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Determination of Biological Reference Points (BRPs) for key SIOFA fish stocks (PAM-2024-02)

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Abstract

This report outlines the methodology and progress of Project PAM-02, focused on establishing Biological Reference Points (BRPs) for key Southern Indian Ocean Fisheries Agreement (SIOFA) fish stocks. BRPs serve as benchmarks to evaluate fish stock health and guide sustainable management.
The project aims to develop robust BRPs in alignment with related projects (PAM-2024-01 and PAM-2024-03) and incorporates advice and insights from the SIOFA Expert and Advisory Panels. BRPs include target reference points (TRPs), limit reference points (LRPs), and trigger points, ensuring stock sustainability within biological and operational boundaries. BRPs linked to metrics based on biomass (B40%, B20%, SB_{MSY}), fishing mortality (F_{MSY}, F/F_{MSY}), and CPUE will be evaluated.
Most SIOFA species are data-poor, complicating the development of stock-specific BRPs. Interim BRPs have been set for key species such as orange roughy, alfonsino, and toothfish, but further refinement is needed.
Workshops and recommendations from SIOFA's 10th and 11th Meetings of Parties (MoP10, MoP11) have shaped interim BRPs. Current efforts prioritize data collection, risk assessment methods, and simulations to validate and refine BRPs.

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A tiered framework addresses low, medium, and high-information stocks, incorporating international best practices and life-history data from diverse sources. It will explore regime shifts, environmental variability, and dynamic BRP adjustments.
Regular updates and reports will be shared with stakeholders, culminating in a final report by April 2026.
The study provides a foundation for sustainable fisheries management in the SIOFA region, helping to ensure the health of fish stocks and the long-term viability of the fisheries sector.

Determination of Biological Reference Points (BRPs) for key SIOFA fish stocks (PAM-2024-02)

Introduction

This document outlines approaches to be applied in the development of suitable Biological Reference Points (BRPs) for key SIOFA fish stocks, under the project PAM-02. This project will be carried out in close collaboration with projects PAM-2024-01, which will identify the appropriate policy settings and management approach, and PAM-2024-03 which will inform some of the harvest control rules and biological reference points tested. It will also incorporate feedback from the review panel, covered under PAM-2024-04. The same modelling frameworks will be used to develop and test both the biological reference points (project PAM-2024-02) and the harvest control rules that use those reference points (project PAM-2024-03).

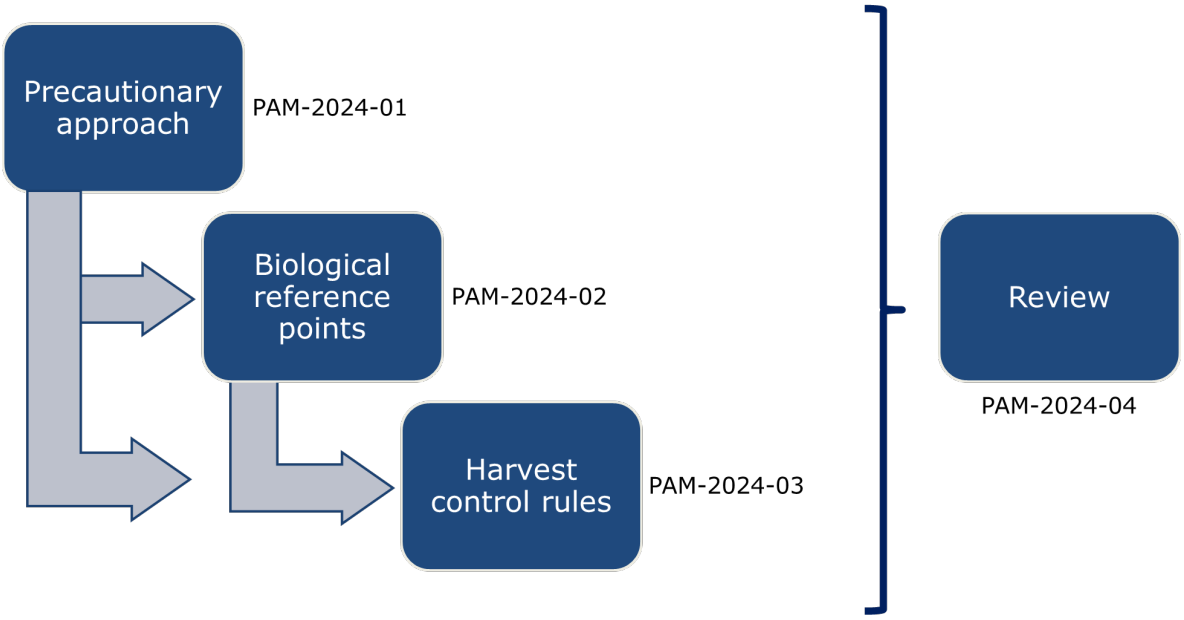

Figure 1:

Further details will be determined in collaboration with the SIOFA project Expert Panel, the project Advisory Panel and the research providers of other PAM-2024 projects.

