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Use of reference points for stock status classification: A global overview

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Abstract	

The Food and Agriculture Organization of the United Nations (FAO) uses the State of Stocks Index (SoSI) to provide global and regional overviews of the status of marine fishery resources. In response to the need for closer alignment with the United Nations Sustainable Development Goals, FAO recently revised its methodology, expanding the coverage of assessed units from approximately 500 to more than 2 600. The updated framework classifies stocks into three main categories: underfished, maximally sustainably fished and overfished.

As part of a broader shift towards cooperative resource assessment, this document presents a candidate framework for consideration by the SIOFA Scientific Committee to map stock assessments to FAO stock status categories. The proposal is intended to address challenges in the SIOFA context, including the need for more standardized terminology across stocks and the difficulty of communicating scientific advice consistently across data-rich and data-limited situations.

The proposed framework is designed as an interpretative approach based on a set of core principles:

- Separation of Status: whenever possible, the framework distinguishes between stock condition (biomass level) and exploitation status (fishing pressure)
- Standardized Communication: It suggests a small set of recognizable categories for managers, including Sustainable, Overfishing occurring, Overfished, Rebuilding, Collapsed or severely depleted, and Status uncertain.
- Tiered Application: To accommodate different data qualities, the framework uses three tiers: Tier 1 for analytical assessments with biomass and pressure metrics; Tier 2 for biomass-based or production models; and Tier 3 for data-limited or qualitative situations where uncertainty must be made explicit.

The document underlines the use of the Precautionary Principle in assessing and managing stocks. The use of targets and limits vary by RFMO and country jurisdiction's and the document lays out alternative possible types that could be used. SIOFA may customise these targets and limits in the context to its own management framework, while FAO, through FIRMS, will continue to support harmonization in the interpretation and communication of stock status categories.

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Introduction

The Food and Agriculture Organization (FAO) has delivered invaluable insights to stakeholders worldwide on the state of fish stocks using the State of Stocks Index (SoSI). Since 1971, these assessments have been central to FAO's work, with the primary objective to provide a comprehensive overview of global and regional marine fishery resources. Since 1995, these evaluations are an integral part of FAO's biennial flagship publication The State of World Fisheries and Aquaculture (SOFIA).

Starting with 146 stocks in 1974, the number of stocks increased to about 500 in 2012 using a standardized methodology to ensure the integrity of the time series. In 2024, the 2012 list was slightly increased with 531 stock units based on 445 species (FAO. 2024). To align with national reporting initiatives, increase expert participation, promote transparency, and preserve time series integrity, FAO recently conducted a comprehensive methodological update on global fish stock classification for computing the SoSI (Sharma et al. 2025). The new methodology continues to generate stock status indices at the FAO fishing regions level, where gaps in assessment can be narrowed over time in a process of continuous improvement. This can be made possible through collaborative action and the involvement of regional fisheries bodies. Furthermore, the UN Sustainable Development Goals (SDG) Indicator 14.4.1 has led to a parallel monitoring system that provides an additional layer of information on stock status classification.

The list of fishery stocks analysed in each FAO region has been systematically revised to better reflect current fishing activities and now includes over 2600 stocks (Sharma et al., 2025) that cover 998 species. The updated methodology classifies fish stocks into three categories—*underfished*, *maximally sustainably fished*, and *overfished*—based on a tiered approach to assessments primarily driven by information criteria. Simplified categories and standardized procedures improve consistency and regional comparability, while an uncertainty score highlights data reliability.

FAO is reconfiguring its data architecture with its Fisheries and Resources Monitoring System (FIRMS) to be the central database, serving as a main data source for FAO's State of Stocks Index (SoSI) and Status of Fisheries and Aquaculture (SOFIA), the flagship biennial report from the next cycle, i.e. 2026. This signals an important paradigm shift towards a cooperative resource assessment and reporting by FAO as the coordinator and Regional Fisheries Bodies and countries as key collaborators and contributors.

At the July 2025 FIRMS Steering Committee, partners reaffirmed their commitment to timely stock status reports and supported biennial data calls for future SoSI editions. FIRMS partners currently contribute up to 30 percent of the stocks in the global SoSI list. SIOFA joined FIRMS in 2020 and has regularly updated its stocks and fisheries reports since then.

The Southern Indian Ocean Fisheries Agreement (SIOFA) is progressively strengthening its scientific basis for stock assessment, advice and management. As part of this process, the Scientific Committee (SC) is increasingly confronted with the need to interpret assessment results, interim biological reference points and precautionary management considerations in a way that is transparent, consistent and readily understandable to managers.

At present, SIOFA is moving forward with work on precautionary approaches, biological reference points, and harvest strategies. This promising development provides an important opportunity to clarify how stock status should be described and communicated during this transitional phase. A practical mapping to FAO stock status categories could help structure advice while remaining fully compatible with future stock-specific harvest strategies and more formal decision rules.

A first potential challenge is that stock status terminology is not yet fully standardized across SIOFA stocks and fisheries. Different assessments may provide different metrics, varying degrees of analytical robustness, and differing levels of certainty. Without an agreed interpretative framework, similar stock situations may be described differently across cases.

A second challenge is that SIOFA must operate across a wide spectrum of information contexts. Some fisheries are supported by formal analytical assessments and increasingly explicit biological reference points, while others still rely on partial information, trends, productivity assumptions or expert interpretation. A workable classification framework therefore needs to be applicable across more than one assessment tier.

The third challenge is communication. Scientific advice is most useful when managers can clearly distinguish whether a stock appears to be:

- within sustainable bounds;
- subject to overfishing;
- in an overfished or depleted state;
- in a rebuilding zone; or
- too uncertain to classify confidently.

In the absence of a common language linking stock assessment outputs to management-relevant categories, advice risks becoming less comparable across stocks and more difficult to interpret over time.

The fourth challenge is timing. Because SIOFA is already investing in reference point development and harvest strategy work, this is an appropriate moment to agree at least in principle how stock status should be presented. An interim FAO-aligned framework can provide immediate value while remaining adaptable as stock-specific reference points mature.

