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The Application of Reference Point Management in WCPO Tuna Fisheries: An Introduction to Theory and Concepts

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1 Executive Summary

Reference points are one key component to a rational fishery management regime that seeks to ensure not only biological sustainability, but also to achieve the various objectives that fishery managers and the fishing industry may have. However, the determination of reference points is a difficult task, compounded not only by the highly technical nature of the debate, but also by the difference in objectives between stakeholders. Engaging in such debate in the context of a Regional Fisheries Management Organisation (RFMO) compounds both of these issues.

This document has been prepared by the Pacific Islands Forum Fisheries Agency Secretariat for use as preliminary reference material to inform wider debate. The paper provides the following:

- A description of key terms used in reference point based management;
- An explanation of some reference points commonly used in fisheries;
- A discussion of some of the practicalities and legalities of setting reference points In particular, the key concepts of Maximum Sustainable Yield and Maximum Economic Yield are explored against issues of sustainability, optimisation and legal requirement.; and
- A very brief discussion on the use of reference points in harvest strategies, particularly in the multi-species context of the WCPO tuna fisheries.

The key conclusion of the paper is that there are no reference points that should be advocated as blanket or default reference points for WCPO tuna stocks but that each should be based on a consideration of the stock, its characteristics and its role in the fishery.

2 Terminology and brief theory of reference point based management

There is a lot of terminology used in this field and often the same terms are sometimes used in different ways. The key terms that used throughout these documents are:

1. Reference Point – is a pre-determined level of a given <u>Indicator</u> that corresponds to a particular state of the stock that management either seeks to achieve or avoid.

2. Indicator – is a quantity used to measure the status of a stock against a given <u>Reference Point.</u>

> **Example 1** – The WCPFC SC has recommended a 30% reduction in fishing mortality of bigeye tuna to maintain the stock at levels that will support Maximum Sustainable Yield. In this case:
>
> - The reference point is "the fishing mortality that results in Maximum Sustainable Yield";
> - The indicator is "fishing mortality", and its current level is 30% above the reference point.

Further to these brief definitions, it should be noted that reference points are part of an overall management strategy, and must be based on agreed scientific modeling and monitoring procedures. However, reference points may initially be provisional and based on less rigorous modeling, or may be set through other means, such as based on similar species or fisheries. Provisional reference points are generally implemented according to the Precautionary Approach and accompanied by enhanced monitoring.

3 Types of reference points

Three primary categories of reference points are commonly discussed:

- Target Reference Points (TRPs), which describe the intended outcome for the stock. TRPs are designed in view of management objectives.

- Limit Reference Points (LRPs), which describe an undesirable state of the indicator that should be avoided with high probability. LRPs set boundaries that are intended to constrain harvesting within safe biological limits. Fishery management strategies should ensure that the risk of exceeding limit reference points is very low.

- Trigger Reference Points (TrRPs), which identify a predefined management response. The set of trigger reference points may include the target and limit reference points, but could also be reference points between the two.

The target and limit reference points are benchmarks for judging fishery performance, whereas the trigger reference points are part of the management system. The basic premise of reference point management is seeking to ensure that the indicator remains near the TRP. When an indicator falls far enough below the TRP, changes should be instituted to prevent it from reaching the LRP and to move it back towards the TRP. If an indicator falls below a LRP, strong management action should be taken (that usually includes severe restrictions on target fisheries).

The trigger reference points define the points at which different management actions are applied and are a major part of the control rules that make up a Harvest Strategy (see Section 7). TrRPs will usually include the LRP (i.e. falling below a LRP should trigger some management action), but not necessarily the TRP (i.e. moving above or below it at any point means that the fishery probably close to the intended state and management action may not be required). Often a control rule will include an additional TrRP between the TRP and the LRP to act as a “buffer” (e.g. management action starts before you cross the LRP).

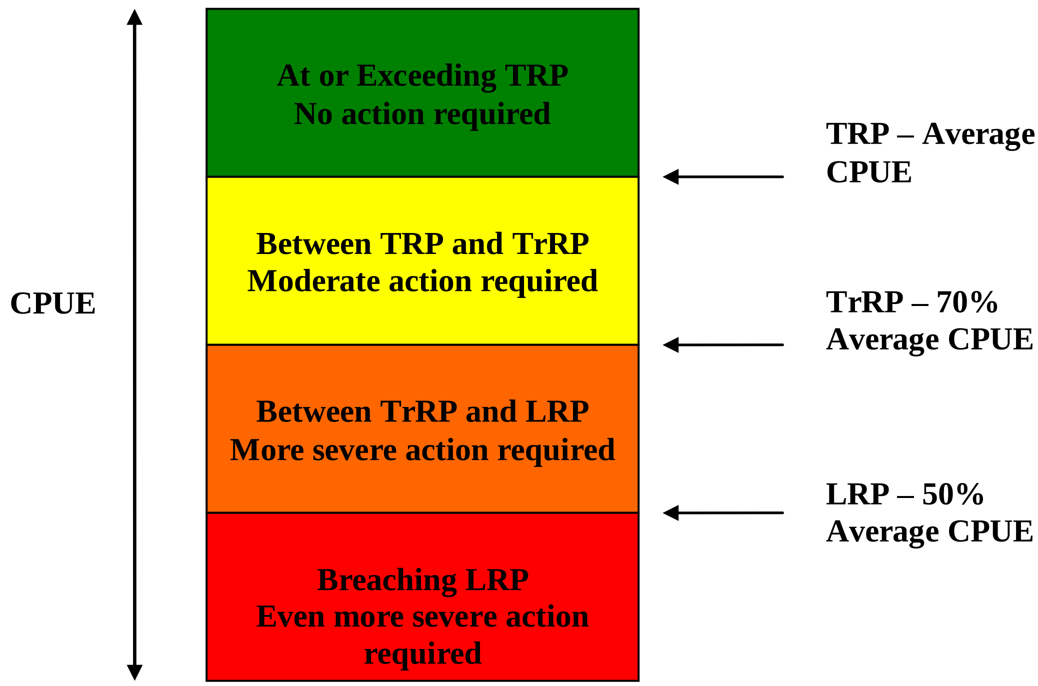
Example 2 – Fishery X uses average Catch Per Unit Effort (CPUE) over 3 years as an indicator. Reference Points are set as follows:

- TRP – set at the average CPUE for a period in the past (e.g. 1985-1995). The fishery seeks to achieve those catch rates into the future.
- LRP – set at 50% of the average CPUE. The fishery has decided that this represents a stock status that should be avoided with high probability.
- TrRP – set at 70% of the average historical CPUE. The 70% reference point is set as an early warning that catch rates are declining, but have not yet reached the LRP. Strictly speaking, the LRP is also a TrRP as it initiates management action (see below).

Various scenarios under this example are described below and in Diagram 1.

- If the CPUE of fishery X was at the average CPUE, no management action would be required: **At TRP**.
- If the CPUE was less than the average, but more than 70% of the average, management action might be taken to reduce fishing pressure in order to achieve the TRP: **Between 70% TrRP and TRP**.
- If the CPUE was less than 70% of the average, but more than 50% of the average, more severe management action would be required to reduce fishing pressure: **Between 70% TrRP and LRP**.
- If the CPUE fell to less than 50% of the average, then very strong management action would be required (potentially including cessation of fishing): **Breaching LRP**.

Diagram 1 – Example of types of Reference Point and resulting management action



4 Indicators and reference points

4.1 Indicators and corresponding reference points

Any metric that indicates the status or trend of a particular stock or species can in theory be used as an indicator. However, enough must be known about the metric/indicator to set meaningful reference points that relate to it. The table below gives examples of metrics that can be used as indicators, as well as examples of reference points that could be used with them.

<table>
<tr><th>Indicator</th><th>Symbol</th><th>Theory</th><th>Comments</th><th>Example Reference Point(s)</th><th>Symbol</th><th>Comments</th></tr>
<tr><td rowspan="2">Catch

(also referred to as tonnage or Yield)</td><td rowspan="2">C

(or: t, Y)</td><td rowspan="2">Reliable stock assessment can model the impact of given catch levels on the stock.</td><td rowspan="2">Reliant on accurate and timely catch reporting to assess performance.</td><td>Maximum Sustainable Yield</td><td>MSY</td><td>The most common reference point that has been applied in the past – but has largely been replaced by more sophisticated and/or precautionary reference points (e.g. those based on F or B).</td></tr>
<tr><td>Maximum Economic Yield</td><td>MEY</td><td>See section 4.2 below for more explanation of the meaning of MEY and implications of applying it to fisheries management.</td></tr>
</table>

Indicator	Symbol	Theory	Comments	Example Reference Point(s)	Symbol	Comments
Effort	E	Reliable stock assessment can model the impact of given effort levels on the stock.	Relies on accurate and timely catch reporting to assess performance. Generally only used for fisheries with specific effort management regimes. Generally only used where there is a reliable known relationship between catch and effort (also see comments on CPUE below)	Effort that results in Maximum Sustainable Yield	E_{MSY}	Given uncertainties about effort and resulting catch (such as a small boat catching less for each fishing day than a large one), an error margin is sometimes used as a buffer (such as $0.9E_{MSY}$, which is 90% of the effort expected to result in MSY).
				Effort that results in Maximum Economic Yield	E_{MEY}	As per comments on MEY and E_{MSY}.
Biomass (also referred to as Total Stock Biomass)	B (TSB)	Biomass is the weight of all fish in the water.	B is a very commonly used indicator, but can be difficult to estimate, particularly for highly migratory species.	Biomass that supports MSY	B_{MSY}	Often recommended as a LRP and applied as a TrRP.
				Biomass that supports MEY	B_{MEY}	Generally considered a TRP
				A given proportion of unfished Biomass	B_X or XB_0 (where X is a %)	Depending on the proportion, can be a TRP (e.g. – B_{40}) or LRP (e.g. – B_{20}). Unfished biomass relates to the weight of fish that would be in the water if fishing had never occurred.

Indicator	Symbol	Theory	Comments	Example Reference Point(s)	Symbol	Comments
Spawning Biomass (also referred to as Spawning Stock Biomass)	SB (SSB)	Spawning biomass is the weight of all mature (reproductive) (generally female) fish in the water, or (preferably) the reproductive potential of the population.	Gives a better indication than B of the reproductive capacity of the stock, and tends to be more stable.	As per examples for Biomass based reference points	SB_{MSY}, SB_{MEY}, SB_X, XSB_0 etc	As per comments on Biomass based reference points. SB_{20} is commonly applied as a LRP.
Spawning Potential Ratio (also referred to as Spawning Potential per Recruit)	SPR	SPR is a measure of the impact that fishing has on the ability of each recruit to contribute to spawning.	SPR is based on the age at maturity, the age at capture, and natural mortality and growth. SPR is expressed as a ratio of the fished population compared to an unfished population.	A given proportion of the SPR of an unfished population.	SPR_X	Depending on the proportion, can be a TRP or LRP. Less subject than SB_{MSY} to problems associated with estimating stock recruitment relationships (see section 5.1).
Yield Per Recruit	YPR	YPR is an estimate of the contribution that each recruit will make to the overall catch of the fishery	YPR basically relates to recruits that are destined to be caught, whereas SPR relates to recruits that are destined to survive (at least long enough to spawn once)	Not commonly used as a reference point in itself, but contributes to others (such as F_X below)		