Project Terms of Reference

1. Provide analyses that will support of the development of suitable BRPs for key SIOFA fish stocks (Appendix A of the SIOFA Fisheries Overview 2024) and propose interim default BRPs for low, medium, and higher information stocks. Specifically, evaluate the potential use of standard biological reference points, such as B40% and B20%, MSY, SBMSY, SB0, SBF=0, SB/SBMSY, SB/SBF=0, SB/SB0, F, FMSY, F/FMSY and F40%, as well as CPUE equivalents and any other appropriate reference points (e.g. as listed in Table 2):

   a. The analysis should include consideration of target ranges, threshold regions, and limit reference points.
   b. Provide example case studies to illustrate their implementation, including examples of different choices of BRPs for the same species or SIOFA species that are harvested in other Regional Fisheries Management Organizations (RFMOs).
2. Review methods for the calculation and interpretation of risk and the quantification of uncertainties related to them. For stocks where quantitative risk analyses are not possible, provide options on how to establish appropriate default reference points and how these may be improved to be stock specific reference points.
3. Determine the conditions for when/if the BRPs would need to be revised or reevaluated (e.g., identify changes in available information or regime shifts).

Background

What are BRPs?

A biological reference point (BRP) is “a benchmark against which to assess the performance of management in achieving an operational objective” (FAO, 1997), and each BRP is associated with a metric. Such metrics may indicate the biomass or abundance of the stock, the fishing mortality or exploitation rate, or catch itself. The relationship between the metric and the benchmark summarizes a stock's biological status and is used to inform fisheries managers about stock health (Ministry of Fisheries, 2011). By representing the biological component of management measures, BRPs are the main component of the initial development of harvest strategies. Other objectives, e.g., socio-economic, may also be considered with additional metrics, and potentially additional reference points.

Reference points can be targets, limits, or triggers, depending on how they will be used.

Target reference points (TRPs) represent desired outcomes of fishery management, such as the optimum yield as determined through fisheries governance processes (Clarke and Hoyle, 2014). Target reference points are generally based on optimizing the benefits obtained from a fishery given a maximum level of risk. The benefits considered are usually, but not necessarily, limited to yields in terms of weight. The metric should fluctuate around its TRP.

Limit reference points (LRPs) set boundaries that are intended to constrain harvesting within safe biological limits (United Nations, 1995). Limit reference points are based on the biology of a species and represent a level at which the risk to the stock becomes unacceptably high (Sainsbury, 2008). The risk of the metric breaching its LRP should be low.

Trigger reference points are sometimes defined in addition to TRPs and LRPs. It is useful to differentiate between the BRPs, which represent objectives, and the operational control points at which management measures might change (Cox et al., 2013; Taylor et al., 2024). Trigger RPs reflect points at which a predetermined management decision is initiated (Sainsbury, 2008), but do not in themselves represent desirable or undesirable states of the stock.

BRPs are required for the species defined in Appendix A of the SIOFA Fisheries Overview 2024 (SIOFA Secretariat, 2024), as listed in Table 4. These species have been identified by the SIOFA SC as primary and secondary species in SIOFA fisheries and are considered to be target species.

All listed species will require LRPs. Species that are managed to achieve production goals will also require TRPs.

Most of the species managed by SIOFA are information-poor, which creates challenges for developing both BRPs and the methods for assessing status against them.

Progress towards SIOFA BRPs

SIOFA has made considerable progress towards management based on BRPs and HCRs, having held a series of harvest strategy workshops: the Workshop on harvest strategy pre-assessment (WSHSPA-2023) in March 2023, the Joint MoP-SC Workshop on Harvest Strategy Management Objectives (WS2023-HSMO) in November 2023, and the Joint MoP-SC Workshop on the Development of Harvest Strategies (WS2024-HSS) in June 2024.

The 10th Meeting of Parties (MoP10) endorsed the recommendations of the 8th Scientific committee (SC8) regarding a framework of interim HCR and BRPs for interim management of orange roughy, alfonsino, and toothfish stocks (see paras 76-79 of the MoP10 meeting report, and paras 176-177 of the SC8 meeting report).

For orange roughy and alfonsino, the interim TRP was set at 40% of unfished biomass (B_0), while for toothfish the interim TRP was set to 50% of unfished biomass to be consistent with CCAMLR. For both species a requirement was set for a 50% probability of being above the target. The interim LRPs for all species were set to 20% of B_0, with 90% probability of remaining above the limit.