Purpose of this information paper

This document is intended as a working proposal for discussion by the SIOFA Scientific Committee. It does not seek to replace ongoing SIOFA work on harvest strategies or stock-specific reference points. Rather, it proposes options for an interim and transparent framework for interpreting available assessment information, including details of mapping to FAO stock status categories.

Overview of International advice standards

Central to most fisheries advice schemes are the reference points, which are used to classify and communicate current status of the resource, but is ultimately designed to help determining fishing opportunities, e.g., the total allowable catch (TAC) in quota managed fisheries. The stock assessment model is often considered the starting point for scientific advice. However, the actual process starts with the processing of imperfect observations for use in the assessment model, which are typically associated with large observation and systematic sampling errors. The assessment model itself relies on many assumptions about the model structure in the form of the underlying deterministic relationships (e.g. the stock-recruitment function) and key population parameters (e.g. natural mortality *M*). All these contribute to the uncertainty associated with the stock assessment output (Patterson et al., 2001; Carruthers et al., 2017), where uncertainty can be seen as a plausible range of differences between the model outcomes and reality. Accounting for these uncertainties is one of the key challenges for operationalizing reference point systems, so they provide consistent and robust scientific advice on catch limits (Ralston et al., 2011). However, despite common commitments to maintain or restore stocks at levels capable of producing maximum sustainable yield (MSY) and the Precautionary Approach to fisheries (FAO, 1995; UN, 1995), international advice standards vary widely in how this challenge is addressed with respect to specifying and estimating the corresponding target-, threshold- and limit reference points, as well as the operational trigger points used in harvest control rules.

Target Reference Points

Target reference points are commonly formulated with respect to the fishing mortality (F_{MSY}) or biomass (B_{MSY}) that can produce the Maximum Sustainable Yield (MSY) in the long-term. Direct estimates for F_{MSY} and B_{MSY} that correspond to the maximum surplus production and thus MSY are the default target reference point in tuna Regional Management Organizations (RMFOs), including the International Commission for the Conservation of Atlantic Tunas (ICCAT),the Indian Ocean Tuna Commission (IOTC), Inter-American Tropical Tuna Commission (IATTC) and the Western and Central Pacific Fisheries Commission (WCPFC) However, there can be exceptions is high uncertainty about the stock recruitment relationship. For example, WCPFC considers $F_{spr\%}$ as proxy for F_{MSY} if the steepness of the stock-recruitment relationship is not well estimated. Similarly, IOTC uses B_{40} (i.e. $0.4B_0$) and a corresponding $F_B 40$ as more conservative proxies for Indian Ocean skipjack tuna.

In the International Council for the Exploration of the Sea (ICES), the PA to fishing (UN 1995; FAO 1995) was introduced first in 1998 without consideration of MSY, and the ICES MSY approach with F_{MSY} as F_{tgt} was only subsequently integrated into the Precautionary Approach (PA) framework in

2009. The ICES reference point system has since evolved and undergone several revisions (Lassen et al., 2014; Silvar-Viladomiu et al., 2021). For age-structured data rich Category 1 assessments in ICES, FMSY is mostly derived through stochastic forward simulations that are externally implemented in the EQSIM software (but see criticism by Winker et al. 2025). F_{MSY} is in the first instance determined as the F that achieves maximum median long-term yield, which is here referred to as F_{MMY} for clarity. Both lower and upper ranges for F_{MSY} are provided, but these are bound on the condition to not reduce the long-term yield corresponding to F_{MMY} by more than 5%. To be consistent with ICES PA the final estimate of F$_{MSY}$ must not exceed the fishing mortality $F_{P.05}$, where $F_{P.05}$ is associated with a 5% probability for biomass to fall below Blim (i.e. F_{MSY} is the minimum of $FP_{0.5}$ and F_{MMY}). A perhaps unique feature is that ICES MSY approach does not have a formal biomass target reference point, with a B_{tgt} estimate corresponding to F_{MSY} being usually not reported (Winker et al. 2026).

In Canada, the maximum acceptable harvest removal reference point is determined analytically as the best estimate of F_{MSY} from the stock assessment model (DFO, 2009). However, the advised fishing mortality (F_{tgt}) can be at or below F_{MSY}, but must not exceed it, i.e. $F_{tgt} \leq F_{MSY}$. The value for F_{tgt} can be set smaller than F_{MSY} (or its proxy, e.g. $F_{0.1}$), by factoring in the impact on other stocks ecosystem considerations and precautions in light of uncertainty. In the New Zealand, Australia and the USA, biological proxies for F_{MSY} and B_{MSY} are predominantly used (Punt et al., 2013). For the New Zealand Harvest Strategy Standard (New Zealand Ministry of Fisheries, 2008), detailed guidelines (New Zealand Ministry of Fisheries, 2011) on selecting proxies, so called "MSY-compatible reference points", are specified for B_{MSY} as ratios to B_0 and F_{MSY} based on the per-recruit spawning potential ratio (F_{spr}). In the USA, the choices of proxies for FMSY and BMSY vary widely, but those based on F_{spr} (typically F_{spr30} to F_{spr45}) and its corresponding spawning biomass estimates of B_{spr} are most frequently used. F_{MSY} or its proxy determines the Maximum Fishing Mortality Threshold (MFMT), where F > MFMT invokes a condition of overfishing and associated management interventions.

Horbowy and Luzenzzyk (2012) interpreted the common use of the typically more conservative biological proxies for F_{MSY} instead of direct estimates to be consistent with the guidelines for applying a PA within an MSY framework in Annex 2 of the UN Fish Stocks Agreement (UN, 1995), which states that fishing mortality that produces the MSY should be considered as a fishing mortality limit rather than a management target. The basis for this is also well founded in the scientific literature, which frequently found that more conservative biological proxies for F_{MSY} are more robust to asymmetric risk associated with fishing below or above the 'true' unknown F_{MSY} (Mace, 2001; Horbowy and Luzeńczyk, 2012; Hordyk et al., 2019), where asymmetric risk describes the phenomenon that one direction of bias for an estimate leads to disproportionately higher risk than if the bias would occur in the other direction (Hordyk et al. 2019).

