitable.

Clarke and Hoyle (2014) note the difficulties in estimating MSY. Reliable estimates of selectivity parameters, and good knowledge of the stock-recruitment relationship, in particular the steepness parameter are required to estimate MSY. Clarke and Hoyle (2014) suggest that, as it is based on yield and sensitive to changes in fishing selectivity, B_{MSY}

[4] **Data-Rich Assessments** = full integrated stock assessment model using multiple sources of data including catch, effort and biological information in a model such as MULTIFAN-CL, Stock Syntheses or similar; **Medium-Data Assessment** = model that uses catch and effort data with/or without some biological parameters to get an estimate of fishing mortality (F) or MSY such as Surplus Production models; **Data-Poor Assessments** = Analyses that estimate a level of risk but do not derive estimates of biomass, MSY or F.

may not be relevant to the conservation objectives intended for LRPs. In turn, as noted by Preece et al. (2011) in their extensive review on this matter, where confidence in the knowledge of the stock recruitment relationship is poor, MSY based reference points are not viewed as appropriate.

Given our inability to confidently estimate the steepness of the stock recruit relationship and given its strong influence on the resulting MSY parameters, we suggest that alternative metrics should be sought for developing LRPs for SWPO striped marlin and billfish in general.

The use of MSY based reference points for billfish is not supported under the Preece et al. (2011) hierarchy, and the SC17 may need to consider resolving whether:

1. MSY should be an objective for considering a LRP for billfish within the WCPFC?;
2. And, if so, what fraction of B_{MSY} or F_{MSY} should be considered for an LRP?

6 WCPO billfish Productivity

When considering a LRP for a species, its biological productivity and resilience to fishing should be considered. Life history parameters, including; growth parameters, length- and age-at-maturity, fecundity, maximum age and natural mortality are important indicators of a species productivity and resilience to fishing (Zhou et al., 2019a). It follows that species with similar life history parameters can be considered to have similar productivity and resilience to fishing. This provides a sound biological basis for considering applying similar LRPs to groups of species, i.e. "tuna like species". Noting that considerable work has gone into establishing the LRPs for WCPFC tuna, it is worthwhile to compare the life history parameters of SWPO striped marlin and other WCPO billfish against the WCPO tuna species that have the accepted LRP of $SB/SB_{F=0}$=0.2. Figure 2 and Table 4 present a comparison between life history parameters for SWPO striped marlin and swordfish and the main WCPO target tuna species.

This broad comparison shows that both SWPO striped marlin and swordfish reach a larger length- and weight-at-age compared to the tunas and that swordfish is longer lived than any of the tuna considered here. In addition, the natural mortality rates of SWPO striped marlin and swordfish are lower than skipjack and yellowfin tuna but similar to bigeye and albacore. Lastly, the spawning potential ogives, and maturity-at-age schedules show that SWPO striped marlin and in particular swordfish, have a lower spawning potential-at-age than that of the tunas. These data suggest that SWPO striped marlin and swordfish are at best as productive, but probably less productive than WCPO target tuna, and for the key parameters of M and age-at-maturity they are most similar to bigeye and albacore.

In order to compare the other billfish species, estimates of natural mortality rate and age-at-maturity are required for the WCPO. However, work done elsewhere suggests that blue marlin is likely to be less productive than swordfish (Hoolihan et al., 2019); black marlin and sailfish appear similar to striped marlin (Zhou et al., 2019b); and shortbilled spearfish productivity is poorly understood. Overall, considering the biology of billfishes, and in particular of SWPO striped marlin, there appears no clear justification based on life history to suggest that they are more productive or resilient than the target tunas in the WCPO. As such, LRPs that provide less protection for striped marlin than those accepted for the target tuna stocks would seem inappropriate if they are to be held to the same conservation standards/objectives as the tuna stocks.

6.1 Biomass and Fishing Mortality Based Reference Points

If a reliable time series of catch and effort data, information on size composition, growth, reproductive biology (maturity ogives), and natural mortality are available, then total biomass (B) and spawning biomass (SB) levels can be estimated within integrated assessments (Maunder and Punt, 2013). Integrated assessment have been conducted for swordfish and striped marlin in the WCPO, and can produce various performance measures for stock biomass that can be used to develop LRPs (e.g. $SB/SB_{F=0}$, SB/SB_0, B/B_0, B/B_{MSY}, SB/SB_{MSY}). Table 5 presents a number of options for reference point metrics. These would comprise the Level 1 and Level 2 elements of the Preece et al. (2011) hierarchical approach (Table 1). For SWPO striped marlin and other billfish, determining biomass based LRPs within "Level 1", i.e., B_{MSY}, is not recommended as they do not meet the criteria of having a reliable estimate of steepness. While it is feasible to estimate B/B_{MSY} and develop somewhat uncertain LRPs based on a chosen fraction of this ratio, i.e., x% B/B_{MSY}, this has not been adopted for the key target tuna species within the WCPFC, primarily due the uncertainty in estimation of MSY based quantities, and therefore by default also seems inappropriate for billfish. This leaves the depletion-based reference points, SB/SB_0 and $SB/SB_{F=0}$ and B/B_0, as candidates for billfish stocks with integrated assessments.

For LRPs we suggest that maintaining spawning biomass above a certain level is more relevant than maintaining total biomass above a certain level, as the biological objectives of LRPs are generally developed considering conservation of reproductive potential. This is the case for the target tuna species, where biomass based reference points are based on spawning biomass rather than total biomass. Further, due to the typically high uncertainty in the estimation of SB_0 and the strong assumption that it represents an unfished equilibrium spawning biomass that the stock would return to if fishing ceased, we suggest $SB/SB_{F=0}$ is a more robust metric than SB/SB_0.

Given that an integrated assessment is possible for SWPO striped marlin, we recommend using dynamic spawning biomass depletion ($SB/SB_{F=0}$). $SB/SB_{F=0}$ is an accepted biomass based reference point for tuna in the WCPFC Convention Area (WCPFC-CA). For tuna assessments, it is typically reported in two forms: $SB_{latest}/SB_{F=0}$ and $SB_{recent}/SB_{F=0}$. In both cases the denominator is the average spawning biomass in the absence of fishing over the previous 10 years from the second last year of the assessment. SB_{recent} is the estimated spawning biomass averaged over for the last four years of the assessment, and SB_{latest} is the estimated spawning biomass in the last year of the assessment. For simplicity we refer to both as $SB/SB_{F=0}$. As a default these forms can be applied to SWPO swordfish, although decisions may need to be made on specifying the forms (i.e. time periods used). This may require further analysis to understand the sensitivity of the metric to various formulations of $SB/SB_{F=0}$.

As discussed previously, there is little justification based on life history parameters for SWPO striped marlin to have less conservative depletion LRPs than the target tuna stocks. Therefore, a dynamic spawning depletion LRP of 20% $SB/SB_{F=0}$ would also seem appropriate as the default LRP for SWPO swordfish and other billfish stocks. The Australian Commonwealth Harvest Strategy Policy (Department of Agriculture and Water

Resources, 2018) lists a default of 20% B_0 as a LRP. That policy, however, notes that stock specific LRP levels can be implemented that deviate from the default and that stocks should be maintained above a LRP at least 90% of the time. We do not consider risk tolerance in this paper, but reiterate the suggestion from Preece et al. (2011) that uncertainty in LRPs and estimation of the indicators of stock status relative to LRPs needs to be considered by fishery managers in determining a risk level that is acceptable for LRPs and the stocks they are applied to.

For non-target billfish, a greater level of depletion could possibly be considered, specified as x% $SB/SB_{F=0}$ that are less than 20%. If the fraction of $SB_{F=0}$ is below 20% this would indicate fisheries managers are prepared to be accept higher biological risk with non-target species. Deciding the level for a more risk prone LRP setting strategy would require a high confidence in identifying the point where recruitment becomes severely impaired, as we expect most LRPs would seek to avoid long-term impairment of recruitment potential. This concept may allow target fisheries to be maintained, but with higher risk allowed for non-target or bycatch species, remembering that any LRP is a stock status that is to be avoided. However, as noted above, where the biology of non-target billfish stocks are comparable to that of target billfish, we suggest that there is no strong basis for adopting a different biological LRP based upon its perceived economic or social importance. Instead, fishery managers can reflect this within their designation of stock-specific risk levels relative to that LRP.

We note that the biomass based LRP for target stocks in the IATTC is 40% B_{MSY}, which is suggested to be equivalent to a depletion level of about ∼8% (USA, 2021). If this were to be considered within the WCPFC, its consistency with Article 5 of the WCPFC Convention Text ("*. . . maintain or restore stocks at levels capable of producing the maximum sustainable yield . . .*") would need to be discussed.

The 20% spawning biomass depletion level is used in many cases as a point where risk of recruitment overfishing starts to become unacceptable. While some analyses show that the 20% level of spawning depletion is not universally applicable (Myers et al., 1994), allowing depletion to fall below this level means we agree to accept more risk for bycatch than target tuna species. Being less conservative with bycatch LRPs may be driven by socio-economic objectives of the fishery but may not deliver on the conservation objectives for the species or stock if the biomass approached the LRP level. While this is possible under the WCPFC Convention Text (Article 6b), as noted below, moving below $SB/SB_{F=0}$ of 20% as the default LRP should be considered with due caution.

While B_{MSY} and F_{MSY} can be difficult to estimate for stocks that are data-poor, proxies for F_{MSY} can be calculated that do not require knowledge of the stock recruitment relationship. These are often based on yield per-recruit (YPR) (Braccini et al., 2015), or on the SPR. SPR is defined as the proportion of the unfished reproductive potential that remains at any given level of fishing pressure (Goodyear, 1993). For example, a SPR of 30% means that at that particular level of fishing mortality the spawning potential of the stock would be at 30% of what it would be if there was no fishing. Due to the focus on achieving MSY for target species, Goodyear (1993) proposed a SPR ratio of 20% as a default F_{MSY} proxy for marine pelagic species. This is typically expressed as $SPR_{MSY}=F_{20\%}$, which equates to F_{MSY} being equivalent to the F that produces a SPR of 20%. Similarly, Mace and Sissenwine (1993) suggested F_{MSY} proxies of $F_{30\%}$; others have suggested lower levels of $>F_{10\%}$ for channel catfish (Slipke et al., 2002) and higher values for vulnerable shovelnose sturgeon of $F_{40-50\%}$ (Quist et al., 2002) as proxies for F_{MSY}. Zhou et al. (2019a) showed that SPR proxies for F_{MSY} could be predicted from life-history parameters and estimated across a range of species SPR_{MSY} values from 13-95%, with a mean of 47% for perciformes. They suggested that SPR_{MSY} is highly variable across species and the assumption that for most species SPR_{MSY} of 30-40% is a good proxy for F_{MSY} is unreliable. None the less, SPR_{MSY} is a common reference point applied to many stocks, including billfish in the north Pacific (i.e., SPR_{MSY}=18% for North Pacific striped marlin).

A combination of depletion or biomass based reference points has been suggested in Australia (Department of Agriculture and Water Resources, 2018a), in that case 20% B_0, and fishing mortality based LRPs such as $F/F_{MSY} = 1$. Fishing mortality based LRPs SPR = $F_{x\%}$, x% F/F_{MSY} or $F/F_{MSY} = 1$ should be considered as options for billfish, noting that the MSY component of the calculation may be challenging to calculate accurately and translate into management action particularly for non-target species where management of fishing mortality is focused on target species. The development of a F-based reference point such SPR = $F_{x\%}$ that is not tied to MSY could be considered for SWPO striped marlin and other billfish.

6.2 Empirical Limit Reference Points

Where model based biomass and F estimates are not possible, but reliable catch and effort data are available, a catch rate indicator such as CPUE can be used as a proxy for status of the vulnerable biomass. Similarly an abundance index from a survey could provide a suitable relative biomass proxy, although survey indices are typically not feasible for widespread pelagic species such as billfish. If a suitable CPUE biomass proxy is available, it could be used to define reference points. For example, a CPUE level that reflects desirable conditions or represents historical levels when a fishery was performing well, can be used directly as an empirical TRP, as in the case for the South Pacific albacore interim TRP (Pilling et al., 2019). If a CPUE TRP can be identified, a CPUE LRP could be determined based on a certain value, level or percentage of the target. The use of time bound CPUE reference points is discussed further below. CPUE indicators could be useful in the development of LRPs for some billfish in fisheries where there is good observer coverage over the medium- to long-term and/or reliable logsheet records exist.

CPUE can be a useful biomass proxy but fishery selectivity and the method for standardising the data need to be consistent across time. Additionally, in some cases CPUE can vary strongly on short time scales, due to variation in recruitment or distributional shifts of the stock or fishery. In order to avoid reactive management if CPUE indicators are used as LRPs, rules will need to be created to guide management responses depending on the persistence of directional trends in the CPUE relative to the LRP value. In New Zealand where CPUE is used along with catch to evaluate stock trends, management procedures are developed where responses will occur if the CPUE trend continues in a negative direction below some pre-agreed level for three consecutive years. If a CPUE index is used for defining a LRP there would be value in having an agreed set of criteria to rank the reliability of alternative indices so that fishery managers understand how reliable (or not) an index is when making management decisions. Finally, any CPUE indicator will have associated uncertainty, similar to depletion based LRPs, and as a result CPUE based LRPs should have an associated risk tolerance. While CPUE based LRPs may currently be limited for some species, they may become more useful in future as improvements in data coverage and standardisation methods occur. However, estimating CPUE for species with non-retention policies or effective mitigation will be challenging.