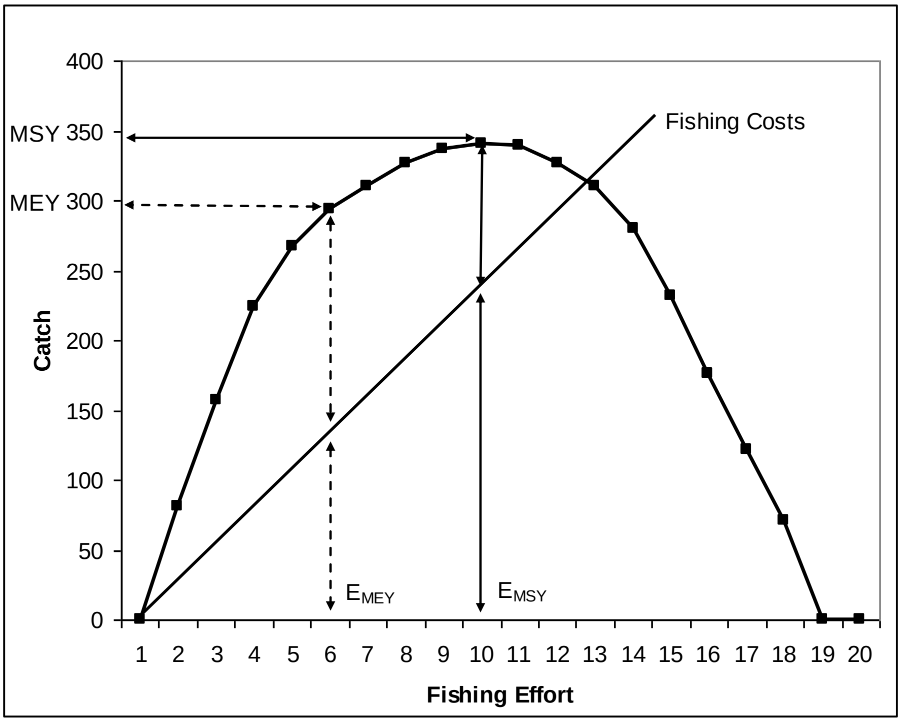
Indicator	Symbol	Theory	Comments	Example Reference Point(s)	Symbol	Comments
Fishing Mortality	F	F relates to the proportional impact of fishing on the total deaths in a stock during a given period.	F is expressed as percentage, generally interpreted as the proportion of the total deaths in the population that are due to fishing.	As per examples for Biomass based reference points	F_{MSY}, F_{MEY}	As per comments on Biomass based reference points.
				Fishing mortality rate where the marginal YPR increase is a given proportion of the marginal YPR increase in a virgin stock	F_X (where X is a proportion)	F_x seeks to optimize fishing mortality (≈ catch) at a level where additional effort would not be worth the change to the long term catch of the fishery. e.g. – $F_{0.1}$ is the point where the relationship between F and SPR is 10% (i.e. 0.1) of the relationship when F = 0.

Indicator	Symbol	Theory	Comments	Example Reference Point(s)	Symbol	Comments
Catch Rates	CPUE	Catch rates have been used repeatedly in the past as proxies for stock abundance on the basis that if the stock is stable, CPUE will be steady, whereas if the stock is declining, CPUE will fall. In this way, CPUE gives an indication of the trend of the stock, rather than its "health".	Numerous issues with CPUE as an indicator have been raised including the way CPUE changes between fishers/areas/years, impact of fishing technology on CPUE, questions as to whether fishing is representative of distribution, hyperstability etc.	CPUE that is a given proportion of a historical level (e.g. – average, maximum or minimum)	CPUE	CPUE can be tuned for greater accuracy, such as by supplementing commercial data with fishery independent data, standardizing catch rates across the fleet and over time and examining CPUE across fish size classes and fishery areas.
				CPUE that shows a given trend (upwards, downwards, flat)		

4.2 Explanation of Maximum Economic Yield (MEY)

MEY is a relatively young concept compared to MSY, which has been a fundamental part of fisheries management for many years. MEY is relatively simple in concept but difficult to determine and apply. It represents a catch level where the difference between total fishing costs and total revenue is the greatest. In business terms, it is simply the "greatest profit scenario". The hypothetical yield curve below shows a simple example of the relationship between catch and cost and the placement of MEY.

Diagram 2 – Hypothetical yield curve showing MSY and MEY fishing scenarios



MEY is the catch amount that is obtained when the distance between the fishing cost line (diagonal) and the catch (bell curve) is the greatest. In this example, the largest difference between cost and catch is demonstrated via the dotted lines. For an effort level of 6 (E_{MEY}), a catch of approximately 300 can be obtained. In contrast E_{MSY} is at an effort level of 10 (66% effort increase from E_{MEY}), which produces a catch of approximately 350 (only a 16% catch increase from MEY). Therefore, while the MSY may be a safe biological harvest option, the final 50 units of catch have been caught under sub-optimal economic conditions, thereby reducing the profitability of the fleet and its capacity to pay access fees or resource rent.

Determining MEY is extremely complex and relies on good information regarding stock structure and biology, fishing costs incurred by the fleet and detailed catch and effort data. MEY is determined through bioeconomic modeling, which assesses the impact of marginal (additional) catches on catch rates that can be achieved and then examines the additional cost incurred. In this sense, MEY is the point where the cost of taking an additional unit of catch is equal to the revenue derived from that unit of catch.