The consequence of fishing above F_{MSY} is that the biomass will decrease relative to B_{MSY}, so that yield levels close to MSY cannot be maintained. Subsequent rebuilding would require fishing mortality lower than F_{MSY}, which may come at high costs of reduced catches and long recovery time. Fishing below F_{MSY} can result in short-term yield loss but in contrast to overshooting F_{MSY} the catch opportunity still exists at higher biomass levels. In comparison to the substantial biomass increase at $F < F_{MSY}$, the long-term loss in yield is relatively small (Hordyk et al., 2019). For example, Beverton (1998) noted that instead of striving for F_{max} "a simple management system based on careful monitoring of fishing effort, biological targets such as F$_{95}$ (i.e. a lower fishing mortality the results in 95% of the maximum yield), and exploitation of a diversity of fish resources may suffice to avert further disaster and hedge against uncertainty." Restrepo et al. (1998) showed that fishing at just 75% F_{MSY} would still yield an average 0.949 - 0.989 of MSY based on deterministic age-structured models that was parameterised with 600 combinations of variations of life history parameters (Mace, 1994). Hilborn's (2010) concept of 'Pretty Good Yield' is also founded on the principle that fishing near but not at the maximum yield will reduce risk of overfishing and increase

robustness to uncertainties with little long-term yield loss. Horbowy and Luzenzzyk (2012) and Punt et al. (2013) showed that fishing mortality corresponding to a biomass at 40% B_0 as a proxy for B_{MSY} leads to high yield and safe biomass levels irrespective of the steepness value of the stock recruitment function. Note that, fishing under a harvest control rule at F$_{MSY}$ is associated with high risk of a stochastic collapse below the target Biomass reference points (B$_{MSY}$) a result of recruitment variability. This risk can be significantly reduced by fishing somewhat below F$_{MSY}$ (Thorson et al., 2015). Hordyk et al. (2019) demonstrated by way of simulations with stock assessment feedback-loop that there is much higher risk to long-term yields and sustainable stock biomass levels when positively biased stock parameter (e.g. M, steepness and historical catches) lead to an overoptimistic F_{MSY} than with the equivalent negative bias. Recently, large scale simulation experiments conducted in ICES WKREF1 and WKREF2 provided evidence that direct estimates of F_{MSY} were insufficiently risk-adverse for many stocks (ICES 2021; 2022).

Limit and Threshold Reference Points

B_{lim} is the central biomass limit reference points used for North-East Atlantic stocks by ICES, which is defined as the biomass below which recruitment is impaired so that reduces with SSB. The additional limit- and threshold (B_{pa}, F_{lim}, and F_{pa}) are used in the context of the precautionary approach are all estimated from B_{lim}, where B_{thr} and F_{thr} with GFCM advice framework are the conceptual equivalents B_{pa} and F_{pa}, respectively. In ICES, the empirical relationship between B_{pa} and B_{lim} is given by

$$B_{pa} = B_{lim}e^{(1.645*\sigma)}$$

where σ is intended to reflect the assessment uncertainty, but is most cases set to a fairly low value to reflect the overall assessment error $\sigma = 0.2$ (c.f. Raltson et al. 2011), such that $B_{pa} = 1.4B_{pa}$.

The most direct approach for estimating B_{lim} is to identify the break point of a segmented regression (Hockey-Stick) that is fitted to Stock-Recruitment (S-R) observations (Type 2; Figure 1). However, applying this approach requires adequate contrast in the stock recruitment (S-R) time series to disguise between the slope where recruitment decreases with SSB and the plateau where recruitment fluctuates around some average. The break point of the SSB between slope and plateau in the S–R relationship can then be estimated defined as B_{lim}, while the average recruitment along the plateau represents an estimate of R_0.
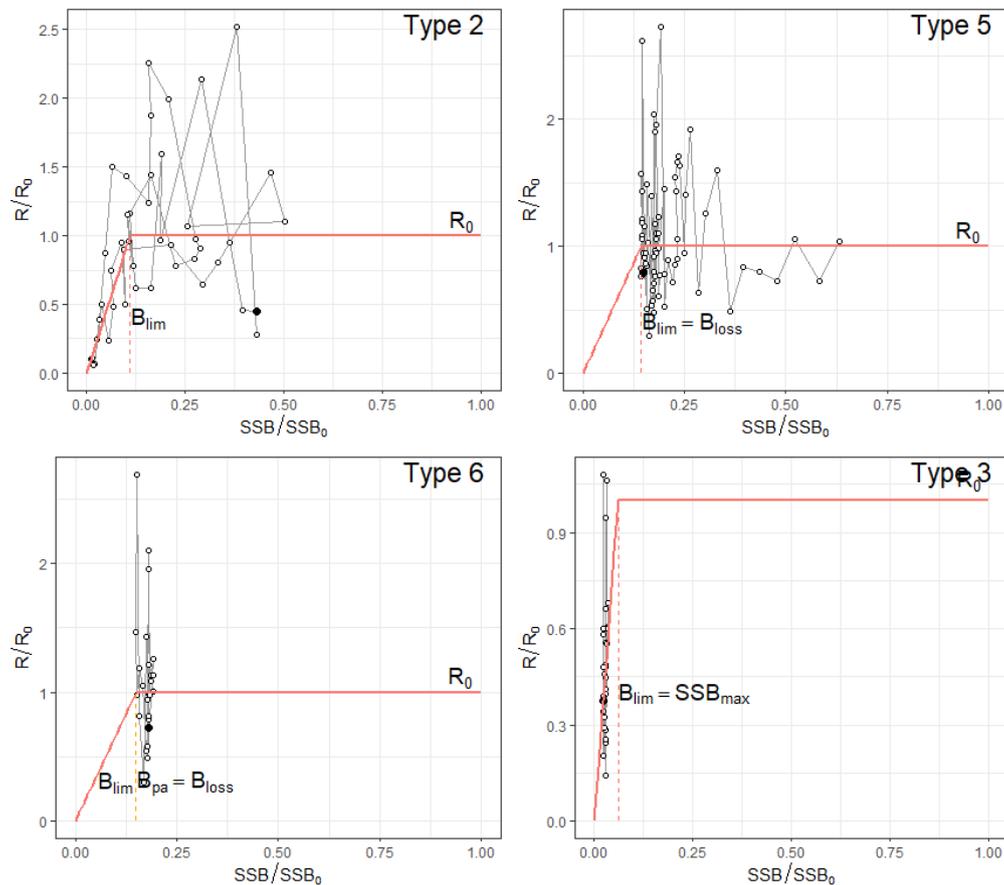
Fig. 1: Illustration of four common S-R pattern types that are considered in ICES for deriving estimates of B_{lim}.