Potential management objectives and performance indicators were drafted by the Joint MoP and SC Intersessional Workshop to Define Harvest Strategy Management Objectives (WS2023-HSMO) in November 2023, and the performance indicators were further refined by SC9 in March 2024 – see Annex H and Annex I of the SC9 report. These were noted by MoP11 in July 2024.

MoP11 in July 2024 also endorsed the recommendations in paragraph 20 and 24 of the Joint MoP-SC Workshop on the Development of Harvest Strategies (WS2024-HSS) Conveners Report that alternative sensitivity choices should be evaluated for orange roughy and toothfish respectively. For orange roughy, analysts should evaluate alternative sensitivity choices of 50-60-70% probability of being at or above a target reference point (TRP) of 30-40-50% B_0, while for toothfish analysts should evaluated the same probability levels but for TRP of 40-50-60% B_0.

MoP11 also adopted a broader set of recommended management objectives and performance indicators for orange roughy and toothfish – see Annexes N and O respectively of the MoP11 report. These included BRPs that were consistent with the interim BRPs discussed above.

For alfonsino, limited CPUE data and simple assessments are available. Although MoP10 endorsed the same BRPs for alfonsino as for orange roughy, MoP11 noted that WS2024-HSS reaffirmed that harvest strategy development work should first focus on toothfish and orange roughy, and that harvest strategies for alfonsino and other SIOFA species could be developed thereafter, as was agreed by MoP10 and SC9.

For other species, data available at present are very limited which creates difficulties for developing reference points and harvest strategies. MoP11 advised that catches should be maintained at the average of recent catches, with sufficient monitoring to identify unsustainable trends. They indicated that it may be feasible to develop BRPs after the completion of work on toothfish, orange roughy and alfonsino.

BRP approaches

BRPs can be expressed in terms of either biomass-related parameters (B) or fishing mortality (F). Biomass-related parameters that may be used include total biomass, vulnerable biomass (the biomass of age/size classes vulnerable to fishing), spawning biomass (biomass of mature adult fish), and spawning potential. Spawning potential is a measure of contribution to spawning. It may be

calculated by summing across all lengths/ages the products at each length/age of numbers, proportion that are female and mature, spawning fraction, and fecundity. Spawning potential is often expressed as SPR, the ratio of fished to unfished reproductive biomass at equilibrium.

A range of information types can be used when developing and applying BRPs. They include stock assessments; catch and effort data and the indices or abundance derived from them; age and length structure; tag recapture data; and life history information. These data types can be used both to determine BRPs, and to estimate status against the BRPs.

Metrics can be grouped into 4 categories with respect to their data requirements (Brouwer and Hamer, 2021). It should be noted that all approaches require spatial information (or assumptions) about stock distribution, stock mixing, and the distribution of fishing.

a) Metrics derived from an integrated stock assessment model.
   The full range of RPs can be estimated, including MSY-related parameters both F-based and B-based, and ratios of current to unfished levels of spawning biomass or biomass such as $SB/SB_{F=0}$ (spawning biomass relative to that predicted in the absence of fishing); $SB/SB_{F=0\ t1-t2}$ (spawning biomass relative to the average predicted in the absence of fishing during the period t1 – t2); $SB/SB_{F=0}$ low (lowest median value during the modelled period of spawning biomass relative to that predicted in the absence of fishing); x% B_0 (vulnerable biomass as a percentage of equilibrium unexploited vulnerable biomass); $B_{0\ t1-t2}$ (average total vulnerable biomass during the period t1 – t2); and Biomass low (the lowest median vulnerable biomass during the modelled period).
   These metrics require sufficient information to fit an age-structured (or size-structured) stock assessment model, such as estimates of growth and maturity, composition data, reliable long-term catch data, and a reliable index of abundance or biomass based on CPUE or survey data.
b) Metrics derived from a surplus production model.
   These include MSY-related quantities such as B/B_{MSY} and F_{MSY}, and ratios such as B/B_0.
   These metrics require reliable long-term catch data, and a reliable index of abundance or biomass based on CPUE or survey data.
c) Empirical reference point metrics – e.g., x% $CPUE_0$, $CPUE_{t1-t2}$ and CPUE low.
   These metrics are usually based on an index of abundance or biomass from CPUE. For $CPUE_{t1-t2}$ and CPUE low the index must have declined to a low / undesirable level and then recovered.
d) Spawning potential ratio (SPR) and risk-based fishing mortality benchmarks F/F_{lim}, and F/F_{crash}.
   These metrics require life history information such as natural mortality, growth, and maturity parameters; estimates of the intrinsic population growth rate; and selectivity. Monitoring would require ongoing estimation of the current F level, and ideally the re-estimation of F_{lim} and F_{crash} as new biological information becomes available.

