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IDENTIFYING POSSIBLE LIMIT REFERENCE POINTS FOR THE KEY TARGET SPECIES IN THE WPFFC

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1. Introduction

Acting on a directive agreed by the Commission at WCPFC-5 in December 2008, a Special Workshop on Reference Points was held at SC5 in 2009. The aims of this workshop were to provide more capacity building on this issue and review some of the technical characteristics of reference points. The SC endorsed the recommendations from this workshop that the following work program should be undertaken during 2010 to assist in the identification of candidate reference points (both type and value) for each of the key target species in the WCPFC and to help SC6 make a suitable recommendation to the Commission:

1. Identify candidate indicators (e.g. $B_{current}/B_o$, SB/SB_{MSY}) and related limit reference points (e.g. $B_{current}/B_o$,$=X$, $SB/SB_{MSY}=Y$), the specific information needs they meet, the data and information required to estimate them, the associated uncertainty of these estimates, and the relative strengths and weaknesses of using each type within a management framework.
2. Using past assessments, evaluate the probabilities that related performance indictors exceed the values associated with candidate reference points.
3. Evaluation of the consequences of adopting particular limit reference points based on stochastic projections using the stock assessment models.
4. Undertake a literature review / meta-analyses to provide insights into levels of depletion that may serve as appropriate limit reference points and other uncertain assessment parameters (e.g. steepness).

In this paper we address aspects of items (1) and (4) above. However, in undertaking this work it was found that a number of reviews, undertaken in recent years on the use of reference points in various fisheries management agencies, had already been completed upon which this project could draw. As such, instead of repeating work completed by these reviews in identifying candidate indicators, as proposed under item (1) above, and undertaking a literature review, as proposed under item (4), we instead only summarise the conclusions of two of these reviews. (The reader seeking more details is directed to each of the reviews as listed in the References). We also summarise the limit reference points incorporated into the harvest strategies adopted by Australia and New Zealand in recent years. The results of past assessments undertaken on the key target species in the WCPO are then used to evaluate the performance of the fisheries in the WCPO against several possible limit reference points. Note, approaches to addressing (3) above are covered in the working paper MI-WP-01 (Davies and Harley, 2010).

2. Background

Annex II of the 1995 UN Fish Stocks Agreement and Article 6 of the WCPFC Convention provides the legal framework for the application of the precautionary approach and guidelines for its application to fisheries management in the WCPO. In particular, Article 6 requests that stock-specific reference points be determined together with the action to be taken if they are exceeded. Currently, however, the Commission has not formally adopted any specific reference points but has largely used default MSY-based reference points in its evaluation of stock conditions.

To progress work on meeting the requirement under Article 6, SC2 adopted a work program which included an investigation of alternative stock status reference points. A consultant's report was subsequently presented and discussed at SC3 which recommended that a draft Work Plan be developed on the potential costs, benefits and difficulties of alternative approaches for identification of appropriate reference points within the WCPO. A second consultant's report was presented and discussed at SC4 which recommended that i) a technical inter-sessional workshop be held during 2009 to review the numerical and technical properties of candidate reference points which may be used in the WCPO, and ii) the Commission establish a parallel/joint process for establishing key management objectives for each target species including the possibility of holding an inter-sessional workshop on management objectives.

At WCPFC-5, while CCMs stated their strong support for articulation of the Commission's fisheries management objectives and the development of reference points, several CCMs also expressed a desire for more capacity building and a more inclusive and collaborative approach to development of WCPFC management objectives and reference points. The Commission therefore agreed that i) SC5 should convene a workshop on capacity building and technical issues associated with reference points, and ii) WCPFC-6 should consider the possibility of holding a dedicated workshop on management objectives in 2010. This workshop has now been post-poned until 2011 and will be further discussed at SC6.