A prerequisite for estimating B_{lim} from the S-R data is that the available time series cover periods where the was both below and above B_{lim} (min to max spawners estimated are on the order of 8-12 the amount seen in min. Biomass; TCChinook 99-3). For those stocks that either never decreased to levels where recruitment is measurably impaired or where the entire time series represents severely depleted state below B_{lim} a break point in S-R data is not identifiable and alternative approaches for estimating B_{lim} are required. In practice, direct B_{lim} estimates were only used for 14% of the 77 ICES category 1 stocks analysed by WKREF1 (ICES, 2021).

For this purpose, ICES provides guidelines for characterizing different S-R data patterns based scatter plots (Fig. 1). These include alternative empirical options for setting B_{lim} in addition to the quantitative segmented approach (Type 2; Figure 4.1). The most common choice is setting $B_{lim} = B_{loss}$ (41%), where B_{loss} is the smallest observed SSB (Type 5; Figure 4.1). This applies to stocks that cover a wider dynamic range of SSB and show no evidence of impaired recruitment or with no clear relation between stock and recruitment. In cases where stocks only cover a narrow dynamic range of SSB with no evidence of past or present impaired recruitment (Type 6; Figure 4.1), B_{loss} may be used instead as a candidate for B_{pa} to then set B_{lim} relative to B_{pa} (e.g. $B_{lim} = B_{pa}/1.4$). On the other end of the spectrum, the Type 3 rule may be used for stocks with clear evidence that stock is severely depleted compared to historical stock levels and the S-R observations show positive relationship (Type 3; Figure 4.1). In this case, B_{lim} maybe set at or close to largest observed biomass (SSB_{max}).

Recent ICES workshops (WKREBUILD, WKGMSE3 and WKRP-CHANGE, WKREF) have noted several limitations of the current guidelines for setting B_{lim}, with concerns raised about subjectivity in the definition and use of S-R types for reference point estimation in cases where segmented regression

fits are unsatisfactory or produce implausible B_{lim} estimates. In particular, conceptual problems for setting reference points related to B_{loss} for Type 5 and 6 stocks and unclear guidance for type 3 stocks that are at low stock sizes were noted (ICES 2021; WKREF). These problems are aggravated for short time series that exhibit a narrow of S-R observations, as is the common case for the majority of age-based assessments in the Mediterranean Sea. As a result, WKREF1 (ICES, 2021) recommended to consider options for determining plausible values B_{lim} as ratios to B_{MSY} or B_0 analytically based on biological principles and the life history of the stock that would be consistent with standards used internationally. There is already some precedence for setting B_{lim} based on analytically derived ratios of B_{MSY} or B_0 within ICES. For assessments conducted with surplus production models (WKMSYSPICT, ICES 2021), B_{lim} is derived as ratio of B_{MSY} the estimate as $B_{lim} = 0.3B_{MSY}$, which adopted based on the rationale that, under the Schaefer production, the biomass corresponding to 50% of MSY is obtained at 30% of B_{MSY}. A meta-analysis of 69 ICES stocks, using segmented regression with break-point fixed at B_{lim} benchmark found that median of B_{lim} around 10% of B_0 (WKREF1 2021).

In Canada, the equivalent to B_{lim} is referred to as the Limit Reference Point (LRP) and the corresponding B_{thr} as the Upper Stock Reference Point (URP). B_{lim} represents the stock status below in which serious harm is occurring to the stock based on biological criteria and established through a scientific peer reviewed process. There are several stock assessment specific methods used to quantify B_{lim}, including a hockey-stick approach with segmented regressions. However, in the absence of an agreed procedure in the context of the precautionary approach, the Department of Fisheries and Ocean, provides provisional guidance to the B_{lim} to a precautionary value corresponding to $0.4B_{tgt}$ and the B_{thr} to $0.8B_{tgt}$.

The Harvest Strategy Standard for New Zealand Fisheries (New Zealand Ministry of Fisheries 2008) considers a "soft" biomass limit reference point that triggers a requirement for a formal, time-constrained rebuilding plan and a hard limit below which fisheries should be considered for closure. The **soft-limit (sensu** B_{thr}) is defined as $0.5B_{tgt}$ or $0.2B_0$, whichever is higher. The hard-limit (**sensu** B_{lim}) is set to $0.2B_{tgt}$ or $0.1B_0$, whichever is higher. The hard-limit is considered breached and stock classified as collapsed. Acceptable risk in terms of the probability of breaching the soft limit must not exceed 10% and the probability of breaching the hard limit must not exceed 2%.

In the US, the equivalent to B_{thr} is referred to as Minimum Stock Size Threshold (MSST) below which the stock is considered to be overfished and invokes requirement for a rebuilding plan. The MSST is explicitly linked to the BMSY proxy for B_{tgt} and is often specified to be larger or equal to $0.5B_{tgt}$. An additional "hard limit" corresponding to B_{lim} is typically not explicitly defined within US advice frameworks. Earlier theoretical and empirical work by Goodyear (1977, 1980, 1989, 1993) and Clark (1991), Mace and Sissenwine (1993) advocated the use of SPR_{20} as a minimum threshold for recruitment overfishing below which the risk of impaired recruitment is increasing and above most commercially exploited stocks are though to maintain acceptable of productivity. Building on this, SPR_{20} (or B_{20}) has become common basis for recruitment overfishing reference points in U.S. fishery management plans (Rosenberg et al. 1993), associated with the common target reference levels of $spr40$ (or B_{40}).

