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REFERENCE POINTS, DECISION RULES, AND MANAGEMENT STRATEGY EVALUATION FOR TUNAS AND ASSOCIATED SPECIES IN THE EASTERN PACIFIC OCEAN

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1. INTRODUCTION

The Antigua Convention commits the IATTC to applying the precautionary approach, in accordance with the United Nations Fish Stocks Agreement (UNFSA):

> "The members of the Commission, directly and through the Commission, shall apply the precautionary approach, as described in the relevant provisions of the Code of Conduct and/or the 1995 UN Fish Stocks Agreement, for the conservation, management and sustainable use of fish stocks covered by this Convention." (Article IV of the Antigua Convention).

The UNFSA states that reference points:

> "Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives." (Annex II of the United Nations Fish Stocks Agreement (UNFSA 1995))

and decision rules should be used:

> "Such reference points shall be used to trigger pre-agreed conservation and management action." (Annex II UNFSA 1995)

The UNFSA further defines how reference points should be used in decision rules:

> "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average." (Annex II UNFSA 1995)

The UNFSA provides minimum standards for some reference points:

> "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points." (Annex II UNFSA 1995)

and decision rules:

> "For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield" (Annex II UNFSA 1995)

Both the UNFSA and the Antigua Convention explicitly state that the amount of uncertainty should be taken into consideration when taking management action, and therefore it should be part of the decision rule:

> "In particular, the members of the Commission shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures." (Article IV of the Antigua Convention)

Reference points and decision rules have become a common part of fisheries management worldwide, but there is a large amount of variation among the different management agencies. The IATTC has historically used an informal decision rule that is based on adjusting effort to correspond to a fishing mortality that produces maximum sustainable yield (F_{MSY}), implying that F_{MSY} is a target reference point (TRP). This is inconsistent with the precautionary approach, which states that F_{MSY} is a limit reference point (LRP), and LRPs should have a low probability of being exceeded. Given the uncertainty in assessing a stocks status and the natural variability of stocks and fisheries, a strict interpretation of a LRP invalidates F_{MSY} as a TRP. The spawning biomass corresponding to maximum sustainable yield (B_{MSY}) has also been used as an informal reference point, but it is not clear if B_{MSY} has been used as a target or a limit reference point. These informal reference points are based on the original IATTC Convention of 1949, which states that the goal of management is to maintain stocks at levels that support maximum sustainable yield:

> "… to facilitate maintaining the populations of these fishes at a level which will permit maximum sustained catches year after year …" (1949 IATTC Convention)

> "Recommend from time to time, on the basis of scientific investigations, proposals for joint action by the High Contracting Parties designed to keep the populations of fishes covered by this Convention at those levels of abundance which will permit the maximum sustained catch." (1949 IATTC Convention)

One interpretation of the 1949 Convention is that the biomass must be at or above B_{MSY} otherwise MSY cannot be taken. One complication of the use of MSY in the tuna fisheries of the eastern Pacific Ocean is that MSY quantities are sensitive to the age of the fish that are captured, which has changed over time as the methods used to catch tuna have changed (Maunder 2002).

MSY may not necessarily be the desired management goal and reference points and decision rules should be tailored to the management goal(s). The precautionary approach considers MSY-based reference points as limits, which implies that managing the stock below B_{MSY} or with fishing mortalities higher than F_{MSY} is not desirable. However, a stock can be managed sustainably below B_{MSY} and with fishing mortalities above F_{MSY} and there have been many stocks that have a long sustainable history at these levels. The catch levels may be lower than optimal because of suboptimal yield per recruit or reduced recruitment, but they are still sustainable, although with a theoretically higher probability of collapse, and may satisfy other societal goals (*e.g.* high catches of other species, as in the case of skipjack harvested in sets on fish-aggregating devices (FADs) that also catch bigeye and yellowfin tuna).