Many of these metrics require a reliable index of abundance based on CPUE. Developing such an index requires a time series of reliable and consistently reported catch and effort data, along with associated information such as vessel ID, fishing location, and operational details. Set-by-set data is strongly preferred (Hoyle et al., 2024; Maunder and Punt, 2004). Index development requires careful data exploration and statistical analysis.

Similar to the related metrics, BRPs may be grouped into three categories: a) estimated BRPs, which are derived from stock assessments; b) empirical BRPs, which are based on observed data such as CPUE, age or length structure, or tag recapture; and c) risk-based BRPs which are derived directly from life-history parameters.

Methodology

The characteristics of the current interim BRPs and potential BRPs will be explored based on a review of relevant literature and through simulation. Standard BRPs and associated indicators will be considered, including $B_{40\%}$, and $B_{20\%}$, MSY, SB_{MSY}, SB_0, $SB_{F=0}$, SB/SB_{MSY}, $SB/SB_{F=0}$, SB/SB_0, F_{MSY}, F/F_{MSY} and $F_{40\%}$, as well as CPUE equivalents and any other appropriate reference points (e.g., the LRPs listed in Tables 2 and 3).

In considering these options we will note constraints such as the need for SIOFA's management of toothfish to be consistent with approaches used by CCAMLR. It is also important to avoid unnecessary inconsistency in the approaches applied to each stock. Nonetheless, as highlighted for SIOFA stocks by Brandão et al. (2022) and Butterworth (2022), the values chosen for some control parameters would likely need to vary substantially from stock to stock.

Reviews and analyses will consider both target and limit reference points, and the operational control points that can be used to define target ranges and threshold regions.

In developing and comparing interim default reference points, we will work within a tiered framework of low, medium, and higher information stocks to differentiate between SIOFA species based on the types and quality of information available. We note that BRP estimates can vary considerably with relatively small changes in the information that informs them (Cox et al., 2013). We will therefore consider the robustness of BRP estimates and the potential benefits and costs of employing alternative BRPs (see also Clarke and Hoyle, 2014; Preece et al., 2011; Zhou et al., 2020a).

To obtain the most relevant life history information available for each species, both published and unpublished, we will explore information sources such as FishBase (Froese and Pauly, 2024) and Google Scholar, and consider sources such as meta-analyses across species (e.g., Thorson, 2020; Thorson et al., 2017). These will be compared against the values used within SIOFA to date (e.g., Butterworth et al., 2021).

Information will be prioritised according to criteria that include sample sizes, analytical methods, whether the data come from the same stock, and whether the data come from the same or a related species (see Table 1). The population dynamics of many species vary spatially (e.g., Williams et al., 2012), so biological parameter values derived from one region may not be appropriate for a model of the same species in a different region (Griffiths et al., 2019). Nevertheless, it will often be necessary to use studies from other regions.

Table 1: Based on Table 1 of Griffiths et al. (2019). Qualitative index used to rank the relative reliability of parameters used for each species, given the methodology used to estimate the parameter, the precision of the parameter estimate, the data source's relevance to the species in the region assessed. Colours correspond to indices (ranging from blue: 0 to red: 10).

		High accuracy		Medium accuracy		Low accuracy		No data
		High precision	Low precision	High precision	Low precision	High precision	Low precision	
Species specific	SIOFA area	10	9	8	7	6	5	0
	Indian Ocean	9	8	7	6	5	4	0
	Other	8	7	6	5	4	3	0
Related species	SIOFA area	7	6	5	4	3	2	0
	Indian Ocean	6	5	4	3	2	1	0
	Other	5	4	3	2	1	1	0

We will review methods for calculating and interpreting risk, and for quantifying the associated uncertainties, such as SAFE (Zhou and Griffiths, 2008; Zhou et al., 2009) and EASI-FISH (Griffiths et al., 2019) analyses. The EASI-FISH method estimates fishing mortality (F) based on the 'volumetric overlap' of each fishery with the distribution of each species. F is then used in length-structured per-recruit models to assess population vulnerability status using conventional biological reference points. Thus it extends the SAFE approach to allow for size-dependent selectivity.

For stocks where quantitative risk analyses are not possible, we will consider options for methods to establish appropriate default reference points, and how these may be improved to be stock-specific reference points.

We will provide example case studies to illustrate the implementation of the BRPs, including examples of different choices of BRPs for the same species or SIOFA species that are harvested in other RFMOs.