Within tuna RFMOs, there is typically no explicit separation between threshold and 'hard` limit reference points. WCPFC agreed on a limit reference point of $0.2B_0$ at WCPFC9 in 2012 for all 'key' tuna species. The WCPFC limit reference points relates closest to a $B_t hresh$ reference point in ICES (B_{pa}), New Zealand (soft-limit) or the US (MSST). In IATTC, by contrast, the limit reference point (S_{LIMIT}) corresponds to the spawning biomass where recruitment is reduced to 50%, and is thus equivalent to the B_{lim} concept. S_{LIMIT} is derived analytically based on a Beverton-Holt stock-recruitment relationship with a moderate steepness (h) of 0.75, corresponding $0.077B_0$ (Maunder and Deriso 2014). The probably of the stock falling below S_{LIMIT} must not exceed 10%. In ICCAT and

IOTC, formal implementation limit reference points remain pending for most stocks, but interim limit reference points are increasingly put forward. For example, in the IOTC interim limit reference were specified as a biomass limit at Blim = $0.4B_{MSY}$ and a corresponding $F_{lim} = 1.4 - 1.5F_{MSY}$ for tunas and swordfish, pending further updates as part of the ongoing MSE development process. By contrast, MSE has already been successfully implemented since 2012 by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) to provide rigid TAC advice for Southern bluefin tuna (Hillary et al., 2015). Here, the management procedure specifies the interim rebuilding objective to achieve spawning stock biomass (SSB) levels above a limit reference point of $0.2B_0$ by 2035.

Stock Status classification

Kobe phase plots are widely used for stock status classification in tuna RFMOs. The Kobe phase plot is a biplot that is divided into four quadrants, defined for B/B_{MSY} on the x-axis and F/F_{MSY} on the y-axis (Fig.2). As noted in Section XX, B_{MSY} and F_{MSY} are often default reference points, but they may be replaced by MSY proxies. The color-coding is green (sustainable) if $B/B_{MSY} > 1$ and $F/F_{MSY} < 1$ and red (overfished) if $B/B_{MSY} < 1$ and $F/F_{MSY} > 1$. The orange quadrant represents a state of overfishing where $F/F_{MSY} > 1$, but $B/B_{MSY} > 1$, and a yellow quadrant a state of rebuilding where $F/F_{MSY} < 1$, but $B/B_{MSY} < 1$. Stock status is typically expressed as a probabilistic statement; for example, a stock is overfished (red) with a 65% probability. ICCAT and IOTC have adopted advice frameworks with the objective of rebuilding and/or maintaining stocks in the green area of the Kobe plot with high probability. Implicitly, F_{MSY} can be seen an upper overfishing threshold, while fishing mortality needs be lower than F_{MSY} to achieve a more than 50% probability stock biomass remaining above B_{MSY}.
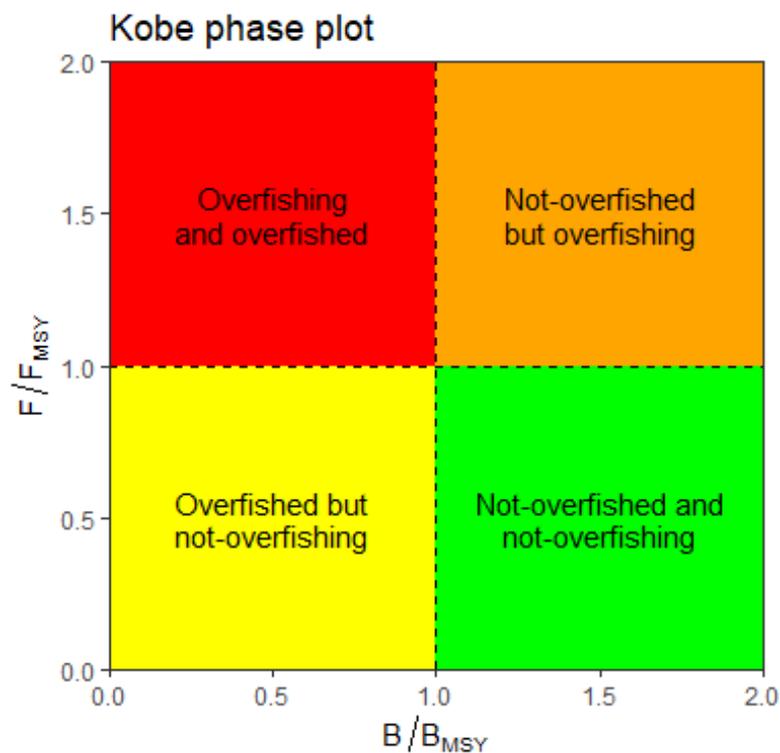

Fig. 2: Kobe phase plot.

Within the WCPFC, the Kobe phase plot is presented, but stock classification is now based on the `Majuro` phase plot (Fig. 3). Majuro plot differs from the Kobe plot in that the ratio B/B_{MSY} is placed by B/B_0. The delimitation of quadrants for biomass along the x-axis is based to a limit

reference point (LRP) in WCPFC (**sensu** B_{trh}), typically $0.2B_0$, instead of a B_{MSY}. The stock is only considered overfished if the stock biomass falls below the LRP (Fig. 3). The underlying principle is that stock biomass is assumed to naturally fluctuate around B_{MSY} if fishing occurs at F_{MSY}. If a stock a subject to overfishing ($F > F_{MSY}$) or there is an increased probability of breaching the LRP, a prompt action is required to ensure that the stock remains within safe biological levels ($B > B_{thr}$) with a high probability.
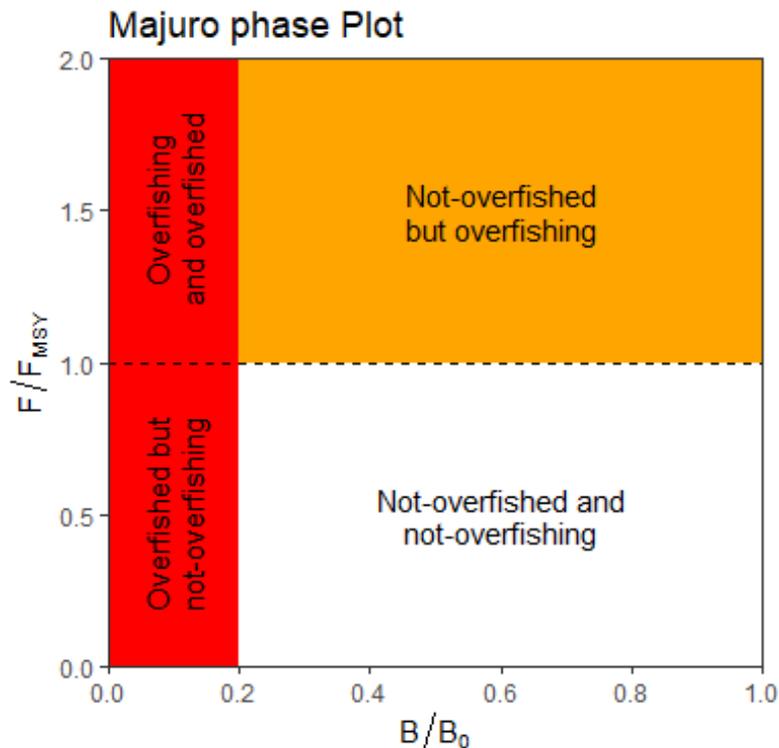