The implementation of the Antigua Convention and the commitment to the precautionary approach requires the formal use of reference points and decision rules by the IATTC for management of tuna and associated species in the EPO. The choice of appropriate reference points and decision rules requires detailed evaluation through management strategy evaluation (MSE), while remaining within the constraints of the precautionary approach. MSE is a well-developed approach in fisheries science (Butterworth *et al.* 1997; De Oliveira *et al*. 1998; Butterworth and Punt 1999), but requires a significant amount of staff time and computational resources to carry out. In this document we present alternative reference points and decision rules that could be included in future MSE work.

2. REFERENCE POINTS

Reference points are generally categorized by the type of reference point (target or limit) and the quantity that they measure (biomass or fishing mortality). In general, LRPs indicate states that management does not wish to exceed due to possible undesirable consequences and TRPs indicate states that management wishes to obtain to maximize benefits from the fishery. Alternative quantities to biomass and fishing mortality can and have been used for reference points, but their use is uncommon. The precautionary approach states that "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low", indicating that LRPs should be substantially different from TRPs given the typical uncertainty in estimating fish stock status and the variability in fish populations and fisheries. Given that the precautionary approach states that "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points", any LRP based on fishing mortality should be at most F_{MSY}, and the TRP lower than F_{MSY}. By analogy (and since F_{MSY} and B_{MSY} are linked in equilibrium in such a way that, if F_{MSY} cannot be a target, neither can B_{MSY}), but not explicitly stated in the precautionary approach, any biomass-based LRP should be at least B_{MSY}, and the TRP should be considerably higher than B_{MSY}. This implies that in general fishing is carried out at a level (possibly substantially) below MSY, and that MSY can only be obtained if uncertainty is negligible, which is consistent with the intent of the precautionary approach. It also suggests that TRPs should be defined based on the assessment uncertainty, so that, as the assessment uncertainty reduces, the TRP should get closer to the LRP.

The calculation of MSY and the associated reference points requires knowledge of several biological (*e.g.* growth, natural mortality, stock-recruitment relationship) and fishery (*e.g.* selectivity) related quantities. For many stocks, some of these quantities are not available, and managers use proxy reference points (Clark 1991, 1993, 2002). In particular, the stock-recruitment relationship is difficult to estimate, and precautionary reference points based on spawner per recruit (SPR) are used. These proxies are designed to work in a precautionary sense for a range of life histories, and do not require knowledge of the stock-recruitment relationship. An alternative approach is to estimate the MSY based quantities assuming a precautionary value for the steepness of the stock-recruitment relationship. Zhu *et al*. (2012) showed that, due to the yield curve being flat when steepness is high, the risk of loss in equilibrium yield is lower if steepness is under-estimated rather than over-estimated. However, there may be loss in short-term yield if fishing mortality has to be reduced.

For some stocks, the absolute level of the population size and fishing mortality is difficult to estimate and standard reference points are not appropriate. In this case, reference points based on historical biomass or fishing mortality levels may provide LRPs based on the assumption that those levels occurred in the past and the population remained sustainable, but the outcome is unknown if they are exceeded.

Several reference points are described in Table 1.

3. DECISION RULES

A decision rule specifies the action that is taken given the current status of the fishery. Decision rules can be as simple as taking a constant proportion of the population to more complex rules such as those that accelerate rebuilding when the population is overfished. Decision rules can control several different quantities (*e.g.* fishing mortality, catch), which may relate to other quantities that are more practical to implement (*e.g.* effort, landings). A common decision rule is fishing mortality as a function of biomass, using biomass-based reference points to control changes in the fishing mortality. Figure 1 illustrates such a decision rule, where the fishing mortality is reduced linearly with biomass when the stock is below the biomass-based TRP and fishing ceases when the biomass is below the biomass-based LRP.