There are numerous difficulties with such an approach, such as the disparity of fishing costs and catch rates between vessels and fishing areas. If MEY can be determined for a fleet, it only remains true while the same mix of inputs (boats, fisher experience, operating capital etc) and outputs (catches or catch rates) exist. If these fundamentals change, the relationship between cost and catch will also vary. Similarly, if the cost structure of the fishery changes rapidly (such as through imposition or removal of government fees or rapid changes in a key input such as labour), then MEY will also change. Economic theory of supply and demand suggests that the revenue curve would eventually shift to match the revised cost structure, but in the meantime, fish will be harvested above or below MEY.

Determination of MEY-based reference points is particularly complicated in WCPO tuna fisheries by the different economic objectives that stakeholders have for the fishery. For example, it is reasonable to assume that vessel owners would be interested in the fishing scenario that allows them to achieve maximum efficiency in their financial returns. Similarly, a country with the sole interest of obtaining the highest possible access fees from the vessels it licenses would likely adopt this approach. In contrast, many Pacific Island Countries seek to obtain a range of wider economic benefits from fishing including maximum at sea and land based employment, onshore infrastructure investment, export opportunities or other value adding. In such circumstances the cost structure that should be used is varied (for example, if the aim is to maximise at sea employment, then wages on fishing vessels should be removed from the fishing cost curve as they are a benefit, not a cost). The incorporation of such “value added” components is an issue that has not been widely explored in bioeconomic modeling and is likely to require a fundamental shift due to the consideration of both at sea and on shore cost and revenue structures.

Calculation of MEY in a single species context may also be inappropriate for multi-species, multi-gear fisheries where achieving the best overall economic outcome may require trading off costs and benefits among fleets and/or species.

Notwithstanding these difficulties, emphasis on MEY-related reference points is increasing in recognition of the need for management arrangements that cater for profitability and capacity to pay access fees (resource rent). MEY has the associated benefit that it is almost always lower than MSY, thereby introducing a higher level of stock protection by default. One case where this may not be the case are multi-species fisheries, where *on economic grounds* it may be more optimal to overfish one species in order to maximise profitability from another. The availability of subsidies to some fishing fleets also changes the relationship between catch, effort, cost and profit and therefore impacts on the placement of MEY compared to MSY.

It should be noted that MEY is a concept that only relates to the fishery as a whole. Management measures provide the basis for maximizing profit at the individual level, but this obviously remains reliant on the way that each individual does business.

4.3 Indicators as ratios

Expressing an indicator as a ratio allows managers to assess the state of an indicator (whether it is B, F or any other indicator) against the reference point. Ratio indicators are usually expressed as the *status quo* divided by the reference point. For example, the ratio $F_{CURRENT}/F_{MSY}$ is used to assess current fishing mortality status against the F_{MSY} reference point.

A ratio of 1 means that the indicator is at the level prescribed by the reference point. Ratios higher or lower than 1 may be desirable or undesirable depending on the indicator being measured. For example if $F_{CURRENT}/F_{MSY}$ equals 1.2, current fishing mortality is 1.2 times (or 20% higher than) the fishing mortality that will result in MSY, meaning that this reference point is being breached. In contrast, however, if $B_{CURRENT}/B_{MSY}$ equals 1.2, it would mean that current biomass is 20% higher than the biomass that would support MSY, meaning that this reference point is not being breached.

The table below interprets various ratios. It should be noted that the relative status of a stock at given ratios of its reference point is largely driven by its biological characteristics. This information is generic and included as an example only.

Indicator	**Ref. Point**	**Ratio**	**Type of Ref. Point**	**Examples of Indicator Status**		
				Good	**Fair**	**Poor**
Fishing mortality	F_{MSY}	$F_{CURRENT}/F_{MSY}$	TRP	Below 1.0	1.1 – 1.2	Above 1.2
			LRP	Below 0.7	0.7 – 0.9	Above 0.9
	F_{MEY}	$F_{CURRENT}/F_{MEY}$	TRP	1.0 – 1.2	1.2 – 1.3	Above 1.3 or Below 1.0
Biomass	B_{MSY}	$B_{CURRENT}/B_{MSY}$	TRP	1.1 – 0.9	0.9 – 0.8	Below 0.8
			LRP	1.3 – 1.2	1.2 – 1.1	Below 1.1
	B_{MEY}	$B_{CURRENT}/B_{MEY}$	TRP	1.1 – 1.0	1.0 – 0.9	Below 0.9 or Above 1.1

The table above introduces the concept that maintaining a stock well above B_{MEY}, or having fishing mortality well below F_{MEY} is counter-productive, at least based on the components included in the economic model.

5 Selecting reference points

5.1 The conceptual context

In deciding on the reference points to be used in any given fishery, managers must first decide on the most appropriate indicator for the situation. Considerations when choosing the indicator include the fishery dependent and independent data that is available, reliability and sophistication of stock assessments, reliability and regularity of reporting, basis of the management regime and the ability of managers to implement and understand different indicators.

Using these factors, it is generally possible to identify one or more indicators that can be used to establish reference points. Establishing reference points under more than one indicator can provide additional security if there are concerns over the accuracy of measuring the indicator, for example multiple indicators are used for the WCPO tuna stock assessments (F, B and SB).

Example 3 – Species X does not have any reliable stock assessment information or fishery independent data. A long time series of operational catch and effort data is available, but there has been very little research into the biology of the species.

> Given the dearth of any "scientific" information, CPUE may be the best indicator for this species.

Example 4 – Species Y has a current stock assessment that produces reliable estimates of the Biomass trends. The fishery also collects reliable data on size and age at capture and numerous biological studies have been undertaken.

> In this case, more sophisticated indicators, such as F, B and SB could be used.