Fig. 3: Majuro phase plot.

Sustainable fishing definitions of advice standards used in the US, New Zealand, Canada or ICES do not require stock biomass to be above B_{MSY} at all times. but will oscillate around their average MSY and B_{MSY} levels. Because of natural variability, even if F_{MSY} could be achieved exactly each year, catches and stock biomass will oscillate around their average MSY and B_{MSY} levels, respectively, and it is not possible to keep all stock and fishery attributes at a constant level simultaneously.

In Canada, the stock status zones are defined as the Limit Reference Point (LRP) at the Critical-Cautious zone boundary, and an Upper Stock Reference Point (USR) at the Cautious-Healthy zone boundary (Fig. 4). In the absence of a pre-agreed harvest rule developed in the context of the PA, DFO (2019; Appendix 1b) provides provisional guidance for specifying the LRP and USR for stock status classification (Fig.4). These were developed based on practices and standards used internationally, such as New Zealand, USA and the FAO, informed by scientific review and meta-analyses, and consistent with the language found in various international agreements (Shelton and Sinclair, 2008).

- *Critical Zone*: The stock is considered to be in the "critical zone" if the biomass is less than or equal to a B_{lim} (LRP) corresponding to 40% B_{tgt}, which invokes that F_{tgt} = 0.

- *Cautious Zone*: The stock is considered to be in the "cautious zone" if the biomass is higher than B_{lim} (LRP) but lower than a B_{thr} (USR) of 80% of B_{tgt}. In this zone F_{tgt} is reduced linearly reduced the between B_{lim} and B_{thr}.

- ***Health Zone***: The stock is considered to be "healthy" if the biomass, or its index, is higher than B_{thr} (i.e. > 80% of $B_t gt$) and fishing mortality is smaller or equal to F_{tgt}.
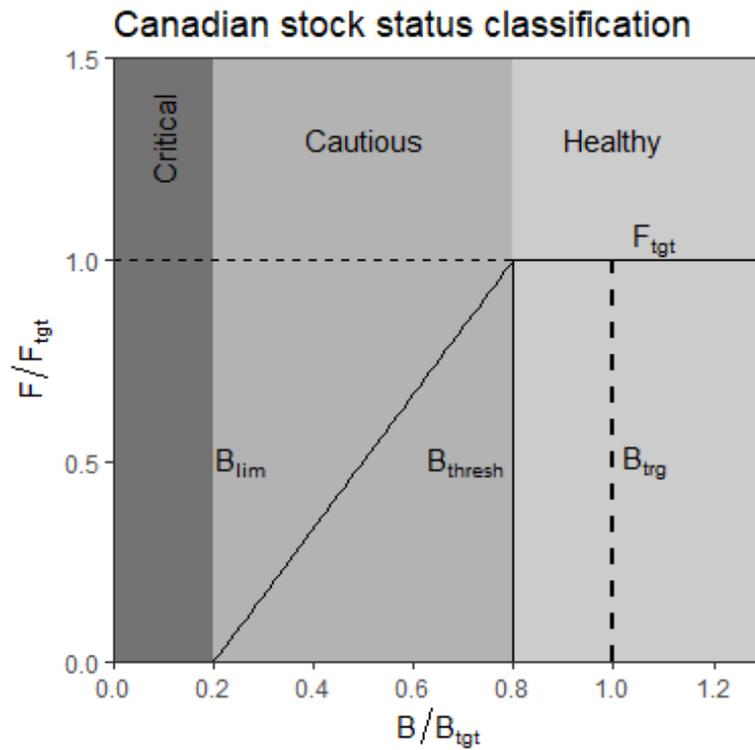

Fig. 4. Plot illustrating the stock classification system for Canadian stocks based on general guidelines provided by DFO.

The New Zealand harvest standard consists of three core elements: (1) a specified B_{tgt} of $B_M SY$ or its MSY-compatible proxy about which a fishery or stock should fluctuate; (2) a "soft" biomass limit reference point that triggers a requirement for a formal, time-constrained rebuilding plan ; and (3) a hard limit below which fisheries should be considered for closure. Stock status with is classified as follows:

- **Depleted**: The stock is considered to be depleted if the biomass breaches the "hard" limit ($0.25B_{tgt}$ or $0.1B_0$, whichever is higher) corresponding to a B_{lim}.

- **Collapsed**: The stock is considered to be collapsed if the biomass falls below the "soft" limit ($0.5B_{tgt}$ or $0.2B_0$, whichever is higher), corresponding to a B_{trh}, but above the "hard" limit.

- **Overfishing**: Overfishing occurs if fishing mortality exceeds F_{tgt} (i.e. F_{MSY} or its proxy).

- **Sustainable**: A stock exploited sustainable with $F \leq F_{tgt}$ and $B > B_{thr}$.