The minimum standards outlined in the precautionary approach can be used to define a decision rule based on the following guidelines:

1. B_{MSY} should be considered a limit;

2. The risk of exceeding the limit reference point should be very low;
3. Fishing mortality should not exceed F_{MSY}.

Interpreting these guidelines, B_{MSY} should be the LRP, the TRP should be above B_{MSY} so that the probability of falling below the LRP is low (*e.g*. use the upper x% of the confidence interval (CI) on B_{MSY}), fishing mortality should equal F_{MSY} above the TRP The choices that need to be made are x%, the fishing mortality at the LRP, and the fishing mortality below the LRP. If the LRP is B_{MSY}, it is unreasonable to cease fishing when the stock is below B_{MSY}, so a simple assumption could be that fishing mortality declines linearly to zero below the L RP. This decision rule is shown in Figure 2. Another option could be that fishing mortality is set to zero at the lowest historical biomass.

A simple rule could be to set the fishing mortality rate at a precautionary level (*e.g*. $F_{MSYx\%}$ or $F_{MSYh=x}$) independent of the biomass level. If a population is depleted below B_{MSY} and fishing remains at F_{MSY}, theoretically the population will rebuild back to B_{MSY}. If F_{MSY} is replaced with a precautionary value, then the population will rebuild faster than if F_{MSY} is used, assuming no estimation or implementation error. The precautionary approach allows for the fishing mortality to be equal to F_{MSY} if the population is above the limit reference point. However, if B_{MSY} is the LRP, this would not result in a low probability of exceeding the LRP. If $F_{MSYx\%}$ is used, then the fishing mortality would get closer to F_{MSY} as the uncertainty is reduced (*e.g*. due to improved data). The presence of a flat yield curve may result in inefficient (low catch-per-unit-of-effort) fishing mortality rates as they approach F_{MSY}, so a target fishing mortality more consistent with management objectives may be desirable as the uncertainty is reduced.

4. OTHER CONSIDERATIONS

Reference points and decision rules are related to the Kobe Plot. The Kobe Plot (see Maunder 2012) represents the status of the stock in terms of biomass (x-axis) and fishing mortality (y-axis). The plot is divided into quadrants based on biomass and fishing mortality corresponding to MSY. The lower right quadrant is the desirable status of the stock implying that the MSY-based reference points are limit reference points with management action occurring if the stock is not in this quadrant.

Many reference points are dependent on the age-specific selectivity of the fisheries (Maunder 2002). If the selectivity changes (*e.g*. if there are multiple fisheries with different selectivities and the allocation of effort among gears change) then the reference point will also change.

Reference points and decision rules are generally developed for a single species. However, most fisheries capture multiple species. This complicates the use of reference points and decision rules because they will differ among species as will the status of each species. Strict application of the precautionary approach may severely constrain catch of some target species due to catch of other species.

4.1. Management strategy evaluation

Management Strategy Evaluation (MSE) is a comprehensive approach to evaluating decision rules (Butterworth *et al*. 1997; De Oliveira *et al*. 1998; Butterworth and Punt 1999). Simulation analysis is used to test the performance of a complete management system under different possible states of nature. The management system includes the data that are collected, the method used to analyze the data, and the decision rule used to determine the management action. This means that MSE takes into consideration the uncertainty of estimating the population status and the reference points. The Kobe matrix (see Maunder 2012) is a form of MSE in which performance measures (such as the probability that a stock remains above LRP) are evaluated in a probabilistic setting (taking into account possible states of nature) under a range of alternative decision rules (such as level of fishing effort). The Kobe matrix differs from a traditional decision table in that it presents strategies that produce a set of prescribed probabilities of exceeding a LRP rather than the probability of exceeding a LRP (in this case) for prescribed management strategies. Therefore, the Kobe matrix is more complicated to calculate and difficult to fit into the decision rule framework.