The workshop on Reference Points held at SC6 reviewed the following six classes of reference points mentioned in the second consultancy report:

i) MSY-based
ii) Yield per Recruit, YPR
iii) Historical observations
iv) Relative depletion
v) Empirical
vi) Economic

It was noted that given the lack of direct observations of spawning biomass and recruitment, and the difficulty of identifying reference points based on socio-economic factors, that candidate reference points would perhaps need to be limited to those based on MSY-, Yield-per-recruit-, Spawner-per-Recruit, or depletion indicators. While it was noted that due to their general use, and in lieu of alternatives not being identified, MSY-based reference points could be used as limit reference points for the key target species in the WCPFC, it was also discussed whether reference points other than those based on MSY would be more appropriate for the key target stocks in the WCPO.

In selecting appropriate indicators and associated reference points, the workshop noted that a good indicator should satisfy the following criteria:

1) it be based on an understanding of what information managers need,
2) it be appropriate to the species under management,

3) we have the data and / or associated models to estimate it,
4) it can be estimated reliably,
5) it will ideally have a linear relationship with the aspect of the system it is a measure of (e.g. standardised CPUE should be linearly related to the size of the fish population available to the associated fishing gear),
6) it can be easily implemented and is useful to guiding management of the fishery.

Furthermore, it was also noted that reference points set for the individual species within a multi-species fisheries, such as the WCPFC fisheries, may need to vary from species to species and should be determined using the best available scientific advice. It was also noted that any reference points developed for each of the key species should ultimately be considered in a multi-species fisheries context.

3. Candidate Limit Reference Points

According to Sainsbury (2008) "limit reference points provide operational definitions of what constitutes unacceptable outcomes, such as unacceptably high fishing mortality, unacceptably depleted fish stocks or unacceptably low profit levels…. While there remains some societal value judgment about what constitutes 'unacceptable', limit reference points are strongly determined by ecological considerations and thresholds—such as stock productivity, the chance and speed of recovery from fishing impacts, the resilience and persistence of the fished stocks and ecosystem, abrupt recruitment collapse, and impacts on dependent or associated species. Unacceptable outcomes are strongly based on avoiding irreversible, slowly reversible or long-term impacts of fishing and so there is an emphasis on avoiding recruitment overfishing, stock collapse and excessive depletion of very long-lived organisms".

Given the emphasis on avoiding 'unacceptable outcomes', and in order to help identify appropriate reference points for use by the WCPFC, in this section we summary the conclusions of two reviews which have been undertaken in recent years concerning the use of reference points and the adoption of the precautionary approach in fisheries management.

In the first review considered (Mooney-Seus and Rosenberg, 2007) a review was undertaken of the progress in adopting the precautionary approach and ecosystem-based management by thirteen Regional Fisheries Management Organizations (RFMOs), including I-ATTC, ICCAT and WCPFC. The review concluded that the adoption of Limit Reference Points should be based on the following principles:

- Minimum/Average historical biomass
- MSY a limit for fishing effort not a target
- Fishing not allowed when stocks below a predetermined proportion of carrying capacity (e.g., IWC 54%,)

The following RMFOs were identified as applying best practice: CCAMLR, I-ATTC, IBSFC (cod), IPHC, IWC, NAFO, NASCO(river specific), NEAFC.

The second review (Sainsbury, 2008) undertook a more comprehensive review of the types and range of reference points used in fisheries management and, based on an extensive review of the their adoption across a range of fisheries agencies, made recommendations of reference points for five elements of environmental management that are central to modern fishery management – the target species; bycatch species;

threatened, endangered or protected species; habitats; and food webs. The project team included a number of eminent fisheries scientists who together encompass a comprehensive set of experiences in a wide-range of fisheries. (Dr Andrew Constable – Australian Antarctic Division, Dr Bill Clarke – International Halibut Commission, Dr Patricia Livingston – NMFS, Dr Pamela Mace – NMFS, Dr Andre Punt – University of Washington, Dr Jake Rice – Fisheries and Oceans, Canada and ICES, and Dr Gunnar Stefansson – Icelandic Marine Research Institute).