In the USA, biomass is permitted to fluctuate around the MSY based target reference point (B_{tgt}), while B_{thr} is the Minimum Stock Size Threshold (MSST) below which the stock is considered to be overfished. If the stock breaches the MSST a long-term rebuilding plan becomes mandatory for continuing fishing. F_{MSY} or its proxy determines the Maximum Fishing Mortality Threshold (MFMT), where $F > MFMT$ invokes a condition of overfishing and associated management interventions. The target fishing mortality F_{tgt} is set lower than F_{MSY} (or its proxy) so that the probability of overfishing is reduced below 50% according to the degree of scientific uncertainty, which is referred to as P* approach for data-rich assessments (Shertzer et al., 2008).

International practice and lessons relevant to SIOFA

The review of international advice standards highlights that most fisheries bodies anchor stock status communication in explicit relationships between biomass, fishing pressure and reference points, even if the exact terminology differs.

An important lesson is not that one single international model that can be implemented directly, but rather that most systems share a common structure:

- a **target zone**, associated with desirable stock and exploitation conditions.
- a **threshold or precautionary zone**, where intensified management response is warranted.
- a **limit zone**, where the stock is in an undesirable state and rebuilding becomes the priority;
- a distinction, where possible, between the **state of the stock** (biomass condition) and the **state of exploitation** (whether overfishing is occurring)

This review is particularly relevant for SIOFA because it demonstrates that a transparent category framework can be developed even while harvest strategies are still evolving. In other words, stock status communication need not wait for the finalization of a full management procedure.

Proposed framing for SIOFA

The proposal is to present the framework as an **interim interpretative approach** rather than a final management standard. This distinction is important. It would allow the SC to improve the consistency of status communication now, while preserving flexibility for future stock-specific development.

The following principles are proposed:

<u>Separate stock condition from exploitation status where possible</u>

Where the available assessment provides both biomass and fishing pressure relative to agreed reference points, SIOFA could distinguish between:

- **stock condition**: whether biomass is within safe biological limits, below a threshold, or below a limit;
- **exploitation status**: whether fishing pressure is consistent with the target, or whether overfishing is occurring.

This mirrors widely used international practice and helps avoid conflating biomass depletion with current fishing pressure.

<u>Use a small set of communication categories</u>

For communication to the SC and Meeting of the Parties, the following categories could be considered (Fig. 5):

- **Sustainable** (Not overfished nor overfishing occurring)
- **Overfishing occurring**
- **Overfished**
- **Rebuilding**
- **Collapsed or severely depleted**
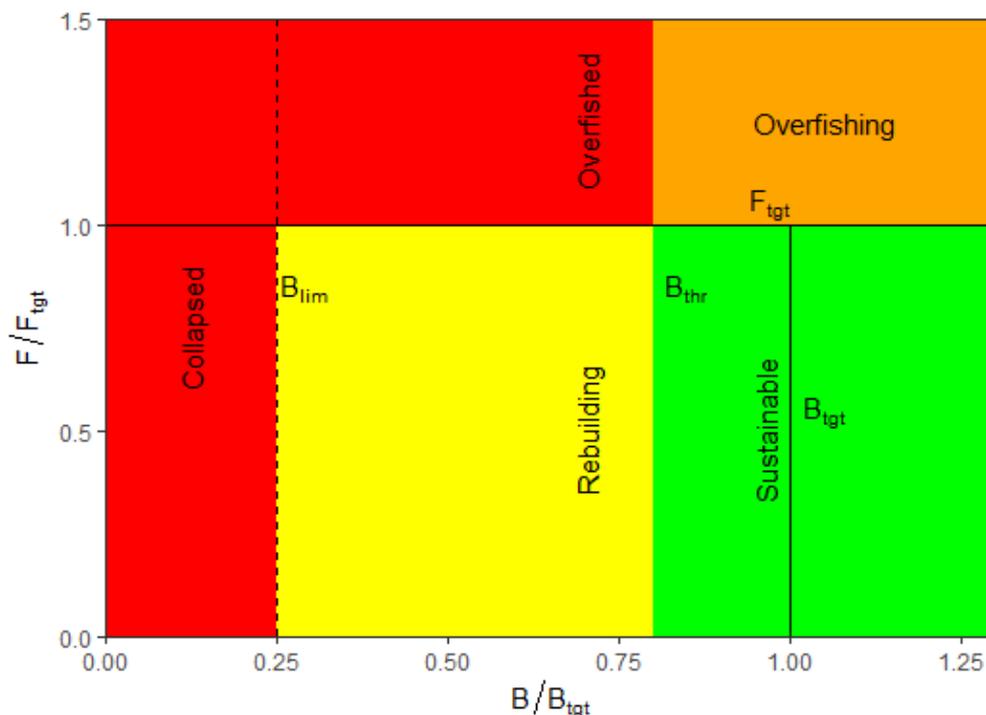- **Status uncertain / insufficient information**

Fig. 5: Candidate interim interpretative stock status classification framework

Biologically sustainable

A stock may be presented as **biologically sustainable** where the best available evidence indicates that biomass is at or above the relevant threshold and exploitation is at or below the relevant target, or where precautionary interpretation suggests that the stock is within safe biological bounds.

Overfished

A stock may be considered **overfished** where biomass falls below the agreed threshold for safe biological limits. If a lower limit reference point is also defined, breaching that limit would indicate a more severe depleted or collapsed state.

Overfishing

Overfishing refers to a current rate of fishing pressure that exceeds the target or maximum acceptable level. This should be reported separately from the biomass state wherever possible.

Rebuilding

A stock could be described as **rebuilding** where biomass remains below the desired target threshold (e.g. $B < 0.8B_{MSY}$), but exploitation has been reduced to a level intended to promote recovery (i.e. $F < F_{MSY}$).

Collapsed or severely depleted

Where biomass falls below a defined limit reference point, the stock could be classified as **collapsed** or **severely depleted**, subject to SC agreement on terminology.

Uncertain / unclassified

Where available information is not sufficient to make a defensible mapping, the stock should be reported as **uncertain**, **unclassified**, or **insufficient information**, rather than being forced into a more definitive category.

Alignment with FAO State-of-Stocks classification.