Once indicators have been chosen, the next requirement is to decide on the reference points for each indicator.

Historically, MSY based reference points (such as F_{MSY}, B_{MSY}, E_{MSY}) were considered appropriate as TRPs, however, with the greater emphasis on the principles of Ecologically Sustainable Development and the Precautionary Approach, this situation has changed over the past 10 years. One key driver of this change has been the greater ability to quantify uncertainty in fisheries science, which requires "buffers" around indicators as point estimates, i.e., defining risks associated with status estimates. Many stock assessments now report the probability of the indicator being below a reference point level, whereas previous assessments often reported only point estimates.

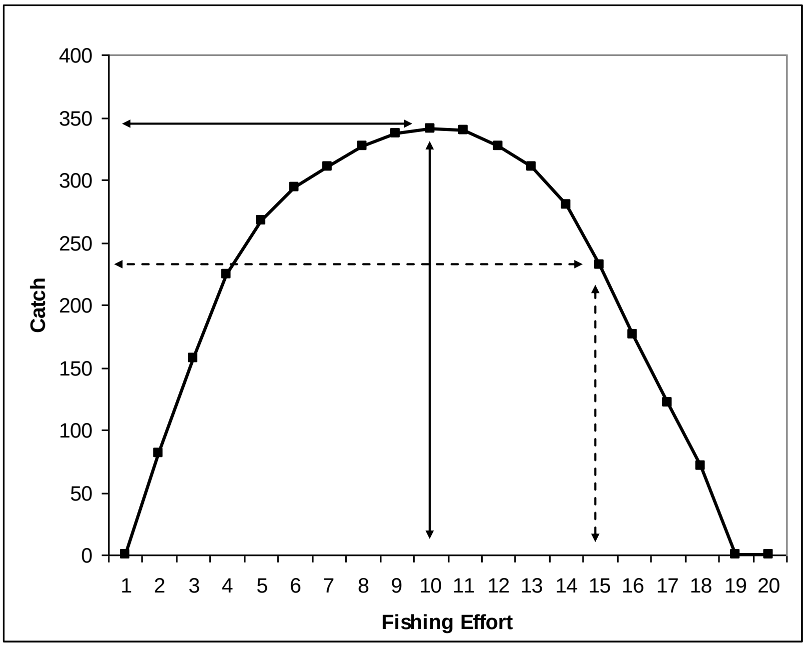
The greater influence of economic return considerations in fisheries management has also seen a shift of emphasis for TRPs towards MEY based measures (such as F_{MEY}, B_{MEY}, E_{MEY}), or other quantities that are proxies of MEY (such as 1.2 B_{MSY} or 0.8 F_{MSY}). There are cases, however where it can be argued that MSY-based TRPs are suitable. Fisheries with a heavy focus on food security as an objective are an example, although sound management would advocate the inclusion of buffers around the MSY-TRP to account for issues of risk and uncertainty as well as inter-annual variation.

Debate is ongoing as to where LRPs should be set. Best practice dictates that MSY based reference points should be used as minimum limits and there is some support for this in various international fisheries instruments (see section 5.3). In contrast, it has also been argued that in many circumstances, it is appropriate to have LRPs that are below MSY. This is particularly the case in deciding on single species reference points within a multi-species fishery.

It may be argued that fishing at a rate greater than F_{MSY}, or reducing biomass to less than B_{MSY} is not "unsustainable", if it is assumed that conditions are maintained at equilibrium. Diagram 2, shows a hypothetical yield curve for a given fishery. In theory, the yield at any point on the curve is sustainable if the conditions that maintain equilibrium are held constant.

"Equilibrium state" is the term used to describe a fishery that has been subject to constant external mortality and recruitment drivers for a period of time long enough to affect all age classes in the population. Because external drivers such as fishing mortality and oceanographic factors are both highly significant and highly variable in tuna stocks, true equilibrium state is rarely, if ever achieved.

Diagram 3 – Hypothetical equilibrium yield curve showing two different fishing scenarios



In this example, the fishing strategy resulting in MSY (and therefore also B_{MSY} and F_{MSY} in an equilibrium state) is shown via the solid arrows. For a constant fishing effort level of 10, a catch of almost 350 can be obtained (theoretically in perpetuity given equilibrium). An alternative strategy is shown via the dotted lines, where a constant effort level of 15 results in a long term catch of less than 250.

The alternate strategy is obviously high risk, as it is getting close to the area where even extremely large amounts of fishing effort will be unable to take any significant level of catch, and such a situation is indicative of a stock problem. Evidence from collapsed fisheries worldwide has shown that fishing down a fish stock to low levels is particularly risky because of natural variability from external and intrinsic factors (such as environmental effects on recruitment and multispecies interactions). Depleting stocks to low levels increases the variability of catches and exacerbates the impacts of natural periods of low recruitment in driving further, sometimes rapid, stock decline. The considerable uncertainty surrounding the behavior of fish stocks reduced to low levels and the non-equilibrium state of tuna fisheries further add to the risk of setting LRPs at extremely low levels. These issues all necessitate careful consideration of LRPs.

Notwithstanding, LRPs need not be based on some measure of MSY. The role of managers, informed by scientists, is to determine a harvest strategy (including setting LRPs) that ensures that the risk posed to the stock is within acceptable limits. This risk is usually discussed in terms of the likelihood of recruitment failure or the threat to the stock's ability to rebuild. Various LRPs have been used in fisheries that may be lower than MSY, including measures such as B_{20} or 0.5 B_{MSY}. The use of such points embraces the concept that LRPs are intended as a "fail-safe" to prevent significant stock harm.