This study noted that two types of reference points are in common use: fishing mortality-based reference points, and biomass-based reference points. They also noted a third type of reference point, empirical-based reference points, that have not been commonly used but do provide distinct advantages in some circumstances because they are easily understood and communicated, and are often simpler and cheaper to apply. The study identified fisheries which showed very good practice in the use of reference points and provided the following summary of key observations from these fisheries (refer to the glossary provided in Appendix A for a definition of terms):

Fishing Mortality-based Reference Points

- Limit reference points for fishing mortality that define overfishing are used in most of these fisheries.
- F_{MSY} under the Maximum Annual Yield (MAY) interpretation is a frequently used limit, with a conservatively specified Maximum Constant Yield (MCY) interpretation used in some cases. The conservative specification of MCY includes consideration of uncertainty in estimation, resource dynamics, recruitment variability and the ecosystem role of the target species.
- Where F_{MSY} cannot be estimated because of data limitations, proxies based on $F_{35\%}$ to $F_{40\%}$ have been successful for many stocks, although levels of $F_{50\%}$ or lower have been found to be necessary for long-lived and low productivity stocks. (Note, $F_{x\%}$*:* is defined as the fishing mortality that reduces the spawning biomass per recruit to x% of the spawning biomass per recruit at the unfished level.)
- Fishing mortality or catch decision rules are commonly used as a means of avoiding limits and maintaining the fishery in a desirable state, even if explicit targets for fishing mortality are not specified.

Biomass-based Reference Points

- $0.25B_0$-$0.5B_0$ and approximately B_{MSY} are commonly used biomass limit reference points.
- In several fisheries the minimum biomass limit reference point is set at a level to ensure that average recruitment does not decline. This is more conservative than the limit implied by previous recruitment overfishing definitions, which were at a level where serious or significant reduction in average recruitment occurs. In some cases the biomass limit reference point is identified on the basis of historical observations, and in others the lowest observed biomass is treated as this limit even though a decline in recruitment has not been observed at that biomass.
- The US National Guidelines (NMFS 1998) and the Australian Harvest Strategy Policy (DAFF 2007) both identify $0.5B_{MSY}$ (or an equivalent proxy) as a limit reference point. However this can result in large reductions in biomass, with the consequent risk to economic benefits, ecological and genetic functionality and

reversibility that is associated with low population biomass. For example $B_{35\%}$ is a common proxy for B_{MSY} and for many productive species B_{MSY} is in the vicinity of $0.35B_0$, so setting $B_{lim}=0.5B_{MSY}$ can result in limit reference points that are very low (i.e. $0.175B_0$ or $B_{17.5\%}$) compared to the approaches used in the other fisheries examined.

- In situations where natural fluctuations in productivity or recruitment result in large fluctuations in stock size, the limit reference point is modified to track these changes through time, while also placing a limit on the absolute level of depletion that is acceptable. This results in the limit being the greater of two quantities, a time-varying fraction of the predicted unfished biomass and a static fraction of B_{MSY} or B_0 (or their spawning biomass equivalents). This approach can be expected to provide some protection against non-stationarity in fish production due to events such as climate change.

For target species, the study recommended setting reference points for both biomass and fishing mortality. This is because while fishing mortality is under more direct management control, it is biomass (and related population structure) that influences key ecological processes and functions. Specifically populations with relatively large biomass and with full age/size structure are expected to be more likely to maintain their genetic diversity and natural genome, to be more resilient to recruitment overfishing, recruitment variability and environmental perturbations, and to maintain food-web structure and stability. The study also recommended that Limit Reference Points (LRPs) should be set primarily on biological grounds to protect the stock from serious, slowly reversible or irreversible fishing impacts, which include recruitment overfishing and genetic modification.

A listing of the Limit Reference Points recommended by the review is provided in Table 1.

In recommending F_{MSY} (and the $F_{50\%}$ proxy) as the fishing-mortality LRP, the study noted that for the stock-recruitment steepness seen in most fish (i.e. greater than about 0.3) $F_{50\%}$ provides more than 80% of the MSY and depletes the biomass to no more than about 30% of the unfished level. However, higher fishing mortality reference points (e.g. $F_{40\%}$) could be justified if there is information to suggest that the stock-recruitment relationship has high steepness.