Declines in average length of the upper length class could also indicate that a stock is being negatively impacted by a fishery (Cope and Punt, 2009). Punt et al. (2001) have noted that changes in mean length could better reflect trends in biomass and fishing impacts, and contend that an upper length statistic can be used to measure "biomass loss", but noted that the procedure for selecting a meaningful length based reference points is complex. In addition to the issues with choosing a relevant value as the LRP, length may not be useful for all WCPO billfish as it can be problematic due to time and fleet varying selectivity issues with longline fisheries, particularly for non-target species, and could not be used for those with poor length composition data histories. As a LRP, the limit could be to maintain the stock such that mean length does not fall below some pre-determined level. However, mean length can change with varying recruitment patterns, changes to the fishing gear selectivity, depth of gear, spatial distribution of fishing, and the density dependant changes in productivity. Furthermore, non-retention and effective mitigation policies will also preclude the collection of length data if they are used effectively.

Comparing mean length to CPUE trends for all billfish in the central WCPO showed length data show no signal while the the Peatman et al. (2018) CPUE data vary, in some cases strongly (Figure 5). Noting the data in this study were from the central WCPO for striped marlin, it is reasonable to assume the general conclusions would likely be similar for SWPO. Length data from the southern area of the Western Pacific (where large females feed) has shown a long-term decline in fish size, while CPUE is variable (Holdsworth and Saul, 2019) and appears more responsive to changes in the stock size. Similarly, Clarke and Hoyle (2014) showed that the catch rate indicators were more sensitive than the mean length for indicating relative depletion trends in WCPO elasmobranch bycatch species. Length based indicators are not likely to be reliable proxies for biomass but in situations where the data collection is standardised and consistent across time they may be useful indicators of changes in fishing mortality and fishing impact, but determining how to apply these metrics as LRPs requires more work. As a result length based LRPs are unlikely to provide enough information to be informative LRPs for billfish and are not considered further in this report. Further work, perhaps involving simulation studies, would be required to better understand the potential for LRPs based on length composition data.

Methods that set acceptable levels of catch such as Depletion-Based Stock Reduction Analysis (DB-SRA) (Dick and MacCall, 2011) and Depletion-Corrected Average Catch (DCAC) (MacCall, 2009) could be included as empirical LRPs for catch. Although, as discussed previously reference points for catch are not directly informative of stock status. DCAC has been suggested as a possible approach for blue marlin in the Indian Ocean (Fan et al., 2019). However, it is suggested that DCAC not be used for providing management advice in data-poor situations and its applicability needs to be further investigated considering situations where data mis-reporting and/or non-reporting occurs (Fan et al., 2019). Therefore, prior to its consideration as a LRP for WCPO billfish an analysis of billfish reporting accuracy should be undertaken.

6.3 Time Bound Reference Points

Time bound LRPs are specified as time periods for a stock status indicator, where the stock has declined to some undesirable state but then recovered. These can be useful as LRPs because there is information suggesting that the stock can recover from the observed low level. They can be specified as either a single point in time, e.g. $SB/SB_{F=0}$_low, CPUE_low and Biomass_low, or as a time period, e.g. $SB/SB_{F=0\ t1-t2}$ and $CPUE_{t1-t2}$. Importantly the stock must have recovered to a higher level from the low point, which means the low point can not be the end point in a time series. These time bound metrics are similar in concept to what is used as a biomass proxy in the USA, where $CPUE_{YEAR}/CPUE_0$ is used as a proxy for B_{YEAR}/B_0 (Western Pacific Regional Fishery Management Council, 2009). In situations where a CPUE index consistently declines it could be possible to set a CPUE LRP based on some percentage of the early CPUE assuming it to be indicative of a low exploitation equilibrium. For example the LRP could be x% $CPUE_0$. Noting that for some fisheries the early reporting can be unreliable, caution would be needed in deciding the early period (i.e., year(s) selected for $CPUE_0$).

There is some precedent for time bound reference points within the WCPFC context. In 2011 the ISC proposed a reference point specified as the "spawner biomass for the average ten year historical low" (SSB-ATHL) (ISC, 2011). This could be a useful metric as that assessment showed that the stock recovered from that level of depletion, indicating that recruitment had not been irreversibly impaired, or impaired over the long-term. SC7 considered the SSB-ATHL reference point to be a LRP, and some members noted that it should be evaluated against other, more common, reference points so that an understanding of its implications can be gained (WCPFC, 2011).

6.3 Consideration of the proposed metrics for a LRP

We considered potential LRPs using the outputs from the most recent SWPO striped marlin assessment (Ducharme-Barth et al., 2019) and present the results in Figure 3, Figure 4 and Table 6. The plot at the top in Figure 3 contains the spawning biomass trajectory from the model grid estimated in (Ducharme-Barth et al., 2019) as well as three example LRPs: $20\%SB_0$ (20% of the equilibrium unexploited spawning potential); SB_{1991} (SB_low); and $SB_{1990-1992}$ (SB_{t1-t2}). From the 300 model runs undertaken, 23% of model runs fell below the 20% SB_0 LRP. The LRPs SB_{1991} (i.e., the lowest estimated level of biomass) and $SB_{1990-1992}$ (i.e., a selected low period from which the stock has recovered) were chosen as example 'time bound' LRPs, however, there was little difference between all three. 20% SB_0 was relatively low as a LRP and the stock was below that level from 2010-2015, but showed some sign of a recovering trend from that low level in 2016 and 2017. This may suggest that the biomass had not fallen below a level from which it could not recover. Follow-up work involving stock projections (Hare et al., 2020) based on the 2019 assessment predicted that as fishing impact was reduced the stock recovered and equilibrated in a less depleted state over a relatively short-time period (i.e., 10 years). This provides some indication that the recent estimated biomass level was still above the level at which prolonged recovery was likely.

Two levels of depletion (10 and 20% $SB/SB_{F=0}$) and two levels of fishing mortality (F/F_{MSY} = 1 or 1.4) are considered as example LRP options. These data are presented in Figure 3 and in a Majuro plot for comparative purposes with the recent SWPO striped marlin assessment results (Figure 4). Eight percent of the model runs from the recent assessment uncertainty grid fell below the 10% depletion LRP in the terminal year of the assessment and 39% fell below 20% depletion. Eleven percent of model estimates were above the F/F_{MSY}=1 and 1.7% were above F/F_{MSY} = 1.4 in the terminal year of the assessment (Table 6). Risk of being above or below the depletion SB/$SB_{F=0}$ or F/F_{MSY} based LRPs, in this instance, is based on the uncertainty in the assessment as reflected in the assessment's uncertainty grid. It is worth noting that this type of uncertainty can change as assessment uncertainty changes due to new information that alters the assessment and structure of the uncertainty grid. Further uncertainty in the F estimates can differ from that of the biomass or depletion estimates, and they need to be considered separately in terms of risk tolerance to estimation uncertainty. Finally, F-based reference points do not substitute for biomass based reference points and ideally both should be applied for striped marlin, and have associated management responses if breached. The sensitivity of F_{MSY} estimation to steepness assumptions (Hilborn, 2002) would suggest that F/F_{MSY} levels as LRPs require caution in their application. Further, proxy levels for estimating F_{MSY} from per recruit analysis that do not take account of the stock recruitment relationship may also only be reliable if stock size has a low influence on recruitment (i.e., very high steepness) (Mace, 1994). Where the stock-recruitment relationship is not well known, if proxy levels for F_{MSY} are used as a basis for LRPs, conservative proxies are recommended. For the recent SWPO swordfish, steepness was included in the uncertainty grid with the same standard three values applied to tuna of 0.65, 0.8 and 0.95, treated with equal weighting. We note a new approach is being taken within the 2021 assessment (Ducharme-Barth et al., 2021).

We present as example empirical LRPs 20% $CPUE_0$, $CPUE_{t1-t2}$, and CPUE_low using three CPUE series from Ducharme-Barth et al. (2019) (Figure 6), and one that averages the three series (Figure 7). For the 20% $CPUE_0$, the LRP was higher for the fishery with the longer time series which was not surprising as it is higher at the start when the stock was less exploited. For this fishery the CPUE series was below the example LRP from 2001-2017. For the other two that had a shorter trajectory the 20% $CPUE_0$ LRP was higher and both were above the LRP at the end of the series.

It is somewhat subjective choosing the start and end years for time bound $CPUE_{t1-t2}$, but generally these should be considered as a level to avoid in future. Here the LRP reference periods mid-2000s, mid-1990s and 2010-2013 were chosen for fisheries 1-3 respectively. In all cases they were a low point that the stock had recovered from and in all three CPUE series the terminal year was above the LRP (Table 6).

CPUE_low is less subjective, but can represent an extreme value in situations where the index has large inter-annual fluctuations. CPUE_low was the lowest reference level in all cases. However, when the indices are averaged, the LRPs can de derived slightly differently.

As examples we use 20% $CPUE_0$, $CPUE_{t1-t2}$ and CPUE_low and estimate the LRP from the entire combined CPUE time series or only from the (more recent) part of the index where all three indices are present. In this case most LRPs (four of the six) were very similar, but 20% $CPUE_0$ differed markedly for the long-term and recent periods, with 20% $CPUE_0$ for the the recent period being substantially lower than the other example LRPs (Figure 6). In addition, for the 20% $CPUE_0$ LRP we used the average of the first five years to represent $CPUE_0$, given the rapid decline in both the start of the long term and recent periods of the mixed index, averaging over a shorter period may be more appropriate

(Figure 7). Agreeing on the most representative CPUE series (and time period) when considering empirical LRPs is therefore essential to having an appropriate and defensible CPUE-based LRP.

Caddy (1999) noted that a range of reference points should be considered simultaneously and if most concur then any of them could be used as the reference point. Therefore, in this case both $CPUE_0$ example LRPs could be discarded, and the LRP chosen from the remainder. Alternatively, if candidates don't all concur a weighting approach may be required to develop management advice. Note that if a CPUE-based LRP is chosen for any billfish in the WCPO, future monitoring of that stock against the LRP should use the same CPUE index and standardisation approach. If the CPUE approach is considered for defining a LRP, CCMs would need to agree on the appropriate CPUE indices and reference years for CPUE_low, *t1* and *t2*.

6.4 Risk-based Fishing Mortality Benchmarks

Aside from F, biomass and related proxies, other benchmarks for fishing risk can be evaluated such as the 10% risk of fishery collapse used by Bergh and Butterworth (1987). When detailed catch and biological data are not available, but some general biological knowledge about the species and stock exists, the stock could be categorized by productivity, e.g., as low, medium, or high productivity (Cortes and Brooks, 2018). This categorisation allows inferences about the species' likely ability to sustain varying levels of exploitation. Reference points can be developed around the level of risk a fishery poses to a fish stock. Here data-poor and medium-data assessments may need to be undertaken.

Zhou and Griffiths (2008) proposed two risk-based LRP benchmarks for bycatch species: risk of overfishing (F_{msm} - maximum sustainable fishing mortality) and F_{crash} which is the point at which there is high probability of collapse of the fishery (Cadima, 2003). These can be estimated for species with detailed levels of biological and fishery information, as well as those with data-poor fishery information but where some biological information exists. For data-poor species they proposed Sustainability Assessment for Fishing Effects (SAFE). They contend that ecological sustainability is likely to be more acceptable as a basis for LRPs to multiple users whereby the fishery does not aim to maximize the yield of a bycatch species, but ensures that fishing impacts do not drive the population to very low levels.

A target stock is technically overfished when its biomass is lower than the biomass that produces MSY, or if it is fished at a rate where yield per-recruit is lower than the maximum level. However, as noted above and in Hilborn (2002), catch in such a stock is not necessarily unsustainable and maintaining the stock above F_{crash} with a high degree of certainty could be a reasonable objective for a LRP. Under this circumstance F_{crash} may become a possible LRP. In this case the LRP becomes $F/F_{crash} > 1$ (which is a similar concept to the 10% risk of fishery collapse used by Bergh and Butterworth (1987)).

Overall, Zhou and Griffiths (2008) noted that it was difficult to conclude which method is the best across all species assessed as available life-history parameters and their quality have a marked impact on the quality of the estimates. Zhou et al. (2019) used three LRPs (F_{msm}, F_{lim} and F_{crash}) rather than a single LRP. They noted that, under simplifying assumptions about population dynamics, of the three LRPs, F_{lim} corresponds to 25% B_0 and is closer to 20% $SB/SB_{F=0}$ than the other two LRPs. Therefore, Zhou et al.

(2019) argued that F_{lim} corresponded most closely to the requirements of Article 10 of the WCPFC Convention text inferring that this could be used as a LRP for elasmobranchs.

For data-poor stocks, estimates of the size of the population are not possible, but estimates of fishing mortality can be made. In this case the LRPs are one dimensional, but could be combined with a biomass proxy such as CPUE. Using the knowledge of the species biology, estimates of F_{msm} (which is thought to approximate F_{MSY}); F_{lim} [5]; and F_{crash} are made. Any number of LRPs, e.g. some proportion of F_{lim} (x% F_{lim}) can be developed, and in some cases F_{crash} has been used as the LRP (Cadima, 2003), but it would need to be a hard limit where if reached the fishery is closed. To standardise the LRPs between species the metrics F/F_{lim} and F/F_{crash} should be used.