We will consider international examples (Brouwer and Hamer, 2021; Clarke and Hoyle, 2014; Harley et al., 2009; Ministry of Fisheries, 2011; Sun et al., 2021; Taylor et al., 2024; Zhou et al., 2019; Zhou et al., 2022; Zhou et al., 2020a; Zhou et al., 2020b), reported reasons for RFMOs adopting (or not adopting) alternative BRPs, feedback from other PAM-2024 scientists, and the SIOFA project Expert Panel and project Advisory Panel. Particular attention will be given to processes used in other Regional Fisheries Management Organisations (e.g., SPRFMO, WCPFC, ICCAT). We will evaluate the robustness of the BRPs to misspecification of life history characteristics such as natural mortality, growth, maturity, and steepness. The utility of reference points will also be considered in the context of productivity variation associated with climate change (Duplisea et al., 2021; Merino et al., 2019) and in particular regime shifts. This is particularly relevant to the choice between BRPs based on fixed versus dynamic B_0 (e.g., SB/SB_0 versus $SB/SB_{F=0}$) (Ouzoulias et al., 2024).

We will determine the conditions in which BRPs would need to be revised or reevaluated (e.g., based on changes in available information or significant environmental changes / regime shifts).

Modelling of BRPs in the context of harvest control rules

Simulations developed for the stocks of interest (toothfish and orange roughy) in the context of PAM-2024-03 will be used as a starting point for testing of BRPs. In order to evaluate the effectiveness of these BRPs for stocks with less data, additional models for the toothfish stock will be stripped of some information, allowing direct comparison of results with the same model and additional data.

Simulations will then be carried out applying the different biological reference points and varying the projected productivity of the stocks. Simulations will apply constant-F strategies, to permit straightforward comparisons among BRPs. The results of the different simulations will be compared based on management objectives, including stock productivity and reference points, risk, and effect on the fishery.

All work will be carried out in close conjunction with the SIOFA project Expert Panel (project PAM-2024-04), the project Advisory Panel and the research providers of projects PAM-2024-01 and -03 to ensure the best applicability of the research.

Reporting

Regular reporting to the SIOFA project Expert Panel and the project Advisory Panel will be carried out throughout the project. Feedback will be integrated into the work programme. Presentations will be given at the appropriate SIOFA meetings, as required. Draft and final reports will be provided as per the project tender. All data and code will be provided to the Secretariat.

The project will be carried out in accordance with the tender terms, conditions, and provisions. The timelines detailed in the tender document will be adhered to, specifically:

- regular (i.e. every 2-3 months), proactive updates to the project Expert Panel and project Advisory Panel throughout the project,
- presentation of preliminary methods and results by 18-27 March 2025,
- draft report by 31 December 2025,
- presentation of final results to the SIOFA SC annual meetings (March 2026),
- final report by 1 April 2026,
- provide all the information collected and code developed, by 1 April 2026.

REFERENCES

Brandão, A.; Butterworth, D.; Johnston, S. Initial results for comparing three approaches to set TACs for the major fisheries in the SIOFA area of the Southern Indian Ocean. SERAWG-04-11. 4th Stock and Ecological Risk Assessment Working Group (SERAWG4). Online; 2022

Brouwer, S.; Hamer, P. Appropriate LRPs for Southwest Pacific Ocean Striped Marlin and Other Billfish. WCPFC-SC17-2021/MI-WP-08. WCPFC Scientific Committee, 17th Regular Session. Online meeting; 2021

Butterworth, D. On the development of a roadmap for new formal harvest strategies for SIOFA. SC-07-INFO-12. 7th Meeting of the Scientific Committee. Online: SIOFA; 2022

Butterworth, D.; Brandão, A.; Holloway, S. Report on the development of Harvest Strategies for key target species in the SIOFA area (Project code SE2020-01). SERAWG-03-10. 3rd Meeting of the Stock and Ecological Risk Assessment Working Group

(SERAWG3). Online: SIOFA; 2021

Clarke, S.; Hoyle, S. Development of Limit Reference Points for Elasmobranchs, WCPFC-SC10-2014/ MI-WP-07. Western and Central Pacific Fisheries Commission, 10th Scientific Committee. Majuro, Republic of the Marshall Islands; 2014

Cox, S.P.; Kronlund, A.R.; Benson, A.J. The roles of biological reference points and operational control points in management procedures for the sablefish (Anoplopoma fimbria) fishery in British Columbia, Canada. Environmental conservation. 40:318-328; 2013.

Duplisea, D.E.; Roux, M.-J.; Hunter, K.L.; Rice, J. Fish harvesting advice under climate change: A risk-equivalent empirical approach. PLoS One. 16:e0239503; 2021.