In recommending 30% of the unfished biomass level[2] as a biomass-based LRP the study saw this as appropriate even to stocks that can apparently maintain average recruitment at lower biomass. This was because for populations with very high ‘steepness’, and where the MSY may occur near or below $30\%B_0$, similar catches can still be taken at higher biomass. On the other hand, by limiting the reduction in biomass to 30%, there is a greater chance of maintaining ecological and population processes (including as yet poorly understood genetic, physiological, population and ecosystem effects of low population size), providing a safety margin for unforeseen dynamics (including changing environmental trends or variability), and avoiding levels of depletion from which it is potentially difficult to recover.

[2] The report refers to biomass. However, a recent clarification sought from Dr Sainsbury indicated that the use of spawning biomass in this context should be seen as “best practice”. He stated that the interpretation of the term biomass remained unclear in parts of the report.

While the study recognised that $0.2B_{unfished}$ is commonly used as a limit reference point, and that there is good empirical support that this avoids recruitment overfishing for productive stocks (i.e. is an appropriate B_{lim} for such stocks), it was not regarded as the best practice limit reference point because this level of depletion (i) does not avoid recruitment overfishing in low productivity stocks, (ii) may not provide adequate protection for other fishing impacts that are likely to be slowly reversible or irreversible (e.g. reduced age structure with consequences to the quality of spawning, ease of population recovery from the limit), (iii) is less robust to uncertainty in estimation and model specification, including to changes in the climate or ecosystem, and (iv) is not consistent with the precautionary reference point approach of ICES, where B_{pa} was found to be about $1.4B_{lim}$ in fishery assessments based on good data sets. On this issue it can be noted that the meeting of Strategy and Management Working Group for the Commission for the Conservation of Southern Bluefin Tuna held in 2009 "agreed that 20 percent of the original spawning biomass was an appropriate interim rebuilding target reference point to move the SBT stock away from its current low level of around 10 percent", with the ultimate aim of rebuilding the stock to a higher level (Anon, 2009).

The use of SB_{lim}, the average spawning stock biomass below which average recruitment declines or stock dynamics are highly uncertain, is commonly used as a LRP. The review gives examples, but they include ICES and the language of the FAO Code of Conduct. Even the Fish Stocks Agreement implies its use, such as "Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits..... to account, inter alia, for the reproductive capacity". On the other hand, the third biomass-based LRP included in the recommendation (the biomass from which rebuilding to the target reference point could be achieved in a period that delivers human intergenerational equity) is not a common one but was included as it seems to be implied by many conventions and policies[3]. It is what the CCAMLR Convention implies and has used in, for example, its krill harvest strategy.

Finally, in selecting Limit Reference Points for target species the study provided the following set of key principles:

- There should be a low chance that reasonable expectations of natural variability, in combination with the fishery, will result in the limit being approached or exceeded. This is usually expressed as:

  $$Pr(B_{current} < B_{LRP}) < x \qquad \text{or} \qquad Pr(F_{current} > F_{LRP}) < x$$

  where x is small, say 5%.
- A stock that is below the biomass target should be harvested at a lower rate than one above the target. This can be implemented through the use of a pre-agreed decision-rule.
- If a biomass limit reference point is breached, or is predicted to be breached under expected natural and fishery conditions, then a recovery or avoidance plan should be triggered.
- Target reference points should be set safely away from limit reference points. There should be a very low chance that a fishery assessed as being near the target is actually near or beyond the limit. The study notes that given the

[3] Keith Sainsbury, personal communication

accuracy of most assessments, the biomass target would usually be expected to be above 40%B_0 to avoid a limit of 30%B_0.

The implementation of these key principles should be demonstrated, for example by simulation testing or some other reviewable method, so that the decision rules and trigger reference points have a good chance of being able to achieve target and avoid limit reference points under the range of circumstances that the fishery might be reasonably expected to face (e.g. uncertainty or variability in stock productivity, in monitoring and in assessment, and in regulating fishing operations).

4. Harvest Strategies Adopted by Australia and New Zealand.

In recent years both Australia and New Zealand have adopted policies which will see all fisheries managed under harvest strategies which implicitly include both target and limit reference points.