The purpose of MSY as a fishing strategy is simply to maximise the yield, or fishery production. It is possible, and in many cases more appropriate, to use different quantities specifically designed around minimizing the risk of undesirable biological outcomes such as recruitment failure or a given level of stock depletion. The placement of such reference points varies form species to species, but would generally be lower than MSY and its associated reference points.

It should be noted that aside from being more risky than the MSY scenario, in most cases the alternate strategy above is also counter-productive, with high fishing costs for low economic returns and is generally to be avoided. In the example, a 50% increase in fishing effort (above E_{MSY}) has resulted in a 30% decrease in overall catch. As mentioned above, in multi-species fisheries, such inefficiency may be appropriate as a tradeoff to gain more optimal catches of another species provided biological considerations are still addressed in the placement of LRPs.

Stock Recruitment Relationships (SRRs) are an important consideration when deciding on LRPs. A SRR is a statistical relationship between the size of a stock (as a result of fishing and natural mortality) and the number of juvenile fish it can produce. It stands to reason that for every stock, there comes a point where the number of adult fish in the water is insufficient to produce enough recruits to sustain the population. Management Strategies (including the placement of LRPs and rules to respond to them) must be effective in ceasing fishing well before that point is reached.

Obviously, the SRR for each species is different, but they are generally very difficult to estimate. The scientific evidence available suggests that even in highly fecund broad-scale spawners like tuna, average recruitment is likely to be affected by low stock size and perhaps more importantly, recruitment is likely to become more variable at low stock sizes.

5.2 Reference points for multi-species fisheries

Multi-species fisheries complicate the selection of reference points. It is paramount that the overall sustainability of each species is ensured, but within these limits it is also important to ensure that the species mix is harvest optimally. This may require fishing some species at a “sub-optimal sustainable yield”, such as in the second example above, so that maximum benefit from the fishery overall can be obtained.

Because of the need to ensure sustainability, LRPs are identified for individual species from biological considerations. However, TRPs are not primarily biological, but reflect the benefits obtained from the fishery. Given the interactions among species and fleets in the WCPFC tuna fisheries, and the diverse management objectives of different stakeholders, identification of TRPs for either individual species or for the overall fishery may be difficult.

5.3 The legal context

As signatories to various international law instruments, WCPFC members, territories and cooperating non-members (CCMs) have an undeniable obligation to enact management arrangements that comply with the instruments and their intent. More importantly, there is there is also a direct economic incentive for coastal states to implement appropriate reference points and manage fisheries accordingly.

Provisions relating to reference points or overall management objectives that can be expressed as reference points are contained in The Law of the Sea Convention (UNCLOS), the United Nations Fish Stocks Agreement (UNFSA) and the WCPFC Convention. There is a degree of ambiguity and potential conflict both between and within some of these instruments that need to be balanced in implementation. Some of these provisions are discussed below and summarised in the table.

UNCLOS: Article 61 – Conservation of the living resources

Article 61 contains provisions that can be interpreted as setting both TRPs and LRPs.

Firstly, Article 61(2) places an onus on coastal states to ensure "…that the maintenance of the living resources in the exclusive economic zone is not endangered by overexploitation" and to cooperate with international organizations in this regard. The term "endangered" has been given specific meaning under other international instruments and relates to stocks/species that face a very high risk of extinction in the wild. Examples of reference points related to such management objectives are $B_{EXTINCT}$ (the minimum viable biomass before extinction) or $F_{EXTINCT}$ (the maximum fishing mortality before extinction). It should be noted that these are un-precautionary LRPs and are generally inadvisable, but are the minimum standard established under UNCLOS.

Secondly, Article 61(3) states that conservation and management measures should "…be designed to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield…". This sets B_{MSY} as a TRP for harvested stocks. Under equilibrium theory, the only way to achieve B_{MSY} is to fish at F_{MSY}.

Article 61(3) goes further to add socio economic and operational qualifications to the default application of MSY as a management objective. This suggests that there may be circumstances where TRPs may differ from B_{MSY}.

UNFSA: Annex II – Guidelines for the application of precautionary reference points in conservation and management of straddling fish stocks and highly migratory fish stocks

Annex II is probably the most explicit statement in international law about reference point selection and is also often quoted as the most stringent or precautionary. However, even within Annex II, there is uncertainty and potential conflict.

The bulk of Annex II advocates the use of MSY as minimum LRPs. This is most evident in paragraph 7: "The fishing mortality which generates maximum sustainable yield should be regarded as a minimum standard for limit reference point". However, the same paragraph also states "For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target".

Therefore, while there is an explicit statement that F_{MSY} should be a LRP, there are some cases in which B_{MSY} can be a TRP. Lastly, it should be noted that Annex II are "guidelines" and, while part of a binding agreement, rely heavily on words such as "should" when dealing with the setting of reference points.

WCPFC Convention: Article 5 – Principles and measures for conservation and management; and
Article 6 – Application of the precautionary approach

Article 5(b) states that the members of the Commission shall "ensure that such measures…are designed to maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors, including the special requirements of developing States in the Convention Area, particularly small island developing States, and taking into account fishing patterns, the interdependence of stocks and any generally recommended international minimum standards, whether subregional, regional or global…"

This wording closely reflects UNCLOS article 61(3) indicating that BMSY can be a TRP, but can be qualified according to various other factors.

In contrast, Article 6(a) states that members of the WCPFC will apply UNFSA Annex II, thereby advocating the application of F_{MSY} as a minimum LRP.

Summary

In summary therefore, while UNFSA provides guidance that F-based LRPs *should* be based on MSY, other international instruments[2] suggest that it is not necessary to have as a default position that LRPs must be based on some measure of MSY. The non-use of MSY as a LRP in any other RFMO (see next section) and in the domestic policies of some WCPFC members further supports this conclusion.