FAO. Fisheries management. FAO technical guidelines for responsible fisheries, N° 4. in: Division F.F.R.D.a.F.P.a.P., ed: FAO Rome, Italy; 1997

Froese, R.; Pauly, D., (eds.). FishBase. World Wide Web electronic publication. www.fishbase.org 2024

Griffiths, S.P.; Kesner-Reyes, K.; Garilao, C.; Duffy, L.M.; Román, M.H. Ecological Assessment of the Sustainable Impacts of Fisheries (EASI-Fish): a flexible vulnerability assessment approach to quantify the cumulative impacts of fishing in data-limited settings. Marine Ecology Progress Series. 625:89-113; 2019.

Harley, S.; Hoyle, S.; Hampton, J. Characteristics of potential reference points for use in WCPFC tuna stock assessments. 2009.

Hoyle, S.D.; Campbell, R.A.; Ducharme-Barth, N.D.; Grüss, A.; Moore, B.R.; Thorson, J.T.; Tremblay-Boyer, L.; Winker, H.; Zhou, S.; Maunder, M.N. Catch per unit effort modelling for stock assessment: A summary of good practices. Fisheries Research. 269:106860; 2024.

Maunder, M.N.; Punt, A.E. Standardizing catch and effort data: a review of recent approaches. Fisheries Research. 70:141-159; 2004. 10.1016/j.fishres.2004.08.002

Merino, G.; Arrizabalaga, H.; Arregui, I.; Santiago, J.; Murua, H.; Urtizberea, A.; Andonegi, E.; De Bruyn, P.; Kell, L.T. Adaptation of north Atlantic albacore fishery to climate change: Yet another potential benefit of harvest control rules. Frontiers in Marine science. 6:620; 2019.

Ministry of Fisheries. Operational Guidelines For New Zealand's Harvest Strategy Standard. Wellington, New Zealand; 2011

Ouzoulias, F.; Massiot-Granier, F.; Alewijnse, S.; Devine, J.; Dunn, A.; Earl, T.; Le Clech, R.; Maschette, D.; Masere, C.; Péron, C.; Readdy, L.; Walker, N.; Ziegler, P. Effects of implementing dynamic B0 in toothfish fisheries. CCAMLR WG-SAM-2024/25; 2024

Preece, A.; Hillary, R.; Davies, C. Identification of candidate limit reference points for the key target species in the WCPFC. WCPFC-SC7-2011/MI-WP-03. Western and Central Pacific Fisheries Commission Scientific Committee, Seventh Regular Session; 2011

Sainsbury, K. Best Practice Reference Points for Australian Fisheries. A Report to the Australian Fisheries Management Authority and the Department of the Environment, Water, Heritage and the Arts; 2008

SIOFA Secretariat. Overview of SIOFA Fisheries 2024. Southern Indian Ocean Fisheries Agreement (SIOFA); 2024

Sun, M.; Li, Y.; Ren, Y.; Chen, Y. Rebuilding depleted fisheries towards BMSY under uncertainty: harvest control rules outperform combined management measures. ICES Journal of Marine Science. 78:2218-2232; 2021.

Taylor, N.; Miller, S.; Duprey, N. A REVIEW OF OBJECTIVES, REFERENCE POINTS, AND PERFORMANCE INDICATORS FOR MANAGEMENT STRATEGY EVALUATION AT TRFMOS. 2024.

Thorson, J.T. Predicting recruitment density dependence and intrinsic growth rate for all fishes worldwide using a data-integrated life-history model. Fish and Fisheries. 21:237-251; 2020.

Thorson, J.T.; Munch, S.B.; Cope, J.M.; Gao, J. Predicting life history parameters for all fishes worldwide. Ecological Applications. 27:2262-2276; 2017.

United Nations. UN Fish Stocks Agreement - Agreement for the implementation of the provisions 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. 1995

WCPFC Scientific Committee. Summary Report. Seventeenth Regular Session of the WCPFC Scientific Committee. Electronic Meeting: The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean; 2021

Williams, A.J.; Farley, J.H.; Hoyle, S.D.; Davies, C.R.; Nicol, S.J. Spatial and sex-specific variation in growth of albacore tuna (Thunnus alalunga) across the South Pacific Ocean. PLoS One. 7:e39318; 2012. 10.1371/journal.pone.0039318

Zhou, S.; Deng, R.; Hoyle, S.; Dunn, M. Identifying appropriate reference points for elasmobranchs within the WCPFC. Report to Western and Central Pacific Commission, Pohnpei, Federated States of Micronesia; 2019.

Zhou, S.; Deng, R.A.; Dunn, M.R.; Hoyle, S.D.; Lei, Y.; Williams, A.J. Evaluating methods for estimating shark natural mortality rate and management reference points using life-history parameters. Fish and Fisheries. 23:462-477; 2022.