LRPs derived from risk-based fishing mortality benchmarks need to be regarded with caution. They can be based on tenuous information and are a very generalised estimate of a species' ability to withstand fishing pressure. They are not a measure of the biological status of the population. As a result, they should be used as interim measures until such time as the data improves and more certainty in the stock status can be obtained. Alternatively, they could be used in conjunction with other measures like CPUE and if both LRPs are approached or breached then management action should be applied to rectify the situation.

6.5 Comparisons Against Risk-based Fishing Mortality Benchmarks

Using the yield simulation in MFCL as part of the SWPO striped marlin assessment (Ducharme-Barth et al., 2019), and the methods used by Tremblay-Boyer et al. (2019), estimates of F, F_{lim} and F_{crash} were obtained from 300 model runs, based on simulating theoretical yields under equilibrium conditions with varying levels of steepness and natural mortality.

The results are presented in Figure 8 which shows the distribution of the data as well as a stylised "traffic light plot", developed for the WCPFC Shark Research Plan (Brouwer and Hamer, 2020), to show the stock status of the species evaluated against risk-based fishing mortality benchmarks. The data are plotted as a ratio of F relative to F_{lim} and F_{crash} (i.e. F/F_{crash}). F_{lim} is thought to corresponds to 25 % B_0 and 20% $SB/SB_{F=0}$ (Zhou et al., 2019). None of the model runs estimated $F > F_{crash}$ and only 14% of models estimated $F > F_{lim}$ (Table 6).

7 Limit Reference Points Applied for Billfish in Other Jurisdictions

Target and limit reference points are in place for fish stocks in many jurisdictions around the world. These are normally aimed at high value target species and seldom apply to non-target species. For billfish, a number of institutions have discussed the implementation of LRPs but few have agreed LRPs. While most assessments report against MSY based reference points by default, only Australia (Department of Agriculture and Water Resources, 2018), the International Commission for the Conservation of Atlantic Tunas

[5] Note here $F_{lim} = 1.5\ F_{msm}$ but the value of 1.5 is a management decision and can be increased or decreased depending on the fishery objectives.

(ICCAT) (ICCAT, 2017) and the Indian Ocean Tuna Commission (IOTC) (IOTC, 2015) have agreed LRPs for swordfish, and only Australia has agreed LRPs for striped marlin (Department of Agriculture and Water Resources, 2018) (Table 8). ICCAT has a biomass LRP of 0.4*B_{MSY} for swordfish and IOTC has a biomass LRP of 0.4*B_{MSY} and a fishing mortality (F) LRP of 1.4*F/F_{MSY} for swordfish. Australia relies on a default biomass LRP of 20% B_0 and F LRP of $F/F_{MSY} = 1$ for both swordfish and striped marlin, but stock specific LRPs can be implemented that deviate from the defaults; however, no specific LRPs have been applied.

The USA Western Pacific Regional Fishery Management Council uses a Maximum Fishing Mortality Threshold (MFMT) that approximates a threshold reference point and a Minimum Stock Size Threshold (MSST) which is defined as a limit and an additional Minimum Biomass Flag (B_{FLAG}) (Western Pacific Regional Fishery Management Council, 2009). These estimates are derived from F_{MSY}, B_{MSY} and M, and if MSST is reached/breached a management response is required. These values are not consistent through time and change with each assessment (if the biological parameters change). It is also noted that these are guidelines for management and not constraints. They are applied to swordfish, blue marlin and other billfish which we assume to include striped marlin.

In New Zealand overfishing thresholds can be expressed in terms of fishing mortality, exploitation rates, or other valid measures of fishing intensity. Both swordfish and striped marlin in New Zealand have default LRPs of 20% SB_0 (soft limit) and 10% SB_0 (hard limit) applied (Fisheries New Zealand, 2020). These limits are assessed against the WCPFC assessment results and used for reporting on the stock status, but not necessarily for developing domestic management responses.

Both the IOTC and ICCAT have LRPs lower than B_{MSY} for swordfish and the IOTC has an F LRP where $F/F_{MSY} > 1$. Having both biomass and F LRPs when LRPs are set with a more risk prone strategy (e.g. where $F/F_{MSY} > 1$ and $B/B_{MSY} < 1$), could be acceptable as the management actions would react to biomass depletion or effort excess, whichever is breached first.

8 Further Considerations for Limit Reference Points for Billfish in the WCPO

When developing LRPs for WCPO billfish, managers and stakeholders may wish to limit the socio-economic impact of managing the non-target stock on the target fishery. In order to do this, agreement could be sought to allow non-target stocks to be fished at a lower biological state before management interventions occurs, than would be typical for a target species. If these stocks are of lower socio-economic value, fisheries managers and stakeholders may be willing to take a higher level of risk in managing these stocks. In this case, it may be possible to consider a less conservative approach to their biological population status by agreeing to a lower LRP than applied to the target tuna, as has been done in the IOTC and ICCAT, or as we suggest specify a higher acceptable level of risk of falling below the specified LRP.

In this case fisheries, managers and stakeholders deliberately decide to allow fishing of non-target stocks at a higher level of biological risk. This higher risk strategy is a management decision. Within the WCPFC, Article 5 of the convention text notes that management policies should not allow stocks to fall below a point from which they cannot recover; drive them to extinction; or change the functioning of the ecosystem. Therefore, an estimate of the amount of fishing mortality that would drive a population below the level where it can sustain itself needs to be considered. This point is referred to as F_{crash} and if fishing mortality is maintained at or above F_{crash} the population will eventually collapse. Therefore, it is reasonable to expect that fishing at levels around F_{crash} should be avoided with very high probability over the long-term.

A cautionary note. Serious reductions in top predators can have unforeseen negative ecological consequences resulting in alternative stable states arising where systems become dominated by low value high growth species, which can be seriously detrimental to high value fisheries (e.g., Parsons, 1992; Dulvy et al., 2004; Heithaus et al., 2008). Given their ecological importance and relative vulnerability to fisheries, deliberately maintaining WCPO billfish populations at low levels would need careful consideration and the risk of falling below F_{crash} must be exceptionally low. Therefore if risk prone F levels are to be considered for high order predators, ecological risks will need to be considered very carefully.

Preece et al. (2011), Clarke and Hoyle (2014) and Zhou et al. (2019) recommended that reference points be adopted following a tiered or heirachical approach (based on availability of information), this concept is updated here such that:

1. When there is an integrated assessment one should use recognised reference point metrics from the model (Levels 1-3 from Preece et al. (2011)).
2. If model based metrics are not appropriate for management purposes, consider using empirical reference points, for example CPUE, where a reliable relationship with biomass can be demonstrated.
3. If no data-rich assessment is available, use risk-based fishing mortality benchmarks (F_{lim} and F_{crash}).
4. An additional dimension to the original hierarchical LRP approach is whether the species is a target or a non-target/bycatch, along with their ecological interactions and role in ecosystem function. Recognising those characteristics within the Commission's considerations on managing top predator species in the WCPO, the Commission may consider whether target species with dedicated fisheries should have different acceptable risk of falling below specified LRPs to non-target/bycatch species.

9 Summary

While good assessment models may be able to estimate the stock status with some degree of accuracy, this does not guarantee that the metrics used in the assessment are useful or appropriate. There are several examples from the WCPFC where authors have used an ambiguous metric to describe stock status. As a result alternative metrics that are considered in assessments (as in Table 3) should always be presented against conventional metrics, such as $SB/SB_{F=0}$ or SB/SB_{MSY} so that they can be evaluated and understood within the current accepted reference point metrics.

With respect to risk-based fishing mortality benchmarks; (F_{lim}, and F_{crash}), F_{lim} is suggested to approximate 25% B_0 and F_{crash} is the lowest point a stock can reach before the population becomes unable to sustain itself if fishing mortality remains at that level in the long-term. F_{lim} approximates more conventional LRPs, and F_{crash} could be considered a LRP provided that it is avoided with a high degree of certainty. Note that a data-rich assessment can, and should, also estimate risk-based fishing mortality benchmarks for comparative purposes, as this would assist our understanding of their potential in future, and how they relate with the more conventional metrics. The risk-based fishing mortality LRPs are static, therefore there is still a need to be able to estimate F routinely, which would require updated biological data on an ongoing basis as part of the monitoring/assessment programme to track changes through time.

A comparison of empirical reference points and conventional reference point-based rules, was undertaken by Hilborn (2002). He concluded that empirical reference points will often perform better as they are simple and transparent, but their performance will depend on the frequency and reliability of the data. Empirical reference points are being considered within the WCPFC, for example CPUE based decision rules as fishery performance targets within the Harvest Strategy framework for South Pacific albacore (Scott et al., 2019). CPUE is used in the Australian Southern and Eastern Scalefish and Shark Fishery where the LRP is set using a CPUE index and is defined as 40% of the target catch rate which is a group of years when CPUE was at a desirable level (Department of Agriculture and Water Resources, 2018a). While this may show some promise for billfish, if effective mitigation is used that results in fish not being caught and potentially not being reported as they are released, the resulting CPUE of retained fish could decline. This could mislead and trigger a management response that is not necessary as other effective management is in place. Furthermore, changes to fishing practices such as targeting or avoidance can change trends in the data, therefore fleet selection for the analysis would need careful consideration and operational reporting on gear will need to be improved. Finally, CPUE variability could result in frequent reactive management responses, therefore to avoid reactive management, rules should be put in place when management action would only occur if the undesirable CPUE trend continues below the LRP for a number of consecutive years.

Neubauer et al. (2019) provided a useful analysis for assessing alternative assessment methods based on the level of information available. Their paper, while focusing on assessment methods, compared the reliability of lower levels of information to a fully integrated stock assessment. They compared the metrics from each method and commented on their reliability, and by inference the reliability of these metrics as reference points. Neubauer et al. (2019) concluded that as assessments move from fully integrated, through biomass dynamics models to spatial risk assessments the variability increased, and the reliability decreased as the level of information in the analysis decreases. However, they also concluded that each of these methods can be used and provided relatively consistent estimates of reference points (if not more variable) than those derived from the data-rich 2019 oceanic whitetip shark assessment (Tremblay-Boyer et al., 2019). This suggests that in addition to assessment derived metrics, F_{lim} and F_{crash} could be used as LRPs and spatial risk assessment methods could also be used to derive an estimate of relative stock status or risk.

LRPs are the level of biomass or fishing mortality at which the risk to the stock (in terms of recruitment impairment) is regarded as unacceptably high. The distinction between target and non-target or bycatch species is a result of human values and utilisation, rather than one of biology or ecology (Zhou et al., 2019). As such Zhou et al. (2019) argue that there is no biological basis for bycatch and target species to have different LRPs. However, economics do come into play when a LRP for a bycatch species results in management action on a fishery for a target species. In these circumstances considering alternative permissible levels of risk of falling below the specified LRP for bycatch stocks, while taking into account the potential for irreversible biological impacts to occur, may be acceptable to fisheries managers and other stakeholders. Alternative, lower, LRPs might also be considered (but we suggest are not consistent with the logic of LRPs representing levels of biological concern). Therefore, the WCPFC will need to decide whether different treatment of bycatch and target species in relation to LRPs is warranted and applies to billfish species.

There are a number potential LRPs for the SC to consider for SWPO striped marlin and other billfish. These are outlined in Table 5. From Table 5 we suggest that given uncertainty in steepness and potential for variation of B_{MSY} over time, B_{MSY} related LRPs be excluded for the time being consistent with the approach for the target tuna species. In addition, F_{crash} may be unacceptably risky for billfish that are of high ecological importance or target species (i.e., swordfish). However, we suggest that other LRPs could be assessed in relation to risk of F_{crash}. While spatial risk assessment methods can be used to derive an estimate of relative stock status, for WCPFC billfish there is sufficient data to use the other more informative assessment methods and SAFE can be removed as an option. Lastly, Fan et al. (2019) recommended catch based methods (DCAC and DB-SRA) should not be used for providing management advice and are subject to bias in situations with inaccurate catch reporting (common for billfish species), therefore these methods are also not supported as LRP options. This leaves the remaining options denoted in Table 7 as the proposed list of LRP metrics to consider for the SWPO swordfish and other WCPO billfish.

In order to compare the example LRPs with the recent assessed status of the reference points for SWPO swordfish, an evaluation based on the outputs from the 2019 assessment (Ducharme-Barth et al., 2019) was undertaken and the results are presented in Table 6. While these reference point metrics are not all directly comparable, reviewing the number of model runs from the uncertainty grid that breached the LRP, showed that 20% $SB/SB_{F=0}$, 20% $SB_{1990-1992}$ and SB_{1991} were similar with 29-39% of models exceeding the LRP in the terminal year of the assessment and these represent the most conservative options for the LRPs considered here. 20% SB_0, 20% $CPUE_0$ had 23 and 20% of models exceeding the LRP respectively. $F/F_{MSY} < 1$, 10% $SB/SB_{F=0}$ and $F/F_{lim} > 1$ provided similar outcomes with between 8 and 14% of models exceeding the LRP. Finally, $F/F_{MSY} < 1.4$, $SB/SB_{F=0\ 2012-2014}$, $CPUE_{t1-t2}$ and $F/F_{crash} > 1$ had <2% of runs breaching the LRP. With respect to the time bound LRPs these can be modified to be more or less constraining by choosing a time period that is relevant to the particular management objectives for that stock.

Lastly, it would be expected that alternative reference points metrics may be developed overtime. When new reference points are proposed they should be evaluated against those in Table 7 that CCMs are familiar with.