5. DISCUSSION

The Antigua Convention commits the IATTC to apply the precautionary approach, in accordance with the United Nations Fish Stocks Agreement (UNFSA), which requires the use of reference points and decision rules. It also puts several constraints on the construction of the reference points and decision rules. These constraints may not necessarily be desirable and may be too precautionary, particularly when managing multiple species. Comprehensive management strategy evaluation should be used to identify the most appropriate reference points and decision rules. However, candidate reference points and decision rules need to be chosen before the MSE can be conducted. These candidates need to address the exploitive and sustainability considerations of the fishery. Many aspects of the decision rules are arbitrary (*e.g.* the x's in $B_{x\%}$, $B_{MSYh=x}$, $B_{MSYx\%}$) and it is not possible to make objective decisions about these aspects based on scientific information alone. Therefore, managers need to decide what candidate decision rules they consider reasonable and the criteria that should be used to evaluate them within a MSE.

To encourage the development of a set of candidate decision rules we provide some suggestions based on the decision rule illustrated in Figure 2. Following the precautionary approach, the LRP = B_{MSY} and the fishing mortality above the TRP is F_{MSY}. The alternatives are the a) TRP, b) fishing mortality at the LRP, and c) biomass when the fishing mortality is zero. Alternative candidates could be simple rules based on using the values for F_{LRP} for all biomass levels.

Quantity	Candidate	Description
TRP	$B_{MSY,h=0.75}$	B_{MSY} calculated with steepness of the stock-recruitment relationship set at 0.75
	$B_{MSY,20\%}$	The 20% percentile of the confidence interval of B_{MSY}
	$B_{MSY,F=0.9FMSY}$	Equilibrium biomass calculated fishing at 90% of F_{MSY}
F_{LRP}	$F_{MSY,h=0.75}$	F_{MSY} calculated with steepness of the stock-recruitment relationship set at 0.75
	$F_{MSY,20\%}$	The 20% percentile of the confidence interval of F_{MSY}
	$0.9F_{MSY}$	F_{MSY} multiplied by 0.9
$B_{F=0}$	0	Biomass is equal to zero
	B_{min}	The lowest observed biomass

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TABLE 1. Candidate reference points.
TABLA 1. Candidatos de puntos de referencia.

Ref. point	Limit/Target	Quantity	Description
F_{MSY}	Limit	*F*	*F* that corresponds to MSY
B_{MSY}	Limit	*B*	*F* that corresponds to MSY
$SPR_{x\%}$	Target/Limit	*B*	*B* that corresponds to $SPR/SPR_{F=0}$ = x
$F_{SPRx\%}$	Target/Limit	*B*	*F* that corresponds to $SPR/SPR_{F=0}$ = x
$B_{MSYx\%}$	Target	*B*	The (upper) x% of the CI for *B* that corresponds to MSY
$F_{MSYx\%}$	Target	*F*	The (lower) x% of the CI for *F* that corresponds to MSY
$B_{x\%}$	Limit	*B*	The (lower) x percentile of the historic biomass estimates
$F_{x\%}$	Limit	*F*	The (upper) x percentile of the historic fishing mortality estimates
$B_{MSYh=x}$	Target	*B*	The biomass corresponding to MSY when steepness of the stock-recruitment relationship is set at a precautionary level
$F_{MSYh=x}$	Target	*F*	The fishing mortality corresponding to MSY when steepness of the stock-recruitment relationship is set at a precautionary level

Punto de referencia	Límite /Objetivo	Cantidad	Descripción
F_{RMS}	Límite	*F*	*F* correspondiente al RMS
B_{RMS}	Límite	*B*	*F* correspondiente al RMS
$SPR_{x\%}$	Objetivo/ Límite	*B*	*B* correspondiente al $RPR/SPR_{F=0}$ = x
$F_{SPRx\%}$	Objetivo/ Límite	*B*	*F* correspondiente al $RPR/SPR_{F=0}$ = x
$B_{RMSx\%}$	Objetivo	*B*	El x% (superior) del IC para *B* correspondiente al RMS
$F_{RMSx\%}$	Objetivo	*F*	El x% (inferior) del IC para *F* correspondiente al RMS
$B_{x\%}$	Límite	*B*	El percentil x (inferior) de las estimaciones de biomasa histórica
$F_{x\%}$	Límite	*F*	El percentil x (superior) de las estimaciones de biomasa histórica
$B_{RMSh=x}$	Objetivo	*B*	La biomasa correspondiente al RMS cuando se fija la inclinación de la relación población-reclutamiento en un valor precautorio
$F_{RMSh=x}$	Objetivo	*F*	La mortalidad por pesca correspondiente al RMS cuando se fija la inclinación de la relación población-reclutamiento en un valor precautorio