Zhou, S.; Dunn, M.; Williams, A. Appropriate limit reference points for WCPO elasmobranchs (Project 103). WCPFC-SC16-MI-IP-21. Western and Central Pacific Fisheries Commission Scientific Committee, 16th Regular Session. Online; 2020a

Zhou, S.; Griffiths, S.P. 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; 2008. 10.1016/j.fishres.2007.11.007

Zhou, S.; Griffiths, S.P.; Miller, M. Sustainability assessment for fishing effects (SAFE) on highly diverse and data-limited fish bycatch in a tropical prawn trawl fishery. Marine and Freshwater Research. 60:563-570; 2009.

Zhou, S.; Punt, A.E.; Lei, Y.; Deng, R.A.; Hoyle, S.D. Identifying spawner biomass per-recruit reference points from life-history parameters. Fish and Fisheries. 21:760-773; 2020b.

Table 2: Potential limit reference points (Based on Table MI-1 in WCPFC Scientific Committee (2021).

LRP	*Group*	*Assessment type*	*Comments*
x% F/F_{MSY}	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
x% $B/B_{F=0}$	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
x% B_0	Target & Bycatch	Data rich	Choose the level of x based on an evaluation.
SPR x% $B_{F=0}$	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.
B/BF=0, t1−t2	Target & Bycatch	Data rich	Choose a period when the stock was in an undesirable state from which it later recovered.
Bt1−t2	Target & Bycatch	Data rich	Choose a period when the stock was in an undesirable state from which it later recovered.
CPUEt1−t2	Target & Bycatch	Data rich or medium data	Choose a period when the stock was in an undesirable state from which it later recovered.
$B/B_{F=0}$_ low	Target & Bycatch	Data rich	Choose a year when the stock was in an undesirable state from which it later recovered.
B_low	Target & Bycatch	Data rich	Choose a year when the stock was in an undesirable state from which it later recovered.
CPUE_low	Target & Bycatch	Data rich or medium data	Choose a year when the stock was in an undesirable state from which it later recovered. Note CPUEt1−t2 is more precautionary.
F/F_{lim} >1	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be developed.
F/F_{crash} >1	Bycatch	Data poor	Use as an interim LRP until a more reliable metric can be developed.

Table 3: List of potential Limit Reference Points, as proposed for WCPFC billfish – see Table 7 of Brouwer and Hamer (2021), WCPFC-SC17-2021/MI-WP-08.

LRP	Group	Assessment type	Comments
$F/F_{MSY}=1$	Target	Data rich	
$x\%\ F/F_{MSY}$	Bycatch	Data rich	Choose the level of *x* based on an evaluation
$20\%\ SB/SB_{F=0}$	Target	Data rich	
$x\%\ SB/SB_{F=0}$	Bycatch	Data rich	Choose the level of *x* based on an evaluation.
$25\%\ SB_0$	Target	Data rich	
$x\%\ SB_0$	Bycatch	Data rich	Choose the level of *x* based on an evaluation.
$SPR\ x\%\ SB_{F=0}$	Bycatch	Data moderate or data poor	Choose the level of *x* based on an evaluation.
$x\%\ CPUE_0$	Target & Bycatch	Data rich or data moderate	Choose the start of a reliable CPUE series and the level of *x*.
$SB/SB_{F=0t1-t2}$	Target & Bycatch	Data rich	Choose a period when the stock was in an undesirable state from which it later recovered.
SB_{t1-t2}	Target & Bycatch	Data rich	Choose a period when the stock was in an undesirable state from which it later recovered.
$CPUE_{t1-t2}$	Target & Bycatch	Data rich or data moderate	Choose a period when the stock was in an undesirable state from which it later recovered.
$SB/SB_{F=0}\ low$	Target & Bycatch	Data rich	Choose a year when the stock was in an undesirable state from which it later recovered.
SB low	Target & Bycatch	Data rich	Choose a year when the stock was in an undesirable state from which it later recovered.
CPUE low	Target & Bycatch	Data rich or data moderate	Choose a year when the stock was in an undesirable state from which it later recovered. Note that $CPUE_{t1-t2}$ 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 4: List of species identified by the SIOFA SC as primary and secondary species in SIOFA fisheries and considered as target species for the purposes of this overview. Sourced from Appendix A of the Overview of SIOFA Fisheries 2024 (SIOFA Secretariat, 2024).