10 Conclusions

Generally speaking if the consequence of breaching the assigned LRP is high then the risk of breaching the LRP should be very low. For example if the LRP is F_{crash} then the risk should be zero, but if the LRP implies a larger stock size such as $SB/SB_{F=0}$=0.2, then managers could decide that the acceptable risk of breaching the LRP could change. Once a LRP metric and level is chosen, the risk level should be considered through discussions among CCMs and assessment scientists. Furthermore, if the objective of a LRP is to reduce fishing impact on ecosystem structure and function (a key goal in ecosystem-based fisheries management), it would be undesirable to deplete top predators to low levels. However, this runs the risk that a low economic value species could limit fishing effort on a valuable target species, which would then be fished below optimum. Without specific objectives (outside of Article 5 of the convention text) for WCPO billfish that define a state of the fishery that is considered to be either desirable or undesirable, it is difficult to consider the actual 'values' for LRPs. However, we can decide on the reference point metrics to use, and compare these to the current stock status as the basis for further discussions and informed decisions about the value of a LRP.

As the biological productivity levels of WCPO billfish are similar to that of the target tunas with established LRPs, there is no clear biological justification that a LRP for SWPO striped marlin should be any different to the current depletion based LRPs for target tuna, i.e., 20% $SB/SB_{F=0}$.

This paper is intended to facilitate the discussion around which metrics and levels to use for LRPs for SWPO striped marlin, with comments on the value of those metrics for other WCPO billfish. Recalling that, when a LRP is approached, measures should be taken to ensure that it will not be exceeded with high probability. These metrics are outlined in Table 7 and Table 9 and listed in general terms as follows:

1. **Data-rich** - for SWPO striped marlin and those billfish evaluated using a stock assessment model, it is proposed to use assessment-based LRPs (e.g. x% $SB/SB_{F=0}$ or x% SB/SB_0 and x% F/F_{MSY}). Proxies for these could be also considered such as SPR x% SB=0. As the stock-recruitment relationship is uncertain, B_{MSY} based LRPs such as x% SB/SB_{MSY} are currently not recommended as LRPs;

2. **Medium-data** - no integrated assessment model possible, but some useful data on the catch and effort are available, use empirical LRPs such as CPUE (e.g. x% CPUE from some reference period). x% $CPUE_0$, CPUE_low or $CPUE_{t1-t2}$ could be employed as an interim LRP. The data presented in Peatman et al. (2018) seem to indicate that there are enough data to use CPUE for all WCPO billfish depending on the ability to standardise across fleets, and provided that there are no changes in management of the longline fishery that impact catchability.

3. **Data-poor** - no integrated assessment model, but some information on the biology, use SPR and/or risk-based fishing mortality benchmarks such as F/F_{lim} and F/F_{crash}. As these are relatively static they should be used as interim LRPs until such time as more dynamic measure can be reliably determined. While not used for LRP setting, spatial risk assessment methods can be used as a semi-quantitative (i.e. relative) way to prioritise assessment and conservation efforts.

Fishery managers will need to consider the risks to each stock. As a result, the WCPFC will need to establish fishery objectives for WCPO billfish. These objectives may need to be set as interim objectives that could be updated, as they may change as the WCPFC Harvest Strategies process develops a bycatch monitoring strategy and associated bycatch performance indicators. As agreeing on fishery objectives is complex and has been met with limited success within the WCPFC, we suggest as an interim LRP, 20% $SB/SB_{F=0}$ for SWPO striped marlin and swordfish is used.

Lastly, in future, the proposed risk-based fishing mortality benchmarks should be defined as dependent variables in the two main assessment platforms used (Stock Synthesis and MFCL) so that the statistical uncertainty of the estimates can be calculated.

11 Recommendations

The following recommendations are proposed for the SC to consider.

1. The WCPFC should develop interim objectives for SWPO striped marlin to guide the appropriate levels for any agreed LRP and the associated maximum risk levels for breaching a LRP.
2. In the interim, a LRP equivalent to 20% $SB/SB_{F=0}$ for SWPO striped marlin could be used, consistent with the logic behind the application to key tuna stocks.
3. For the other WCPO billfish - develop objectives as species groups, by dividing Western and Central Pacific Ocean (WCPO) billfish into: target species (swordfish); data-rich bycatch species (striped and blue marlin); medium information species with moderate levels of catch (black marlin); and data-poor low-catch bycatch (shortbilled spearfish and sailfish).
4. Consider Table 7 as a list of Limit Referent Point metrics that could be used for WCPO billfish.
5. Consider the values presented in Table 9 for SWPO striped marlin and swordfish as potential LRPs for these and other billfish species.
6. Assess the remaining stocks against the proposed LRPs in Table 7 and Table 9 to determine the appropriate LRPs.
7. Any new proposed LRP metrics that are developed in the future, should be assessed against those presented in Table 7.
8. Incorporate these decisions into the Billfish Research Plan that is scheduled to be developed in 2022 and focus that work on developing objectives, assessing LRPs for each species, and determining if a pathway to a higher level of information and knowledge should be developed.
9. The proposed risk-based fishing mortality benchmarks should be defined as dependent variables in the two main assessment platforms used (SS and MFCL) so that statistical uncertainty of the estimates can be calculated.

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References

Baum, J. K. and Worm, B. (2009). Cascading top-down effects of changing oceanic predator abundances. *Journal of Animal Ecology*, 78:699–714.

Bergh, M. O and Butterworth, D. S. (1987). Towards rational harvesting of the South African anchovy considering survey imprecision and recruitment variability. *S. Afr. J. Mar. Sci.*, 5:937–951.

Braccini, M., Brooks, E. N., Wise, B., and McAuley, R. (2015). Displaying uncertainty in the biological reference points of sharks. *Ocean and Coastal Management*, (116):143–149.

Braccini, M., Molony, B., and Blay, N. (2020). Patterns in abundance and size of sharks in northwestern Australia: cause for optimism. *ICES Journal of Marine Science*, 1(77):72–82.

Brooks, E. N., Powers, J. E., and Cortés, E. (2010). Analytical reference points for age-structured models: application to data-poor fisheries. *ICES Journal of Marine Science*, (67):165–175.

Brouwer, S. and Hamer, P. (2020). 2021-2025 Shark Research Plan. Technical report, WCPFC-SC16-2020/EB-IP-01 Rev1.

Caddy, J. F. (1999). Deciding on precautionary management measures for a stock based on a suite of limit reference points (LRPs) as a basis for a multi-LRP harvest law. *NAFO Sci. Coun. Stud*, (32):55–68.

Caddy, J. F. (2002). Limit reference points, traffic lights, and holistic approaches to fisheries management with minimal stock assessment input. *Fisheries Research*, (56):133–137.

Cadima, E. L. (2003). Fish stock assessment manual. Technical report, FAO Fisheries Technical Paper 393.

Clarke, S. and Hoyle, S. (2014). Development of Limit Reference Points for elasmobranchs. Technical report, WCPFC-SC10-2014/ MI-WP-07.

Cope, J. M. and Punt, A. E. (2009). Length-Based reference points for data-limited situations: Applications and restrictions. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 1:169–186.

Cortes, E. and Brooks, E. (2018). Stock status and reference points for sharks using data-limited methods and life history. *Fish and Fisheries*, (19):1110–1129.

Curtis, K. A., Moore, J. E., Boyd, C., Dillingham, P. W., Lewison, R. L., Taylor, B. L., and James, K. C. (2015). Managing catch of marine megafauna: Guidelines for setting limit reference points. *Marine Policy*, (61):249–263.

Davies, C. and Polacheck, T. (2007). A brief review of the use of the precautionary approach andthe role of target and limit reference points and Management Strategy Evaluation in themanagement of highly migratory fish stocks. Technical report, WCPFC-SC3-2007/ME-WP-03.

Davies, C. and Basson, M. (2008). Approaches for identification of appropriate reference points and implementation of MSE within the WCPO. Technical report, WCPFC-SC4-2008/GN-WP-10.

Department of Agriculture and Water Resources. (2018). Commonwealth Fisheries Harvest Strategy Policy. Technical report, Canberra, June. CC BY 4.0.

Department of Agriculture and Water Resources. (2018a). Guidelines for the Implementation of the Commonwealth Fisheries Harvest Strategy Policy. Technical report, Canberra, June. CC BY 4.0.

Dick, E. J. and MacCall, A. D. (2011). Depletion-based stock reduction analysis: A catch-based method for determining sustainable yields for data-poor fish stocks. *Fisheries Research*, 110(2):331–341.

Ducharme-Barth, N. Pilling, G. and Hampton, J. (2019). Stock assessment of SW Pacific striped marlin in the WCPO. Technical report, WCPFC-SC15-2019/SA-WP-07.

Ducharme-Barth, n., Vincent, M., Hampton, J., Hamer, P., Williams, P. and Pilling, G. (2020). Stock assessment of bigeye tuna in the western and central Pacific Ocean. Technical report, WCPFC-SC16-2020/SA-WP-03.

Ducharme-Barth, N., Castillo-Jord, C. Hampton, J., Hamer, P., Williams, P. and Pilling, G.(2021). Stock assessment of swordfish in the southwest Pacific Ocean. Technical report, WCPFC-SC17-2021/SA-WP-04.

Dulvy, N. K., Freckleton, R. P., and Polunin, N. P. (2004). Coral reef cascades and the indirect effects of predator removal by exploitation. *Ecology Letters*, 7(5):410–416.

Fan, Y., Geng, Z., Zhu, J., Dai, X. and Richard, K. (2019). Estimating blue marlin (*Makaira nigricans*) sustainable yield in the Indian Ocean using a data-poor approach. *Aquaculture and Fisheries*, 4:122–127.

Fisheries New Zealand. (2020). Fisheries Assessment Plenary, November 2020: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand. Technical report, Wellington New Zealand. 639pp.

Fisheries New Zealand. (2020a). Fisheries Assessment Plenary, May 2020: stock assessments and stock status. Compiled by the Fisheries Science and Information Group, Fisheries New Zealand. Technical report, Wellington New Zealand. 1746p.

Goodyear, C. P. (1993). Spawning stock biomass per recruit in fisheries management: foundation and current use. In: Risk evaluation and biological reference points for fisheries management (S. J. Smith, J. J. Hunt, and D. Rivard, eds.), p. 67–81. *Can. Spec. Publ. Fish. Aquat. Sci.*, 120.

Hare, S., Hamer, P. and Pilling, G. (2020). Southwest Pacific striped marlin stock projections to evaluate CMM 2006-04. Technical report, WCPFC-SC16-2020/SA-IP-13.

Harley, S. J., Hoyle, S. D., Hampton, J., and Kleiber, P. (2009). Characteristics of potential Reference Points for use in WCPFC tuna stock assessments. Technical report, WCPFC-SC5-2009/ME-WP-02.

Heithaus, M. R., Frid, A., Wirsing, A. J., and Worm, B. (2008). Predicting ecological consequences of marine top predator declines. *Trends in Ecology and Evolution*, 23(4):202–210.

Hilborn, R. (2002). The dark side of reference points. *Bulletin of marine Science*, (70):403–408.

Holdsworth, J. and Saul, P. (2019). Striped marlin catch and CPUE in the New Zealand sport fishery 2016–17 to 2018–19. Technical report, New Zealand Fisheries Assessment Report 2019/74.

Hoolihan, J. P., Lou, J. and Arocha, F. (2019). Age and growth of blue marlin *Makaira nigricans* from the central western Atlantic Ocean. *Fisheries Research*, 220:105346.

ICCAT. (2017). Recommendation by IACCT amending the recommendation for the conservation of north Atlantic Swordfish, Rec. 16-.3. Technical report, REC.17-02.

IOTC. (2015). On target and limit reference points and a decision framework. Technical report, Resolution 15/10.

ISC. (2011). Albacore Working Group: Stock Assessment of Albacore Tuna in the North Pacific Ocean in 2011. Technical report, WCPFC-SC7-2011/SA-WP-10.

ISC. (2016). Stock Assessment Report for Blue Marlin (*Makaira nigricans) in the Pacific Ocean through 2014.* Technical report, WCPFC-SC12-2016/SA-WP-12.

ISC. (2018). Stock Assessment Report for Swordfish (*Xiphias gladius) in the Western and Central North Pacific Ocean through 2016.* Technical report, WCPFC-SC14-2018/SA-WP-07.

ISC. (2019). Stock Assessment Report for Striped Marlin (*Kajikia audax) in the Western and Central North Pacific Ocean through 2017.* Technical report, WCPFC-SC15-2019/SA-WP-09.

MacCall, A. D. (2009). Depletion-corrected average catch: A simple formula for estimating sustainable yields in data-poor situations. *ICES Journal of Marine Science*, 66(9):2267–2271.

Mace, P. M. (1994). Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Can. J. Fish. Aquat. Sci.*, 51(1):110–122.

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. *Fish and Fisheries*, 2:2–32.

Mace, P. M. and Sissenwine, M. P. (1993). How much spawning potential is enough? In: foundation and current use. In Risk evaluation and biological reference points for fisheries management (S. J. Smith, J. J. Hunt, and D. Rivard, eds.), p. 101-118. *Can. Spec. Publ. Fish. Aquat. Sci.*, 120.

Maunder, M. N. and Punt, A. E. (2013). A review of integrated analysis in fisheries stock assessment. *Fisheries Research*, 142:61–74.

Moore, J. E., Curtis, K. A., Lewison, R. L., Dillingham, P. W., Cope, M. J., Fordham, S. V., Heppell, S. S., Pardo, S. A., Simpfendorfer, C. A., Tuck, G. N., and Zhou, S. (2013). Evaluating sustainability of fisheries bycatch mortality for marine megafauna: a review of conservation reference points for data-limited populations. *Environmental Conservation*, 4(40):329–344.