The updated SOSI 2025 assessment methodology involved a change in terminology when reporting on the stock status. While the way the stock status is determined remains the same as in previous cycles, the terminology is different:

- Overexploited is now Overfished (O)
- Fully exploited is now Maximally Sustainably Fished (M)
- Non-fully exploited is now Underfished (U)

Under the MSY paradigm (Mace, 2001), maintaining fishing mortality at or below F_{MSY} implies biomass will fluctuate around BMSY due to recruitment and environmental variability. FAO applies a precautionary buffer, classifying stocks with biomass between 0.8 and 1.2 B_{MSY} (or it proxy) as maximally sustainably fished, reflecting expected natural fluctuations rather than an expected point estimate to account for uncertainty. To account for the higher uncertainty associated with Tier 2 and Tier 3 methods (i.e. they are either classified as "Maximally Sustainably Fished" or "Overfished"). Only Tier 1 assessed stocks for which the estimate of this ratio is above 1.2 should be explicitly classified as "underfished".

Mapping the above stock classification to FAO's classification can be done transparently without forcing all stocks into a fully analytically classification of reference point target and limits where the information does not support it.

Stock status classification is straightforward in cases where estimates of $B_{tgt} = B_{MSY}$ are available, including absolute or relative biological target reference point proxies (e.g. B_{35} or spr_{cur}/spr_{40}). However, in many data limited situations, stock status classification may be only reliable with

respect to fishing pressure relative to proxies for F_{MSY} (e.g. F_{spr40}, F_{e40} or $F_{0.1}$), also due to difficulties to estimate biomass reference points from relative short time series.

In addition, stock status classification for qualitative Tier 3 assessments is often corroborated by multiple analytical assessments methods, for which an unambiguous, descriptive stock classifier, such as "Possibly in overexploitation" or "Possibly sustainable exploited" could replace, distinct point estimates for F/F_{MSY} or B/B_{MSY} (or proxies).

To accommodate, the following SoSI classification rules can be applied.

If a direct proxy for B_{tgt} B_{msy} is available:

- O: $B/B_{tgt} < 0.8$
- M: $0.8 \leq B/B_{tgt} \leq 1.2$
- U: $B_{tgt} > 1.2$ (Note all cases have $F < F_{tgt}$)

If no biomass reference point exists, but the ratio F/F_{MSY} is available:

- O: $F/F_{tgt} > 1$
- M: $F/F_{tgt} \leq 1$

In the absence of a biomass reference point, the F-based classification becomes binary (O/M). The reason of not classifying as U is that it is not clear if a stock with $F/F_{tgt} << 1$ (e.g. $F/F_{msy} < 0.5$) is under rebuilding ($B < 0.8B_{MSY}$) or underfished (U). The binary classification for a threshold of $F/F_{tgt} = 1$ is selected to achieve overall classification with the GFCM status advice.

For qualitative assessments, with only a descriptive stock status classifier, stock was classified either

- O: "Possibly in overexploitation", "Possibly overexploited" or "Possibly depleted"
- M: "Possibly sustainable" or "Possibly sustainably exploited"

Allow tier-specific application

A practical SIOFA framework can be closely aligned with FAO's tiered approach to classifying stock status, designed to accommodate differences in data availability and quality, while increasingly transitioning from Tier 3 to Tier 1 approaches (Fig. 6).
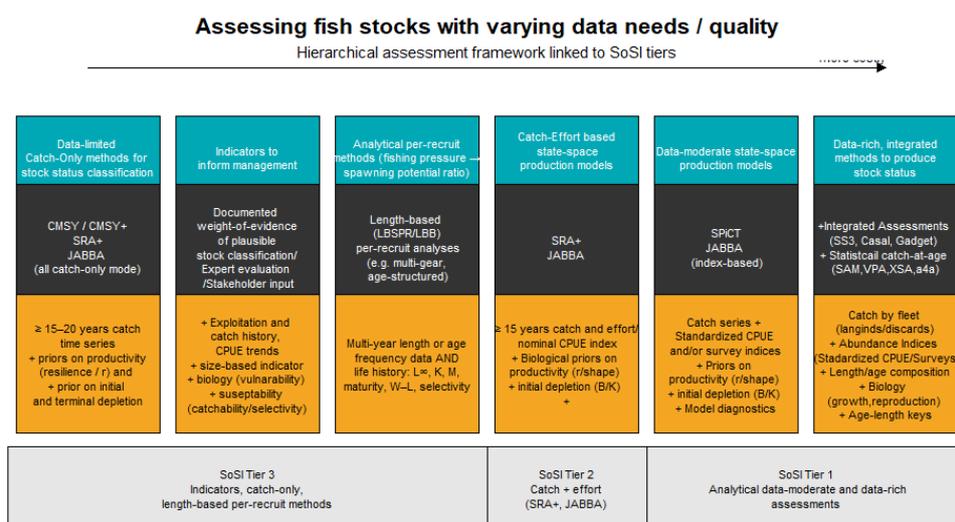
Fig. 6: Hierarchical, three-tiered assessment framework to accommodate differences in data availability and quality.

Tier 1: analytical assessments with biomass and fishing pressure metrics

For stocks with sufficient assessment outputs, status can be expressed in relation to both stock biomass and fishing pressure. This allows full distinction between sustainable, overfishing, overfished, and rebuilding situations.

Tier 2: biomass-based or production-model outputs with more limited exploitation metrics

For some stocks, only biomass-oriented interpretations may be sufficiently robust. In these cases, the framework can focus on whether the stock appears to be above target, between target and threshold, between threshold and limit, or below limit.

Tier 3: data-limited or qualitative situations

For stocks lacking adequate analytical outputs, a reduced set of categories may be preferable, such as:

- likely within safe biological limits;
- possibly outside safe biological limits;
- status uncertain.

The critical point is that uncertainty should be made explicit rather than masked by false precision.

Concluding note

The value of this proposal lies less in proposing a solution by borrowing from an existing stock status classification framework than in establishing a transparent and shared language for interpreting the best available science. For SIOFA, this could provide a practical bridge between current assessment practice and a more formalized future advice framework.

FAO and SIOFA can work together to define the criteria using the precautionary approach to set their target and limit reference points. Once their advice framework is adopted, FAO will accordingly use the mapping as suggested in the document to map out the stocks and advice framework.

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