FAO	COMMON NAME	SCIENTIFIC NAME
BYS	Splendid alfonsino	*Beryx splendens*
ORY	Orange roughy	*Hoplostethus atlanticus*
CDL	Cardinal fishes	*Epigonus spp*
OIL	Oilfish	*Ruvettus pretiosus*
HAU	Hapuka	*Polyprion spp.*
LIB	Brushtooth lizardfish	*Saurida undosquamis*
RUS	Indian scad	*Decapterus russelli*
KZJ	Threadfin bream	*Nemipterus bipunctatus*
UPM	Goldfin goatfish	*Upeneus moluccensis*
DCC	Shortfin scad	*Decapterus macrosoma*
LTQ	Sky emperor	*Lethrinus mahsena*
TOP	Toothfish	*Dissostichus eleginoides*
NGU	Yellow spotted trevally	*Carangoides fulvoguttatus*
NGY	Bludger	*Carangoides gymnostethus*
NGX	Carangoides species	*Carangoides spp*
LEC	Escolar	*Lepidocybium flavobrunneum*
BYS	Splendid alfonsino	*Beryx splendens*
SSO	Smooth oreo dory	*Pseudocyttus maculatus*
BIS	Bigeye scad	*Selar crumenophthalmus*
YBS	bigeye barracuda	*Sphyraena forsteri*
EMN	Marbled coral groper	*Plectropomus punctatus*
LTQ	Sky emperor	*Lethrinus mahsena*
LUB	Emperor red snapper	*Lutjanus sebae*
LJB	Two-spot red snapper	*Lutjanus bohar*
BOE	Black oreo	*Allocyttus niger*
ORD	Oreos nei	*Oreosomatidae*
GRV	Macrourids	*Macrourus spp*
ANT	Violet cod	*Antimora rostrata*
BIL	Billfish *	*Istiophoridae*
TUN	Tuna *	*Thunnini*
YFT	Yellowfin tuna	*Thunnus albacares*

Table 5: Definitions of terms and metrics discussed in this report. Adapted from a table in Appendix I, WCPFC-SC17-2021/MI-WP-08 (Brouwer and Hamer, 2021).

Metric	Description
C_{latest}	Catch in the last year of the assessment.
F_{recent}	Average fishing mortality-at-age for a specified recent period.
YF_{recent}	Equilibrium yield at average fishing mortality for a recent period.
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}
SB	Spawning biomass or spawning potential.
SB_0	Equilibrium unexploited spawning biomass.
$SB_{F=0}$	Spawning biomass predicted in the absence of fishing.
SB_{MSY}	Spawning biomass that will produce the maximum sustainable yield.
$SB/SB_{F=0}$	Spawning biomass relative to SB predicted to occur in the absence of fishing.
SB/SB_{MSY}	Spawning biomass relative to the SB that would produce the MSY.
B	Total vulnerable biomass.
B_0	Equilibrium unexploited vulnerable biomass.
B/B_0	Vulnerable biomass relative to 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 of the CPUE at the start of a CPUE series.
$SB_{F=0\ t1-t2}$	Spawning biomass predicted in the absence of fishing during period t1-t2.
$SB_{MSY\ t1-t2}$	Spawning biomass predicted to produce MSY during period t1-t2.
B_{t1-t2}	Average of total vulnerable biomass during the period t1-t2.
$CPUE_{t1-t2}$	Average CPUE across the period t1-t2.
$SB/SB_{F=0}$ low	Lowest median value for the model period of SB / $SB_{F=0}$.
SB/SB_{MSY} low	Lowest median value for the model period of SB / SB_{MSY}.
Biomass low	Lowest median vulnerable biomass for the model period.
SB low	Lowest median spawning biomass for the model period.
CPUE low	Lowest CPUE in a series.
SPR	Spawning potential ratio, the ratio of fished to unfished reproductive biomass at equilibrium, given the fishing mortality rate.
$SPR_{current}$	SPR at current rates of fishing mortality.
SPR_{MSY}	The SPR that supports MSY and is predicted to occur at F_{MSY}.
$F_{x\%\ SPR,}$ or $F_{x\%}$	Fishing mortality rate that produces SPR of x%.
F_{msn}	Maximum sustainable fishing mortality.
F_{lim}	Fishing mortality estimated to result in 25% B_0.
F_{crash}	Fishing mortality rate where there is high probability of fishery collapse.
F/F_{lim}	Fishing mortality for a specified period relative to F_{lim}.
F/F_{crash}	Fishing mortality for a specified relative to F_{crash}.
SAFE	Sustainability Assessment for Fishing Effects.
EASI-FISH	Ecological Assessment of the Sustainable Impacts of Fisheries.
DB-SRA	Depletion-Based Stock Reduction Analysis to estimate reasonable yield.
DCAC	Depletion-Corrected Average Catch to estimating sustainable yield.