Instrument	Target Reference Point	Limit Reference Point
UNCLOS	B_{MSY} (but can be higher or lower)	$B_{EXTINCT}$, $F_{EXTINCT}$
UNFSA	B_{MSY} (for overfished stocks only)	F_{MSY}
WCPFC Convention	B_{MSY} (but can be higher or lower)	F_{MSY} (through reference to UNFSA)

6 Reference points in other RFMOs

Reference point management is advanced to different degrees in other RFMOs. The table below gives a brief summary of target and limit reference points used elsewhere (modified from Davies and Polacheck 2007). The obvious trend highlighted in this table is that no RFMO currently uses explicit MSY measures as LRPs. In contrast, at least three RFMOs do explicitly cite MSY as a TRP.

[2] Including UNCLOS, which was promulgated before UNFSA, and which UNFSA is subordinate to, and the WCPFC Convention, which is to be interpreted consistently to both UNCLOS and UNFSA.

	LIMIT REFERENCE POINTS	TARGET REFERENCE POINTS
Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	SSB_{20} Aim for probability of less than 10% of going below over 35 years	SSB_{50} or SSB_{75} Aim for median equal to this over 35 years
Commission for the Conservation of Southern Bluefin Tuna (CCSBT)	SSB in 2004	SSB in 1980
Inter-American Tropical Tuna Commission (IATTC)		F_{AMSY}, B_{AMSY} (old convention, but new convention includes precautionary approach)
International Commission for the Conservation of Atlantic Tunas (ICCAT)		F_{MSY}, B_{MSY}
Indian Ocean Tuna Commission (IOTC)		MSY, F_{MSY}

7 Harvest strategies

In simple terms, a harvest strategy is a set of pre-agreed management rules that will be applied in order to ensure that a given fishery continually seeks to achieve TRPs and avoid LRPs. Harvest strategies can vary in complexity, ranging from very simple decision trees to comprehensive, model based systems.

There are three fundamental components of a harvest strategy:

- Indicators and reference points;
- A means of monitoring status against the reference points and assessing performance against the indicators; and
- A set of "control rules" that dictate the action that is required in given circumstances and importantly, the associated timeframes for that action.

In terms of the control rules, a harvest strategy would not necessarily prescribe the type of management action that would be taken (for example, it would not be necessary to agree that if an issue was detected, there would be a certain reduction on one fleet/area over another). Rather, the harvest strategy simply sets out the magnitude of changes that must be made to the indicator and the timeframe within which they must be made. Discretion is retained by the managers to decide how that change should be achieved within the timeframe.

Similarly to the selection of reference points, control rules need to account for the uncertainty in fishery science and therefore act to ensure that reference points are achieved/avoided within acceptable probabilities, which also need to be determined by managers.

Example 5 – Single species harvest strategy – Species X

- Indicators: Fishing mortality and Spawning Biomass
- Reference Points:
  - TRP – F_{MEY} and SB_{50}
  - TrRP – F_{MSY} and SB_{35}
  - LRP – $1.3F_{MSY}$ and SB_{20}
- Monitoring – Stock assessment every two years based on fishery dependent (logbook) and fishery independent (survey) data.
- Control rules:
  - Management action must be implemented within 6 months of stock assessment (if required).
  - Management action required:
    - Both performance indicators above TRP – no action required
    - Either performance indicator between TrRP and TRP – reduce TAC to achieve TRP within 8 years.
    - Both performance indicators between TrRP and TRP – reduce TAC to achieve TRPs within 6 years.
    - Either performance indicator between LRP and TrRP – reduce TAC to achieve TrRP within 4 years.
    - Both performance indicators between LRP and TrRP – reduce TAC to achieve TrRPs within 2 years.
    - Either performance indicator below LRP – cease fishing for 2 years
    - Both performance indicators lie below LRP – cease fishing for 4 years.

This is obviously a hypothetical example and the timeframes and reference points are probably not applicable to the tuna fishery. In reality, the timeframes would be set according to the biology of the fish (how quickly a change in the stock status could occur), the stock assessment schedule and the management regime (how quickly management action could be implemented and enforced).

7.1 Selection of control rules

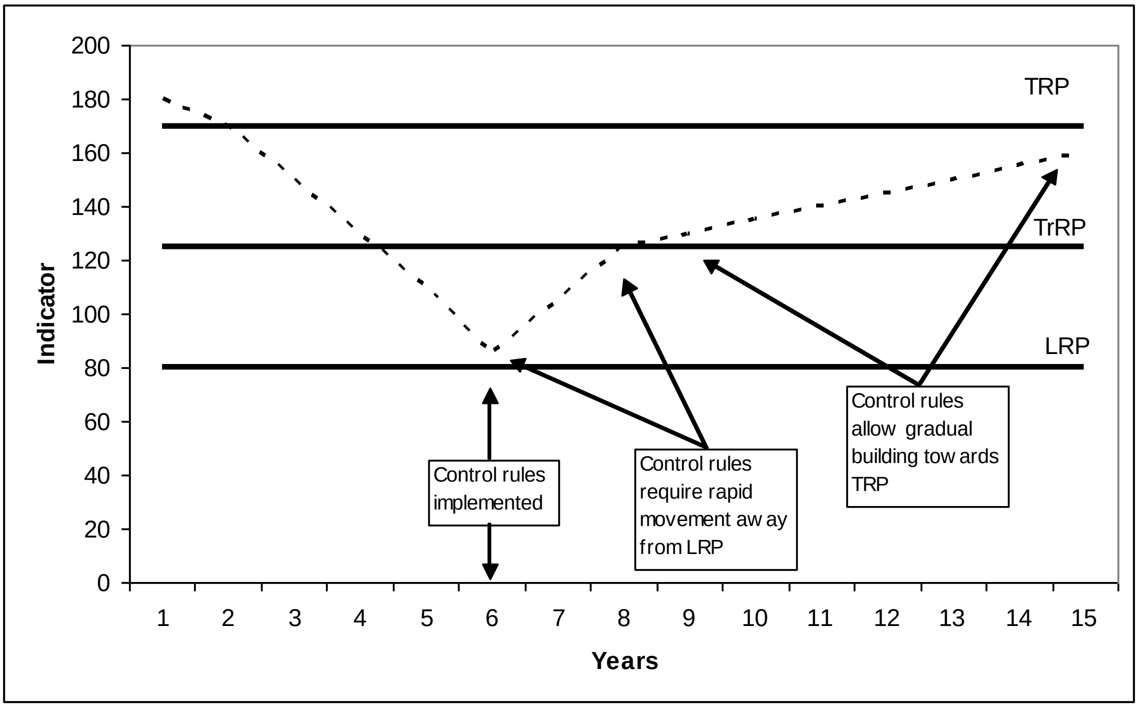
Selecting appropriate control rules is just as important as selecting appropriate reference points. For example, control rules that “over-react” very rapidly may result in unnecessary industry impacts. Conversely, control rules that do not require enough action are likely to result in failure to achieve/avoid relevant reference points. Such a situation can result in a “chase-down” pattern, where the TAC is continually reduced, but never sufficiently to address the stock decline.