Myers, R. A., Rosenberg, A. A., Mace, P. M., Barrowman, N. and Restrepo, V. R. (1994). n serarch of thresholds for recruitment overfishing. *ICES, J. mar. Sci.*, 51:191–205.

Neubauer, P., Richard, Y., and Tremblay-Boyer, L. (2019). Alternative assessment methods for oceanic whitetip shark. Technical report, WCPFC-SC15-2019/SA-WP-13.

Nishijima, S., Kubota, H., Kaga, T., Okamoto, S., Miyahara, H., and Okamura, H. (2021). State-space modeling clarifies productivity regime shifts of Japanese flying squid. *Popylation Ecology*, 63:27–40.

Norris, W. (2009). The application of reference point management in WCPO tuna fisheries: An introduction to theory and concepts. Technical report, WCPFC-SC5-2009/ME-WP-01.

Parsons, T. R. (1992). The removal of marine predators by fisheries and the impact of trophic structure. *Marine Pollution Bulletin*, 25(1–4):51–53.

Peatman, T., Bell, L., Allain, V., Caillot, S., Williams, P., Tuiloma, I., Panizza, A., Tremblay-Boyer, L., Fukofuka, S., and Smith, N. (2018). Summary of longline fishery bycatch at a regional scale, 2003-2017. Technical report, WCPFC-SC14-2018/ST-WP-03.

Pilling, G. P., Berger, A. M., Reid, C., Harley, S. J. and Hampton, J. (2016). Candidate biological and economic target reference points for the south Pacific albacore longline fishery. *Fisheries Research*, 174:167–178.

Pilling, G., Scott, F., and Hampton, J. (2019). Minimum Target Reference Points for WCPO yellowfin and bigeye tuna consistent with alternativeLRP risk levels, and multispecies implications. Technical report, WCPFC-SC15-2019/MI-WP-01.

Preece, A., Hillary, R., and Davies, C. 2011 Identification of candidate limit reference points for the key target species in the WCPFC. Technical report, SC7-2011/MI-WP-03.

Punt, A. E., Campbell, R. A., and Smith, A. D. M. (2001). Evaluating empiricalindicators and reference points for fisheries management: application tothe broadbill swordfish fishery off eastern Australia. *Marine and Freshwater Research*, (52):819–833.

Quist, M. C., Guy, C. S, Pegg, M. A. Braaten, P. J. Pierce, C. L. and Travnichek, V. H. (2002). Potential influence of harvest on shovelnose sturgeon populations in the Missouri river system. *North American Journal of Fisheries Management*, 22(2):537–549.

Rose, G. A. and Rowe, S. (2015). Northern cod comeback. *Can. J. Fish. Aquat. Sci.*, 72:1789–1798.

Scott, R., Yao, N., Scott, F., and Pilling, G. M. (2019). South Pacific albacore management strategy evaluation framework. Technical report, WCPFC-SC15-2019/MI-WP-08.

Slipke, J. W., Martin, D. A., Pitlo, Jr. J. and Maceina, M. J. (2002). Use of the spawning potential ratio for the upper Mississippi River channel catfish fishery. *North American Journal of Fisheries Management*, 224:1295–1300.

Takeuchi, Y., Pilling, G., and Hampton, J. (2017). Stock assessment of swordfish in the southwest Pacific Ocean. Technical report, WCPFC-SC13-2017/SA-WP-13.

Tremblay-Boyer, L., McKechnie, S., Pilling, G., and Hampton, J. (2017). Stock assessment of yellowfin tuna in the Western and Central Pacific Ocean. Technical report, WCPFC-SC13-2017/SA-WP-06.

Tremblay-Boyer, L., Hampton, J, and Pilling, G. (2018). Stock assessment of South Pacific albacore tuna. Technical report, WCPFC-SC14-2018/SAWP-05.

Tremblay-Boyer, L., Carvalho, F., Neubauer, P., and Pilling, G. (2019). Stock assessment for oceanic whitetip shark in the western and central Pacific Ocean. Technical report, WCPFC-SC15/SA-WP-06.

USA. (2021). Management objectives and acceptable levels of exploitation for the tropical tuna stocks - Discussion paper. Technical report, WCPFC-TTMW1-2021-DP01.

Vincent, M., Pilling, P. and Hampton, J. (2019). Stock assessment of yellowfin tuna in the Western and Central Pacific Ocean. Technical report, WCPFC-SC16-2020/SA-WP-04-Rev2.

Vincent, M., Ducharme-Barth, N., Hamer, P., Hampton, J., Williams, P., and Pilling, P. (2020). Stock assessment of skiplack tuna in the Western and Central Pacific Ocean. Technical report, WCPFC-SC15-2019/SA-WP-05.

WCPFC. (2011). Report of the Seventh Regular Session of the Scientific Committee. Technical report, WCPFC.

WCPFC. (2020). Report of the Sixteenth Regular Session of the Scientific Committee. Technical report, WCPFC.

Western Pacific Regional Fishery Management Council. (2009). Fishery ecosystem plan for Pacific pelagic fisheries of the Western Pacific Region. Technical report, Honolulu, Hawaii.

Zhou, S. and Griffiths, S. P. (2008). Sustainability Assessment for Fishing Effects (SAFE): A new quantitative ecological risk assessment method and its application to elasmobranch bycatch in an Australian trawl fishery. *Fisheries Research*, (91):56–68.

Zhou, S., Smith, A. D., and Fuller, M. (2011). Quantitative ecological riskassessment for fishing effects on diverse data-poor non-target species in amulti-sector and multi-gear fishery. *Fisheries Research*, (112):168–178.

Zhou, S., Deng, R. A., Hoyle, S., and Dunn, M. (2019). Identifying appropriate reference points for elasmobranchs within the WCPFC. Technical report, WCPFC-SC15-2019/MI-IP-04.

Zhou, S., Punt, A. E., Lei, Y., Deng, R. A. and Hoyle, S. D. (2019a). Identifying spawner biomass per-recruit reference points from life-history parameters. *Fish and Fisheries*, DOI:10.1111/faf.12459.

Zhou, C., Wang, X., Wu, F., Xu, L., Zhu, J. and Dai, X. (2019b). Length at maturity of four billfish species in the Indian Ocean based on Chinese longline observer data. Technical report, IOTC-2019-WPB17-14.

Tables

Table 1: WCPFC 5-level hierarchical approach to defining LRPs for bycatch species based on the 3-level approach recommended by Preece et al. (2011), and endorsed by WCPFC8, with two additional proposed levels (4 and 5).

Level	Condition	LRP metrics
Level 1	A reliable estimate of steepness is available.	F_{MSY} and B_{MSY}
Level 2	Steepness is not known well, if at all, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated.	$Fx\%_{SPR\_F=0}$ and either $x\%$ SB_0 or $x\%$ $SB_{current,F=0}$
Level 3	The key biological and fishery variables are not well estimated or understood.	$x\%$ SB_0 or $x\%$ $SB_{current,F=0}$
Level 4	Poor biological information, fishery data sparse or patchy with no ability to estimate parameters noted above, or other metrics considered important. But a reliable CPUE index is available.	CPUE $_{t1-t2}$ or CPUE_low
Level 5	The key biological variables (age, reproduction, intrinsic rate of increase and carrying capacity) are reliably estimated.	F/F_{crash} >1 or F/F_{lim} >1

Table 2: WCPFC billfish agreed stock status. The row colour corresponds to Kobe plot cell coloring.

Name	**Species**	**Assessment year**	**Biomass status**	**Fishing effort status**
Swordfish - NP	*Xiphias gladius*	2018	Not Overfished	Overfishing not talking place
Swordfish - SP	*Xiphias gladius*	2017	Not Overfished	Overfishing not talking place
Striped marlin - NP	*Kajikia audax*	2019	Overfished	Overfishing taking place
Striped marlin - SP	*Kajikia audax*	2019	Likely Overfished	Close to experiencing overfishing
Blue marlin	*Makaira nigricans*	2016	Not Overfished	Overfishing not talking place
Black marlin	*Istiompax indica*	None	Unknown	Unknown
Sailfish	*Istiophorus platypterus*	None	Unknown	Unknown
Shortbilled spearfish	*Tetrapturus angustirostris*	None	Unknown	Unknown

Table 3: List of Reference Points reported against in the most recent WCPFC billfish assessments (Ducharme-Barth et al. 2019; ISC 2019; Takeuchi et al. 2017; ISC 2018; ISC 2016). MLS = striped marlin; SWO = swordfish; BUM = blue marlin; SWPO = southwest Pacific Ocean; NWPO = northwest Pacific Ocean.

Reference point	MLS - SWPO	MLS - NWPO	SWO - SWPO	SWO - NWPO	BUM - PO	Comments
C_{latest}	X	X	X	X	X	Not a reference point but a useful metric to display
$Y_{frecent}$	X		X			Not a reference point but a useful metric to display
$F_{current}$		X		X	X	Not a reference point but a useful metric to display
F_{mult}	X		X			Measure of appropriate fishing mortality
F_{MSY}	X	X	X	X	X	Not a reference point but a useful metric to display
$F_{20\%}$					X	Measure of appropriate fishing mortality
MSY	X	X	X	X	X	Not a reference point but a useful metric to display
F/F_{MSY}	X		X			Measure of appropriate fishing mortality
$F_{20\%*SB(F=0)}$		X		X		Measure of appropriate fishing mortality
$SB_{current}$		X		X	X	Not a reference point but a useful metric to display
20% SB					X	Measure and stock decline
SB_0	X					Not a reference point but a useful metric to display
SB/SB_0			X			Measure and stock decline
$SB_{F=0}$	X			X		Not a reference point but a useful metric to display
$SB/SB_{F=0}$	X					Measure and stock decline
SB_{MSY}	X		X	X	X	Not a reference point but a useful metric to display
SB_{MSY0}	X					Measure and stock decline
$SB_{MSYF=0}$	X		X			Measure and stock decline
SB/SB_{MSY}	X	X	X			Measure and stock decline
SB_0	X		X			Not a reference point but a useful metric to display
$SPR_{current}$				X	X	Measure and stock decline
SPR_{MSY}		X		X	X	Measure and stock decline
$SPR_{20\%SBF=0}$		X				Measure and stock decline
Total	14	9	11	10	10	

Table 4: Comparisons of life-history parameters from recent stock assessments.

Coefficients	**Albacore**	**Bigeye**	**Skipjack**	**Yellowfin**	**SWPO Striped Marlin**	**SWPO Swordfish**
L_{inf}	100.78	158.55	86.42	154.66	222.3	244.79
k	0.469	0.347	0.859	0.448	0.449	0.191
t_0	-0.633	-0.333	-0.106	-0.059	-0.749	-2.101
M	0.3	0.454	1.588	0.949	0.401	0.295
Age-at-50% maturity	3.5 years	3 years	9 months	2.5 years	3.5 years	5.5 years

Table 5: List of potential Limit Reference Points, categorised by Target or Bycatch and by assessment type. Robust = able to be measured against a reliable estimate of stock size; SAFE = Sustainability Assessment for Fishing Effects; DB-SRA = Depletion-Based Stock Reduction Analysis; and DCAC = Depletion-Corrected Average Catch. Grey shading is simply for easy separation of LRP groups.

LRP	Group	Assessment type	Robust
F/F_{MSY} =1	Target	Data rich	Yes
x% F/F_{MSY}	Bycatch	Data rich	Yes
20% $SB/SB_{F=0}$	Target	Data rich	Yes
10% $SB/SB_{F=0}$	Bycatch	Data rich	Yes
100% SB/SB_{MSY}	Target	Data rich	Yes
50% SB/SB_{MSY}	Target	Data rich	Yes
25% SB/SB_{MSY}	Bycatch	Data rich	Yes
20% B_0	Target	Data rich	Yes
10% B_0	Bycatch	Data rich	Yes
x% $CPUE_0$	Target & Bycatch	Data rich or Medium data	If CPUE tracks abundance
$SB/SB_{F=0t1-t2}$	Target	Data rich	Yes
$SB/SB_{MSYt1-t2}$	Target	Data rich	Yes
B_{t1-t2}	Target	Data rich	Yes
$CPUE_{t1-t2}$	Target	Data rich or Medium data	If CPUE tracks abundance
$SB/SB_{F=0}$_low	Target	Data rich	Yes
SB/SB_{MSY}_low	Target	Data rich	Yes
Biomass_low	Target	Data rich	Yes
CPUE_low	Bycatch	Data rich or Medium data	If CPUE tracks abundance
$SPR_{current}$	Bycatch	Data rich or Medium data	Posssibly
SPR_{MSY}	Bycatch	Data rich or Medium data	Posssibly
$SPR_{X\%SBF=0}$	Bycatch	Data rich or Medium data	Posssibly
F_{msn}	Bycatch	Data poor	No
F_{lim}	Bycatch	Data poor	No
50% F_{msn}	Bycatch	Data poor	No
$F/\ F_{lim}$ >1	Bycatch	Data poor	No
F/F_{crash} >1	Bycatch	Data poor	No
F_{crash}	Bycatch	Data poor	No
SAFE	Bycatch	Data poor	No
DB-SRA	Bycatch	Medium data	Posssibly
DCAC	Bycatch	Medium data	Posssibly

Table 6: Evaluation of the current stock status of SWPO striped marlin based on outputs from the 2019 assessment (Ducharme-Barth et al., 2019) against potential LRPs. The assessment metrics such as SB/SB$_{F=0}$ should be specified as per the assessment model, where SB is SB$_{recent}$ and SB$_{F=0}$ is recent 10 years prior to last year of assessment. The date ranges noted here are as per the analyses presented in the text for time bound LRPs, except for CPUE $_{t1-t2}$ that remains unspecified as the time periods chosen were specific to each of the five indices used.