Under the Australian policy (DAFF, 2007) each harvest strategy is to ensure that fish stocks remain above a level, B_{LIM}, where the risk to the stock is regarded as too high. The default for B_{LIM} (or proxy) is equal to or greater than ½B_{MSY} (with a default equivalent of 20% B0) and the harvest strategy needs to ensure that the stock stays above this limit at least 90% of the time. For a stock below B_{LIM} a stock rebuilding strategy will be developed to rebuild the stock to B_{TARG}. For stocks above B_{LIM} but below the level that will produce maximum sustainable yield (B_{MSY}) it is necessary to rebuild stocks to B_{MSY}. Once stocks reach B_{MSY} rebuilding shall continue to $B_{TARG,}$ however, the rate of rebuilding is to be determined in a way that considers the appropriate balance between short-term losses and longer term economic gains.

Under the New Zealand policy (Anon, 2008a) each harvest strategy will include a "soft" limit reference point that triggers a requirement for a formal, time constrained rebuilding plan. The default soft limit is ½B_{MSY} or 20%B_0, whichever is higher, and this limit will be considered to have been breached when the probability that stock biomass is below the soft limit is greater than 50%. Stocks that have fallen below the soft limit should be rebuilt back to at least the target level in a time frame between *Tmin* and 2 * *Tmin*[4] with an acceptable probability. Stocks will be considered to have been fully rebuilt when it can be demonstrated that there is at least a 70% probability that the target has been achieved and there is at least a 50% probability that the stock is above the soft limit. Use of a "soft" limit as a biological reference point that triggers a requirement for a formal, time-constrained rebuilding plan does not imply that no action needs to be taken to rebuild stocks that have fallen below targets but have not yet declined to the level of the soft limit. Management action needs to be continually applied to ensure that fisheries and stocks fluctuate around target levels, particularly when they start to fall below those targets. The soft limit, and the associated need for management action, establishes a buffer to ensure that stocks do not breach the hard limit, which may result in fisheries closures. A "hard" limit below which fisheries should be considered for closure will also be set with the default hard limit at 1/4 B_{MSY} or 10% B_0, whichever is higher. Again this limit will be considered to have been breached when the probability that stock biomass is below the hard limit is greater than 50%. The default level at which the hard limit is set represents a minimum

[4] *Tmin* is the theoretical number of years required to rebuild a stock to the target in the absence of fishing. It is a function of three primary factors: the biology of the species, the extent of stock depletion below the target, and prevailing environmental conditions

standard; higher hard limits may be appropriate for some stocks, particularly those with low productivity. Fisheries that have been closed as a result of breaching the hard limit will not be re-opened until it can be demonstrated that there is at least a 70% probability that the stock has rebuilt to or above the level of the soft limit.

5. Application of Possible LRPs in the WCPFC

In this section we evaluate the performance of the fisheries in the WCPFC in relation to several of the LRPs mentioned in the preceding sections using the results of the most recent stock assessment undertaken for each of the principal target species in the WCPO. As it was not possible to evaluate two of the LRPs recommended by Sainsbury (2008) [the values of SB_{lim}, the average spawning stock biomass below which average recruitment declines or stock dynamics are highly uncertain, and the biomass from which rebuilding to a target reference point could be achieved without fishing in a period not greater than a fish generation time plus 10 years] for each species only the performance of the following five indicators were evaluated (note: SB – spawning biomass):

1. $F_{current} / F_{MSY}$ (LRP value 1.0, both reviews)
2. $B_{current} / B_{MSY}$ (LRP value 0.5, Aust, NZ)
3. $SB_{current} / SB_{MSY}$ (LRP value 0.5, Aust, NZ)
4. $B_{current} / B_{current,F=0}$ (LRP value 0.3, Sainsbury)
5. $SB_{current} / SB_{current,F=0}$ (LRP value 0.3, Sainsbury)

The year in which each assessment was completed, together with the table numbers in each report from which the values of each indicator were taken are listed in Table 2, while the low and high value of each indicator are shown in Table 3. The range of values for each species is also shown against the recommended LPR in Figure 1.