Managers should have control rules in mind when they seek to implement reference points as the nature of the rules could play an important part in the acceptability of various reference points. For example, a highly precautionary TRP may be acceptable to stakeholders if there is acknowledgement that the control rules will seek to achieve it over a reasonable time period. If stakeholders perceive that the control rules will seek to achieve the TRP over a very short period, they are likely to seek a less precautionary target.

Control rules and monitoring procedures for the WCPO tuna fishery will be difficult to determine and the multi-species nature of the fishery also complicates the design of robust harvest strategies. Potential harvest strategies for the WCPO Tuna fishery as well as more sophisticated tools such as Management Strategy Evaluation to support management decisions will need to be actively considered by the WCPFC in the near future.

The use of different control rules depending on the state of the fishery compared to different reference points (as per Example 5 above) is often referred to as a "broken stick approach" and recognises that the immediate onus should be on moving away from the LRP. This reflects the fact that the LRP usually indicates an undesirable biological state whereas TRPs usually represent a desirable economic state, thereby allowing some flexibility in the approach taken to achieve it.

Diagram 4 – Hypothetical set of control rules showing the "broken stick" approach



7.2 Sub-regional monitoring and responses

Closely related to the design issues associated with control rules are the issues of differential impacts on each stock in sub-areas throughout the WCPO. That is, stock assessments have demonstrated that biomass is not distributed evenly throughout the region and that fishing mortality is significantly higher in some areas than in others. This is compounded by the fact that there is some degree of mixing between the sub-areas, meaning that extremely high fishing mortality in one area may be "subsidised" by low fishing mortality in a neighbouring area.

When designing harvest strategy frameworks, and specifically when considering management responses to potential issues, it may be necessary for the WCPFC to build-in a degree of sub-regional independence to ensure that management action is directed mainly at fisheries that require attention.

8 Conclusion

This paper provides reference material for the WCPFC in considering the application of reference points to WCPO tuna fisheries. While the paper does not advocate for or against any particular reference points, it does make the case that neither MSY-based LRPs nor MEY-based TRPs need to be implemented as a default position.

9 Reference material

There is a significant body of literature available on reference point based fishery management. This document discusses fundamental concepts that are an integral part of contemporary fisheries management. As such, very few specific references were used or cited in this work. Material that was reviewed or provides useful additional information is listed below.

Caddy, J.F., Mahon, R., 1995, *Reference Points for fisheries management*, FAO Fisheries Technical Paper No. 347.

Davies, C. and Polacheck, T. (2007) *A brief review of the precautionary approach and the role of target and limit reference points and Management Strategy Evaluation in the management of highly migratory fish stocks*. Commonwealth Scientific and Industrial Research Organisation

Department of Agriculture, Fisheries & Forestry, Australia (2007) *Commonwealth Fisheries Harvest Strategy, Policy and Guidelines.*

FAO Fisheries Glossary - http://www.fao.org/fi/glossary/default.asp

Hoyle, S., Langley, A. and Hampton, J. (2008) *Stock assessment of albacore tuna in the south Pacific Ocean*. Secretariat of the Pacific Community

Kompas, T. & Che, T. (2006) *Economic profit and optimal effort in the Western and Central Pacific tuna fisheries*. Australian National University

Kompas, T. & Grafton, Q. (2006) *Economic Profit and Total Allowable Catch in the Australian Albacore Fishery.* Australian National University

Langley, A., Hampton, J., Klieber, P. and Hoyle, S. (2008) *Stock assessment of bigeye tuna in the western and central Pacific Ocean, including an analysis of management options*. Secretariat of the Pacific Community

Langley, A., Hampton, J., Klieber, P. and Hoyle, S. (2007) *Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options*. Secretariat of the Pacific Community

Langley, A. and Hampton, J. (2008) *Stock assessment of skipjack tuna in the western and central Pacific Ocean*. Secretariat of the Pacific Community

Ministry of Fisheries (2008) *Harvest Strategy Standard for New Zealand Fisheries*

Williams, P. & Terawasi, P. (2008) *Overview of tuna fisheries in the western and central Pacific Ocean, including economic conditions – 2007*. Secretariat of the Pacific Community and Forum Fisheries Agency