LRP	Percent models breaching LRP	Number of Models
F/F$_{MSY}$ <1	11.0	300
F/F$_{MSY}$ <1.4	1.7	300
20% SB/SB$_{F=0}$	39.0	300
10% SB/SB$_{F=0}$	8.0	300
20% SB$_0$	23.0	300
20% CPUE$_0$	20.0	5
SB/SB$_{F=0\ 2012-2014}$	1.3	300
SB$_{1990-1992}$	36.0	300
CPUE$_{t1-t2}$	0.0	5
SB/SB$_{1991}$	29.0	300
CPUE_low	0.0	5
F/F$_{lim}$	14.0	300
F/F$_{crash}$	0.0	300

Table 7: Proposed list of potential Limit Reference Points for consideration for WCPFC billfish, categorised as Target or Bycatch and by assessment type. Grey shading is simply for easy separation of LRP groups.

LRP	Group	Assessment type	Comments
$F/F_{MSY}=1$	Target	Data rich	Hold target species to the same standard as target tuna stocks.
x% F/F_{MSY}	Bycatch	Data rich	Choose the level of x based on an evaluation.
20% $SB/SB_{F=0}$	Target	Data rich	Hold target species to the same standard as target tuna stocks.
x% $SB/SB_{F=0}$	Bycatch	Data rich	Choose the level of x based on an evaluation.
25% SB_0	Target	Data rich	Hold target species to the same standard as target tuna stocks.
x% SB_0	Bycatch	Data rich	Choose the level of x based on an evaluation.
SPR x% $SB_{F=0}$	Bycatch	Medium data or data poor	Choose the level of x based on an evaluation.
x% $CPUE_0$	Target & Bycatch	Data rich or Medium data	Choose the start of a reliable CPUE series and the level of x.
$SB/SB_{F=0t1-t2}$	Target & Bycatch	Data rich	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
SB_{t1-t2}	Target & Bycatch	Data rich	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
$CPUE_{t1-t2}$	Target & Bycatch	Data rich or Medium data	Choose a time period where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
$SB/SB_{F=0}$_low	Target & Bycatch	Data rich	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
SB_low	Target & Bycatch	Data rich	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels.
CPUE_low	Target & Bycatch	Data rich or Medium data	Choose a low year where the stock was considered in an undesirable state (and should be avoided in future), but recovered back to suitable levels. Note $CPUE_{t1-t2}$ is more precautionary.
$F/F_{lim}>1$	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be generated.
$F/F_{crash}>1$	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be generated.

Table 8: List of accepted billfish Target (TRP) and Limit (LRP) Reference Points used in other management jurisdictions. MFMT = Maximum Fishing Mortality Threshold; and MSST = Minimum Stock Size Threshold.

Area	Name	Species	LRP	TRP	Reference
Australia	Swordfish - SP	*Xiphias gladius*	20% $SB/SB_{F=0}$ and F/F_{MSY} =1	None	(Department of Agriculture and Water Resources, 2018)
Australia	Striped marlin - SP	*Kajikia audax*	20% $SB/SB_{F=0}$ and F/F_{MSY} =1	None	(Department of Agriculture and Water Resources, 2018)
ICCAT	Swordfish - NA	*Xiphias gladius*	0.4*B_{MSY}	B_{MSY}	(ICCAT, 2017)
IOTC	Swordfish - IO	*Xiphias gladius*	0.4*B_{MSY} and 1.4*F_{MSY}	B_{MSY} and F_{MSY}	(IOTC, 2015)
New Zealand	Swordfish - SP	*Xiphias gladius*	Default of 20% SB_0 and 10% SB_0	$B>B_{MSY}$ and $F<F_{MSY}$	(Fisheries New Zealand, 2020)
New Zealand	Striped marlin - SP	*Kajikia audax*	Default of 20% SB_0 and 10% SB_0	$B>B_{MSY}$ and $F<F_{MSY}$	(Fisheries New Zealand, 2020)
USA	Swordfish - NP	*Xiphias gladius*	MFMT, MSST, B_{FLAG}	None	(Western Pacific Regional Fishery Management Council, 2009)
USA	Swordfish - NP	*Xiphias gladius*	MFMT, MSST, B_{FLAG}	None	(Western Pacific Regional Fishery Management Council, 2009)
USA	Blue marlin	*Makaira nigricans*	MFMT, MSST, B_{FLAG}	None	(Western Pacific Regional Fishery Management Council, 2009)
USA	Other billfish	Istiophoridae	MFMT, MSST, B_{FLAG}	None	(Western Pacific Regional Fishery Management Council, 2009)

Table 9: WCPFC billfish table showing proposed species groupings, assessment data type and proposed Limit Reference Points.

Name	Species	Group	Assessment data	Proposed Limit Reference Points	Can we do it?
Swordfish - NP	*Xiphias gladius*	Target species	Data-rich	20% SB/SB$_{F=0}$ and F/F$_{MSY}$ =1	Yes
Swordfish - SP	*Xiphias gladius*	Target species	Data-rich	20% SB/SB$_{F=0}$ and F/F$_{MSY}$ =1	Yes
Striped marlin - NP	*Kajikia audax*	Bycatch	Data-rich	20% SB/SB$_{F=0}$ and F/F$_{MSY}$ =1	Yes
Striped marlin - SP	*Kajikia audax*	Bycatch	Data-rich	20% SB/SB$_{F=0}$ and F/F$_{MSY}$ =1	Yes
Blue marlin	*Makaira nigricans*	Bycatch	Data-rich	20% SB/SB$_{F=0}$ and F/F$_{MSY}$ =1	Yes
Black marlin	*Istiompax indica*	Bycatch	Medium-data	20% CPUE$_0$ or CPUE$_{t1-t2}$ or CPUE_low or F/F$_{crash}$ or F/F$_{lim}$	Probably
Sailfish	*Istiophorus platypterus*	Bycatch	Data-poor	20% CPUE$_0$ or CPUE$_{t1-t2}$ or CPUE_low or F/F$_{crash}$ or F/F$_{lim}$	Possibly
Shortbilled spearfish	*Tetrapturus angustirostris*	Bycatch	Data-poor	20% CPUE$_0$ or CPUE$_{t1-t2}$ or CPUE_low or F/F$_{crash}$ or F/F$_{lim}$	Possibly

Figures

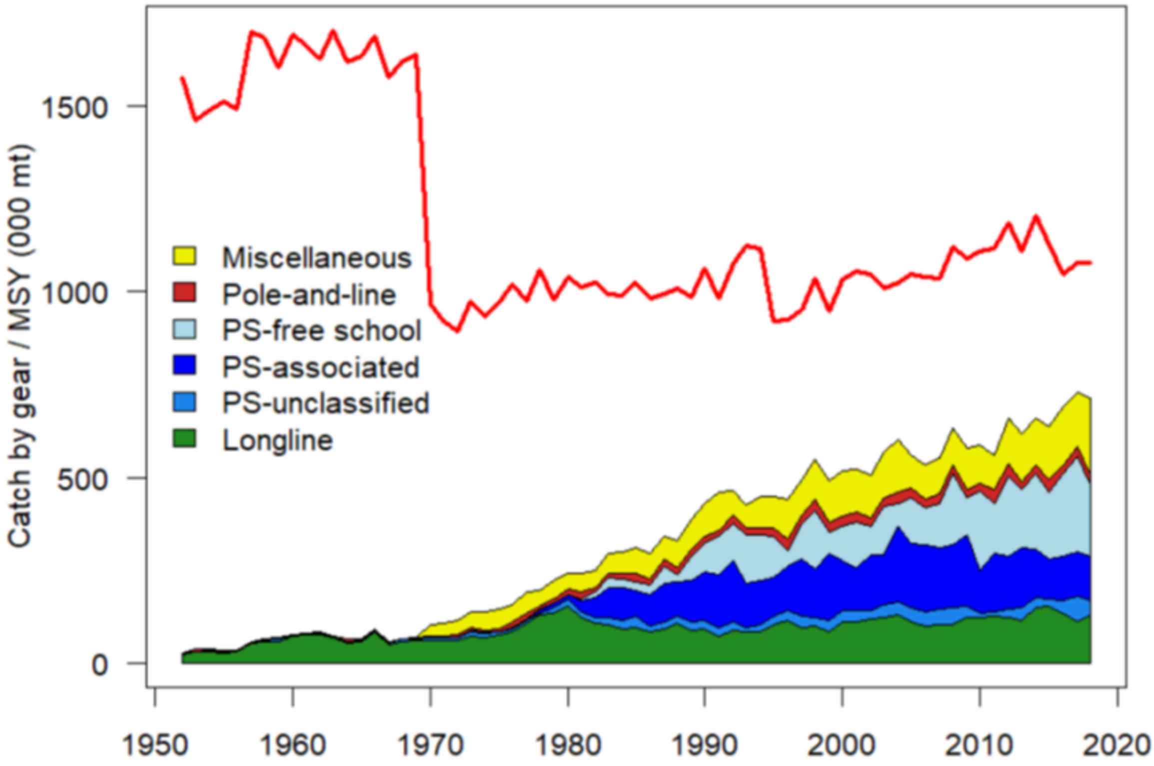

Figure 1: WCPO yellowfin tuna history of the annual MSY (red line) along with the annual catch by gear type (Vincent et al., 2020).

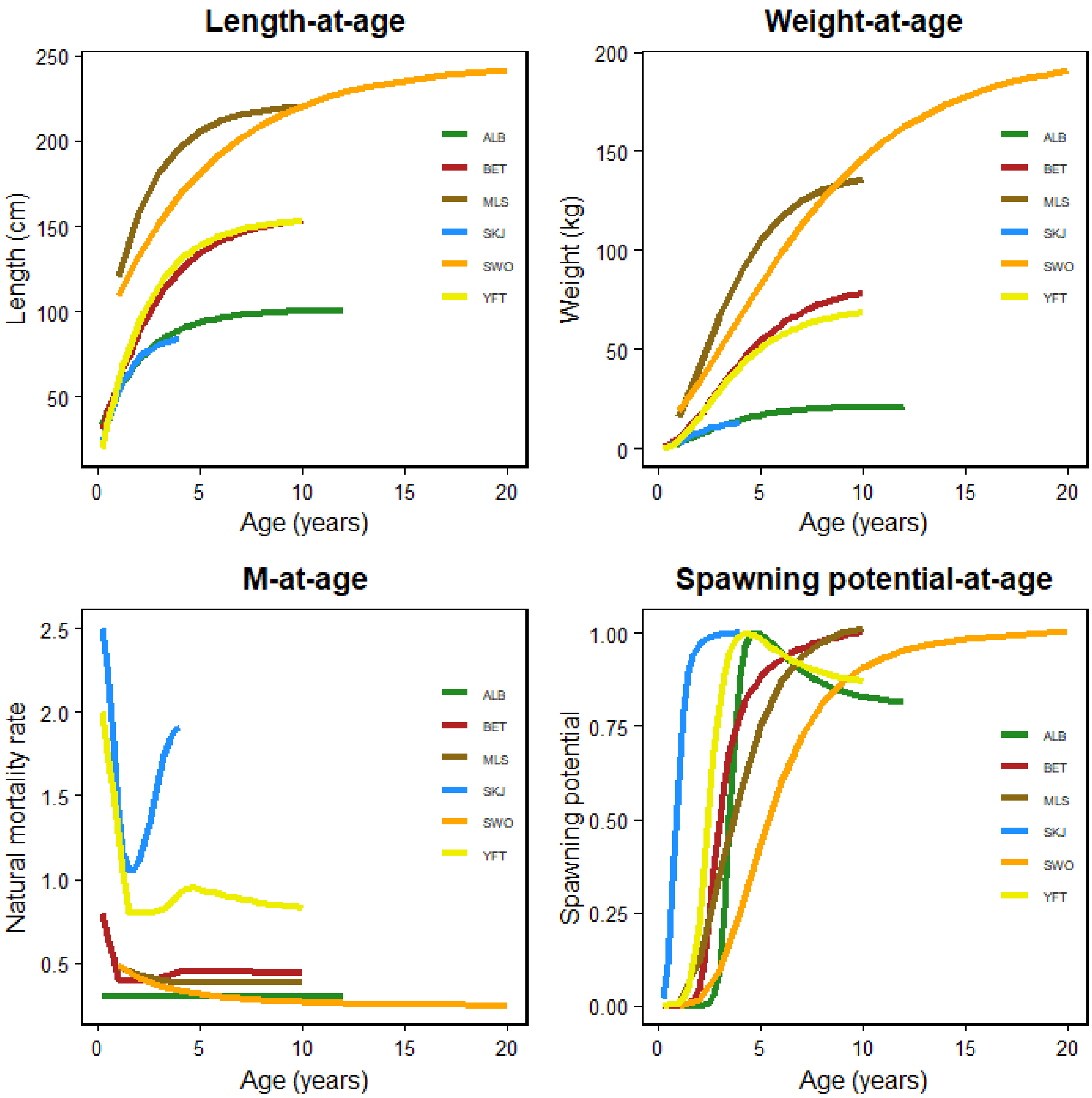

Figure 2: WCPO tuna and billfish biological characteristics derived from the MFCL assessment inputs for albacore (Tremblay-Boyer et al., 2018), bigeye (Ducharme-Barth et al., 2020), skipjack (Vincent et al., 2019), yellowfin (Vincent et al., 2020), striped marlin (Ducharme-Barth et al., 2019) and swordfish (Ducharme-Barth et al., 2021).