For each species, the value of the fishing mortality-based indicator should be below the recommended LRP of 1.0, while the value of the biomass-based indicators should be above the recommended LRPs indicated above. From Figure 1 it is seen that for all species, except bigeye tuna in some instances, the range of values for both indicators have not exceeded the associated LRP. However, the relationship between these indicators and any yet to be adopted target reference points remains unknown.

6. Discussion

This paper has drawn on the results of two recently completed reviews on the use of reference points in fisheries management, together with the adopted harvest strategies in Australia and New Zealand, to help identify limit reference points that may be appropriate for the key target species managed by the WCPFC. While the conclusions of the first review are more general, both reviews identify the use of F_{MSY} as an appropriate limit reference point. This recommendation is also consistent with the limit point for fishing mortality recommended by Lodge et al (2007) and the recommendation in Annex II of the UN Fish Stocks Agreement. Paragraph 7 which states "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points."

The second review also recommends setting both fishing mortality- and biomass-based reference points. Again the recommendation from the first review is more general – that fishing not be allowed when stocks fall below a predetermined proportion of carrying capacity – but remains consistent with the recommendation from the second that the LRP correspond to the average spawning stock biomass below which average recruitment declines. This is also seen to be consistent with the limit reference point for stock size recommended by Lodge et al (2007) – “the size below which it is known or expected that there is a much greater probability of significantly reduced recruitment but at which the probably of significantly reduced low recruitment is still small”.

This principal is incorporated within the harvest strategies of both Australia and New Zealand in specifying limit reference points. For example, the operational guidelines for New Zealand’s harvest strategy standard specify that “A limit represents a point at which further reductions in stock size (or proxies) are likely to ultimately lead to an unacceptably high risk of stock collapse and/or a point at which current and future utility values are diminished or compromised” (Anon 2008b), while under the Australian policy “B_{LIM} should correspond to a biomass level, or level of stock depletion, at which the risk to the stock is unacceptably high, for example the point at which overfishing is thought to occur.” (DAFF, 2007)

Together with the selection of the type of indicator and its associated value as a LRP there is the expectation that, within the natural variability of the stock in combination with the fishery, there will be a low probability that the limit will be approached or exceeded. In a practical context of assessing of the performance of a fishery against a reference point this usually entails specifying the maximum probability, x, such that:

$$Pr(B_{current} < B_{LRP}) < x \qquad \text{or} \qquad Pr(F_{current} > F_{LRP}) < x$$

While each review states that the value of x should be small, neither provides a recommended value. On the other hand, both the harvest strategies adopted by Australia and New Zealand define values of x, with $Pr(B_{current} < ½B_{MSY}) < 10\%$ under the Australian strategy.

The application of the LRPs identified above to the WCPFC was demonstrated using the results of the most recent assessments for five of the key target species in the WCPO. This demonstration, however, only made use of a range of point estimates for each indicator based on several sensitivity runs for each assessment. As such, it was not possible to fully evaluate the current fishery performance against each reference point as discussed above. While there is a need to incorporate uncertainty into the calculation of stock status and the provision of management advice against adopted reference points this is, nevertheless, a complex issue. Current approaches rely heavily on a single model run (e.g. base case) and so-called parameter uncertainty (sensitivity runs within a given model framework). However, it is now clear that structural uncertainty is often larger and alternative plausible model runs can often give quite different result. The Structural Uncertainty Analysis outlined by Harley et al (2009) provides a potential approach for incorporating many of the major sources of uncertainty, but is only at an early stage of its development.

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Appendix A: Glossary (from Sainsbury, 2008)

Blim: The average spawning stock biomass below which average recruitment begins to decline, especially as estimated by segmented regression methods. Below Blim there is a substantial increase in the probability of reduced recruitment, while at Blim the probability of reduced recruitment is still small. Alternatively Blim can be the biomass below which the stock dynamics are unknown (ICES 2003a,b). Blim is a limit reference point for a recruitment overfished stock.

BMSY: The population biomass at which MSY is available. In an MAY interpretation of MSY, the average biomass that results from fishing at FMSY.