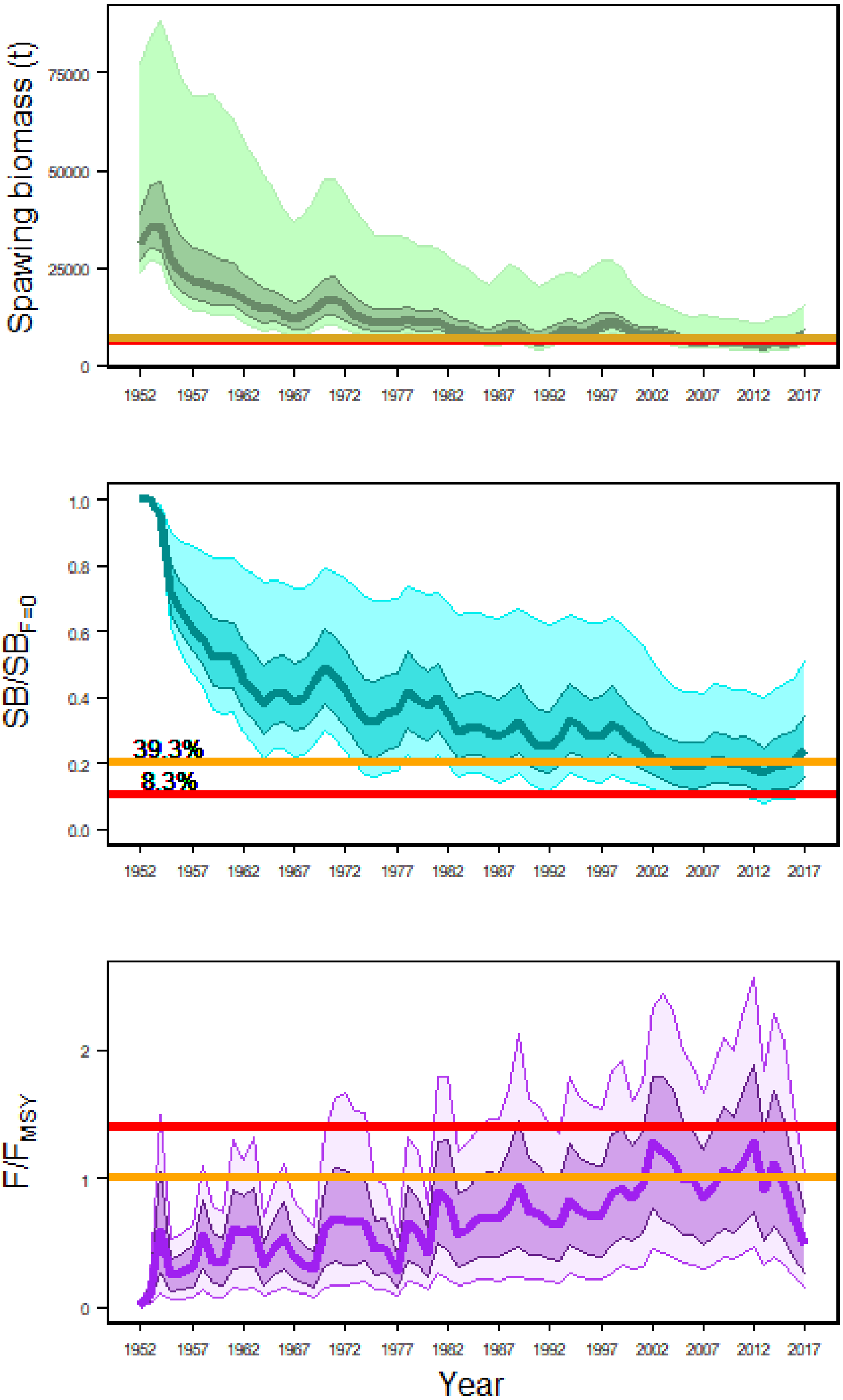

Figure 3: Example plot using data from the SWPO striped marlin stock assessment (Ducharme-Barth et al., 2019). The median of the estimates is shown as the dark line, while the shaded regions show the 50^{th} and 80^{th} percentiles. The top plot shows the spawning biomass with three example LRPs, SB/SB$_{1991}$ (Biomass_low) (red); SB/SB$_{1990-1992}$ (SB/SB$_{t1-t2}$) (gold); 20% SB/SB$_0$ (orange). Depletion (middle) with the example LRPs 20% SB/SB$_{F=0}$ (orange); 10% SB/SB$_{F=0}$ (red). Fishing intensity (bottom) showing two example LRPs F/F$_{MSY}$ = 1 (orange); F/F$_{MSY}$ = 1.4 (red).

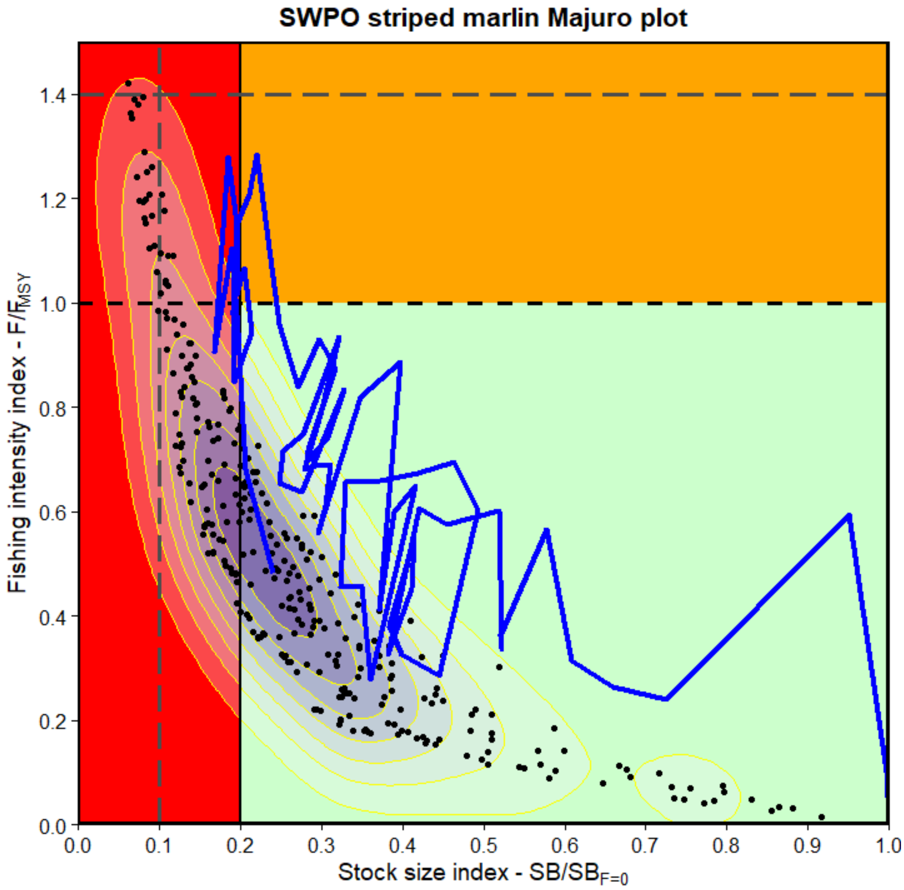

Figure 4: Majuro plot showing the median trajectory of depletion and fishing intensity (blue line), terminal point estimates from the assessment (points) and the density of terminal point estimates contours from the 2019 SWPO striped marlin assessment (Ducharme-Barth et al., 2019).

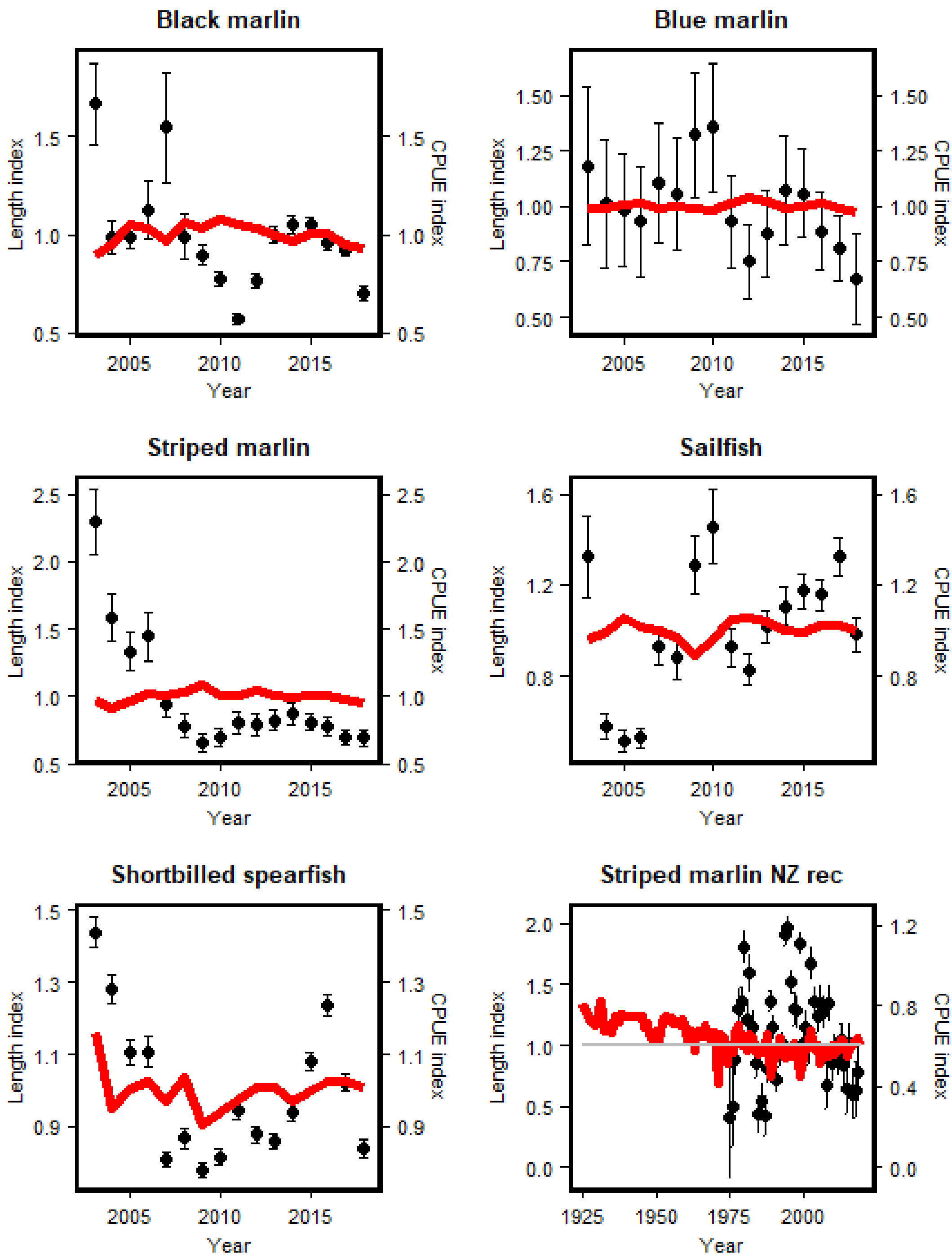

Figure 5: Mean length and CPUE for billfish from the central WCPO. The CPUE data (points and error bars) are from the combined shallow and deep CPUE from (Peatman et al., 2018) and the length index (red line) is mean length, both indices have been normalised to the mean of each series for comparison. The bottom right plot are the New Zealand recreational fishery data from (Holdsworth and Saul, 2019).

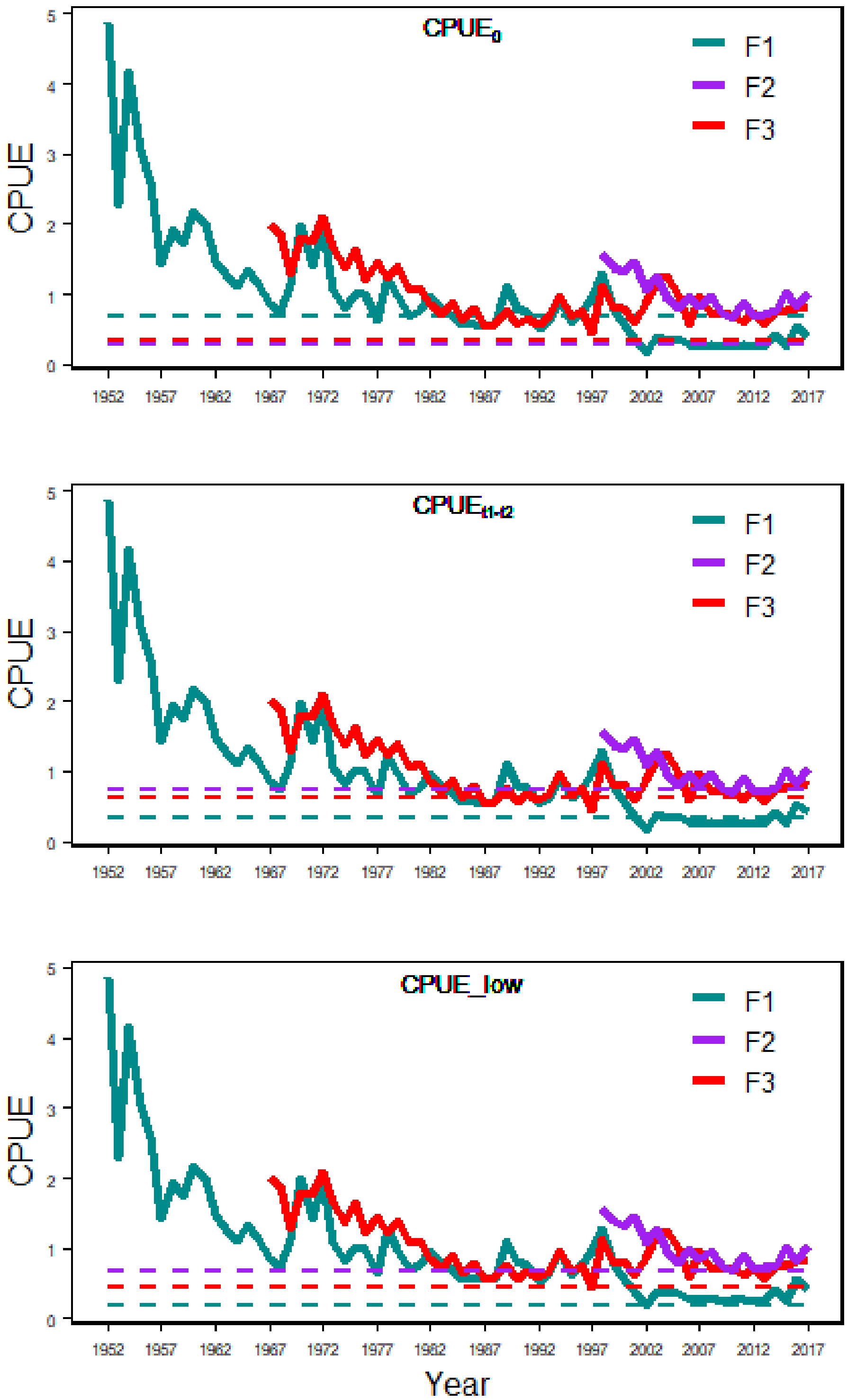

Figure 6: SWPO striped marlin CPUE from three fisheries (F1, F2 and F3) used in the 2019 stock assessment model (Ducharme-Barth et al., 2019) showing example empirical LRPs for each index CPUE$_0$ (top) CPUE$_{t1-t2}$ (middle) and CPUE_low (bottom).

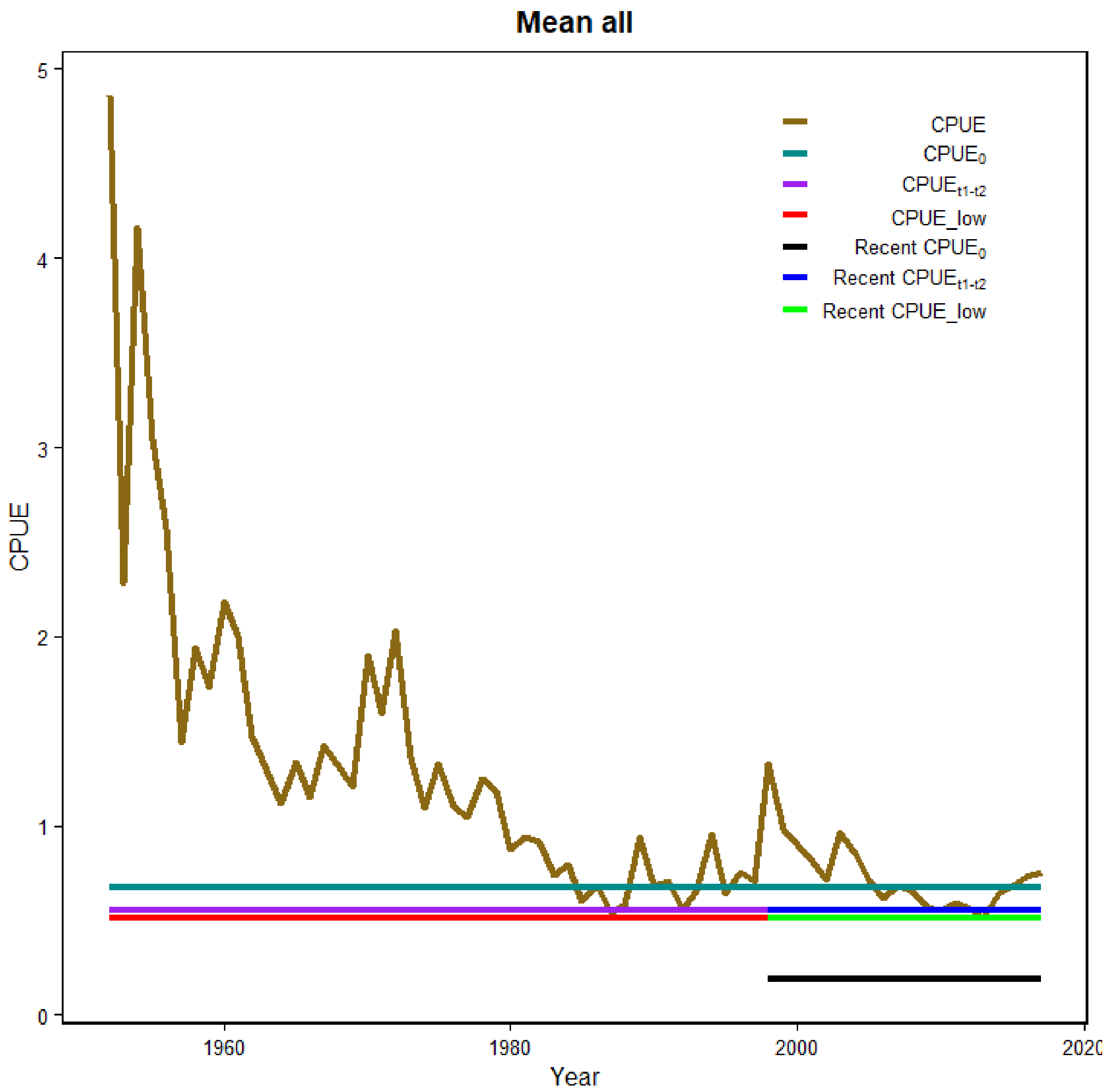

Figure 7: SWPO striped marlin CPUE from the mean of three CPUE indices shown in Figure 6 along with example empirical LRPs base on the entire index and from 1998-2017 only.

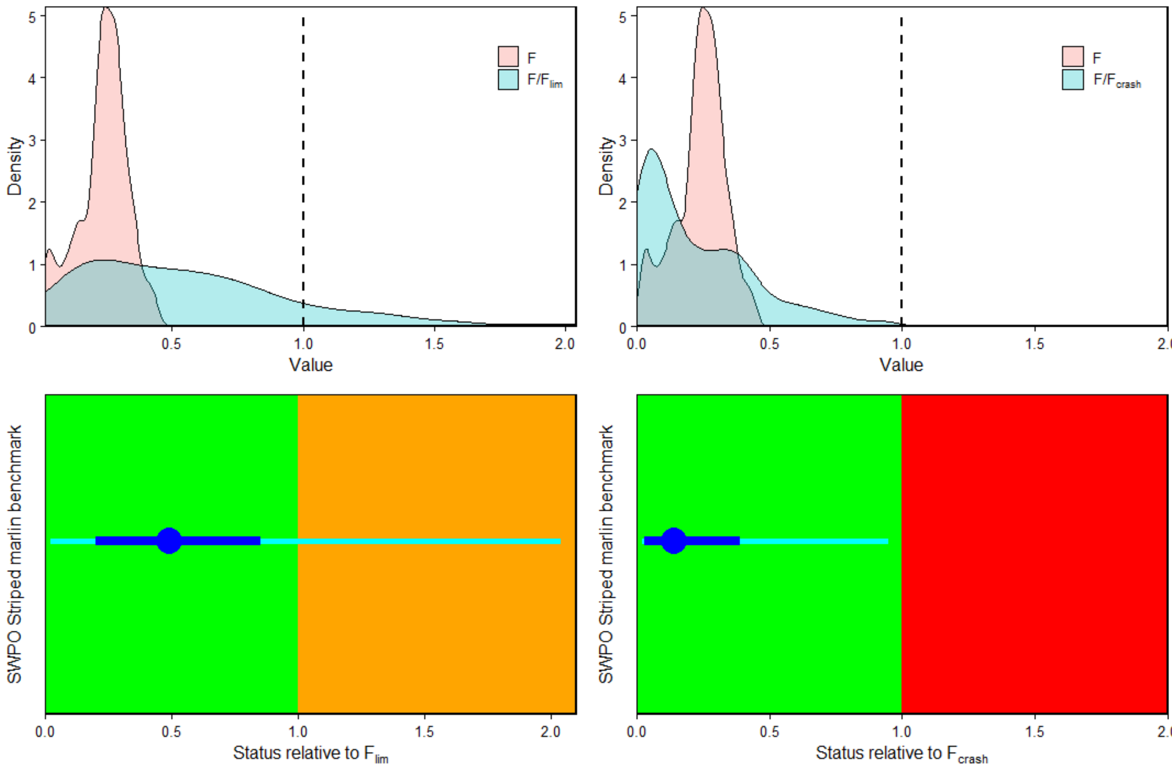

Figure 8: Density distribution of 300 model runs estimating F, F/F$_{lim}$ (top left) and F/F$_{crash}$ (top right) as well as as well as the status relative to risk-based fishing mortality benchmarks showing the median (blue point), 20th and 80th percentiles (thick blue line) and range (light blue line) for F/F$_{lim}$ (bottom left) and F/F$_{crash}$ (bottom right).

Appendix I

Table AI - 1: Description of the metrics discussed in this report.

Metric	Description
C_{latest}	Catch in the last year of the assessment
F_{recent}	Average fishing mortality-at-age for a recent period specified by the assessment
YF_{recent}	Equilibrium yield at average fishing mortality for a recent period specified by the assessment
$f$mult	Fishing mortality multiplier at maximum sustainable yield (MSY)
F_{MSY}	Fishing mortality-at-age producing the maximum sustainable yield
MSY	Equilibrium yield at F_{MSY}
F/F_{MSY}	Average fishing mortality-at-age relative to F_{MSY} for a recent time period specified by the assessment
SB	Spawning biomass usually defined as a period of the last x years specified in the assessment
SB_0	Equilibrium unexploited spawning potential
$SB_{F=0}$	Average spawning potential predicted in the absence of fishing usually defined as a period of the last x years specified in the assessment
SB_{MSY}	Spawning potential that will produce the maximum sustainable yield (MSY)
$SB/SB_{F=0}$	The spawning potential in the latest x time period of the assessment relative to the average spawning potential predicted to occur in the absence of fishing for the y period. x and y periods specified by the assessment.
SB/SB_{MSY}	Spawning potential in a recent time period (specified by assessment) relative to that which will produce the maximum sustainable yield (MSY)
B	Total vulnerable biomass usually defined for a period of the last x years specified in the assessment
B_0	Equilibrium unexploited vulnerable biomass
B/B_0	Vulnerable biomass (for a specified time period) as a percentage or proportion of equilibrium unexploited vulnerable biomass
CPUE	Catch per Unit of Fishing Effort
$CPUE_0$	CPUE at the start of a CPUE series
$x\%$ $CPUE_0$	Percentage or proportion of CPUE at the start of a CPUE series
$SB/SB_{F=0t1-t2}$	The spawning potential in the latest x time period of the assessment relative to the average spawning potential predicted to occur in the absence of fishing for the period t1-t2. x and t1-t2 periods specified by the assessment
$SB/SB_{MSYt1-t2}$	The spawning potential in the latest x time period of the assessment relative to the average spawning potential predicted to produce MSY for the period t1-t2. x and t1-t2 periods specified by the assessment
B_{t1-t2}	Average of total vulnerable biomass across a range of selected years
$CPUE_{t1-t2}$	Average CPUE across a range of selected years
$SB/SB_{F=0}$_low	The lowest median value of the spawning potential relative to the spawning potential predicted to occur in the absence of fishing for the model time period
SB/SB_{MSY}_low	The lowest median value of the spawning potential relative to the spawning potential predicted to produce MSY for the model time period
Biomass_low	Lowest median vulnerable biomass for the model time period

Table AI - 1: ***(continued)***

Metric	Description
SB_low	Lowest median spawning potential for the model time period
CPUE_low	Lowest CPUE in a series
SPR x% $SB_{F=0}$	Fishing morality levels are maintained at levels that produce a spawning potential ratio of x% of unfished spawning potential.
$SPR_{current}$	The proportion of the unfished reproductive potential that remains in the population under current levels of fishing mortality
SPR_{MSY}	The level of fishing mortality that will produce an SPR level predicted to support maximum sustainable yield
F_{msn}	Maximum sustainable fishing mortality
F_{lim}	Fishing mortality estimated to result in 25% B_0
F_{crash}	The fishing mortality level where there is high probability of collapse of the fishery
F/ F_{lim}	Fishing mortality for a specified period relative to F_{lim}
F/F_{crash}	Fishing mortality for a sepcified relative to F_{crash}
SAFE	Sustainability Assessment for Fishing Effects
DB-SRA	Depletion-Based Stock Reduction Analysis to estimate reasonable yield
DCAC	Depletion-Corrected Average Catch to estimating sustainable yield