Bpa: A precautionary limit reference point set to ensure that there is a low chance of the stock being at or below Blim with the methods of monitoring and estimation that are used. When a stock is estimated to be at Bpa there should be a high probability that it is above Blim.

Bunfished: The average biomass likely to exist at any point in time in the absence of fishing. This could be derived from interpretation of observation of unfished reference sites, theoretical calculations or a combination of both of these.

FMSY: The fishing mortality that on average generates MSY and BMSY, especially in the MAY interpretation of MSY.

Fx%: The fishing mortality that reduces the spawning biomass per recruit to x% of the spawning biomass per recruit at the unfished level.

Generation time: The average time in an unfished population between birth of an individual and that individual replacing itself through reproduction. In practical fisheries applications this has been interpreted as being the average age of the contributors to reproduction in an unfished stock, and calculated as [the sum for all ages of (age x survival x contribution to reproduction)] / [the sum for all ages of (survival x contribution to reproduction)], where the contribution to reproduction is commonly taken to be the age specific egg production.

MAY: Maximum Annual Yield which is the long-term average yield obtained when the yield each year results from a constant fishing mortality (FMAY or often simply FMSY) being applied to the available population biomass. The catch in each year under this approach is the Current Annual Yield (CAY).

MCY: Maximum Constant Yield which is a single unchanging maximum yield that can be taken, with an acceptable level of risk, from all probably future levels of biomass and recruitment.

MSY: Maximum Sustainable Yield. Conceptually MSY is the maximum average long-term yield that can be taken from a population. See MAY and MCY for clarification of the dynamic and static interpretations of MSY, and Ricker (1975).

Table 1. Limit Reference Points identified by Sainsbury (2008)

Fishing Mortality	Biomass
F_{MSY} This can be estimated directly or a proxy can be justified and used. $F_{50\%}$ (the fishing mortality that gives a 50% reduction in the spawning biomass per recruit) is a reasonable default proxy for situations in which 'steepness' in the stock recruitment curve is unknown, and use of higher values of fishing mortality (i.e. lower % SPR) requires specific justification.	The greater of the following 3 quantities: • B_{lim}, the average spawning stock biomass below which average recruitment declines or stock dynamics are highly uncertain , • $0.3B_{unfished}$, the biomass in the absence of fishing, and • the biomass from which rebuilding to a target reference point could be achieved without fishing in a period not greater than a fish generation time plus 10 years. Bo can be used as a constant proxy for $B_{unfished}$ for stocks that do not show large natural fluctuations or 'regime shifts'. For stocks that naturally show large fluctuations two limit reference points, related to recent and long-term productivity, must both be met. These limits are 0.3 $B_{unfished}$ and 20% of the median long-term B.

Table 2. Listing of the assessments and results used in evaluating the performance measures for each species.

Species	Symbol	Assessment Year	Tables Used	Number of Runs
Yellowfin tuna	YFT	2009	9a,b,c	14
Bigeye tuna	BET	2010	6	8
Skipjack tuna	SKJ	2010	9,10	Grid
South Pacific Albacore tuna	ALB	2009	9,10,11	Grid
Southwest Pacific Swordfish	SWO	2008	5	5

Table 3. Listing of the range (low and high values) of the four example indicators for each species.

	Fc/Fmsy		Bc/Bmsy		SBc/SBmsy		Bc/Bc,F=0		SBc/SBc,F=0	
	Low	High	Low	High	Low	High	Low	High	Low	High
YFT	0.41	0.85	1.29	1.88	1.44	2.43	0.53	0.63		
BET	1.28	1.97	1.09	1.49	0.97	1.50	0.19	0.28	0.13	0.23
ALB	0.10	0.60	1.40	1.69	1.69	4.65	0.71	0.85	0.53	0.71
SKJ	0.11	0.61	2.01	2.80	2.16	3.37	0.57	0.65	0.57	0.65
SWO	0.18	0.67	1.22	2.06	1.20	3.46	0.45	0.79	0.31	0.63

Note: For ALB, $Bc=B_{2005\text{-}2007}$, $SBc=SB_{2007}$

Figure 1. The range of indicator values for each species against the identified Limit Reference Point for each indicator (shown by the bold line).