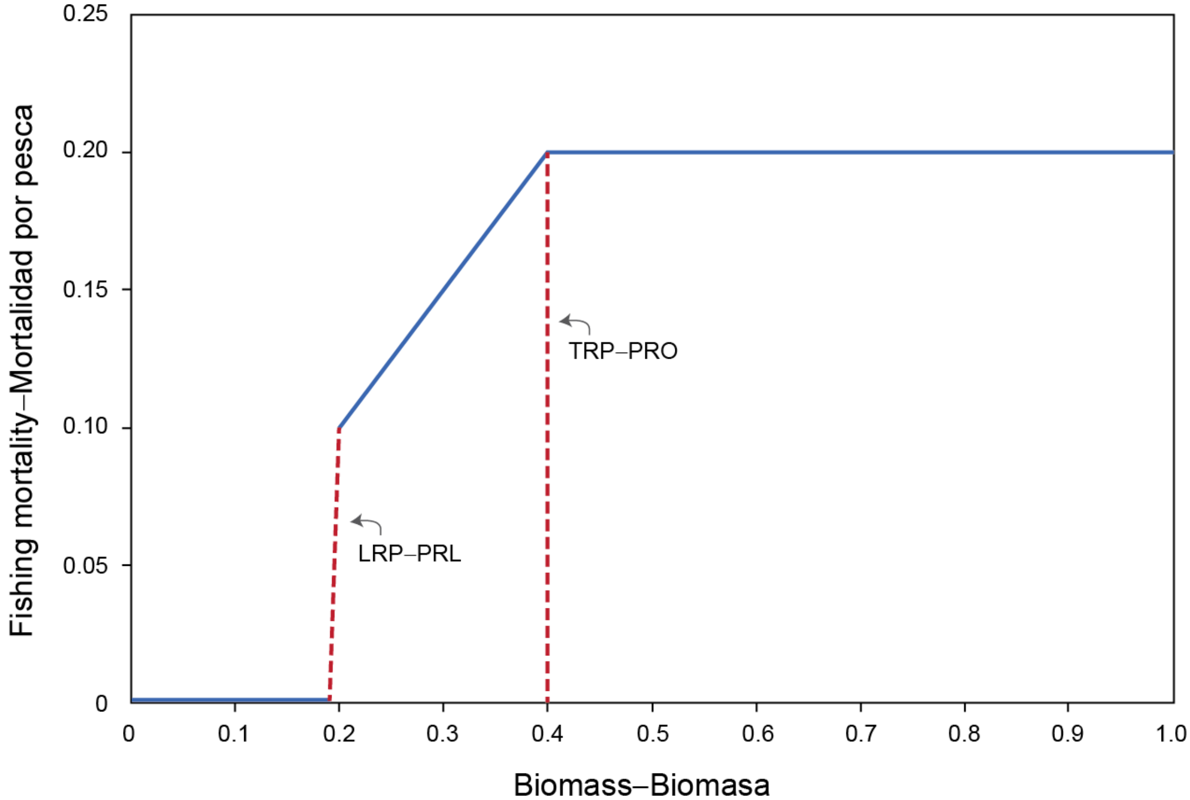

FIGURE 1. Example decision rule that accelerates the rebuilding of the stock when the biomass is below the biomass based TRP and ceases fishing if the biomass is below the biomass-based limit reference points.

FIGURA 1. Ejemplo de regla de decisión que acelera la reconstrucción de la población cuando la biomasa está por debajo del PRO y la pesca cesa si la biomasa está por debajo a los puntos de referencia límite basados en biomasa.

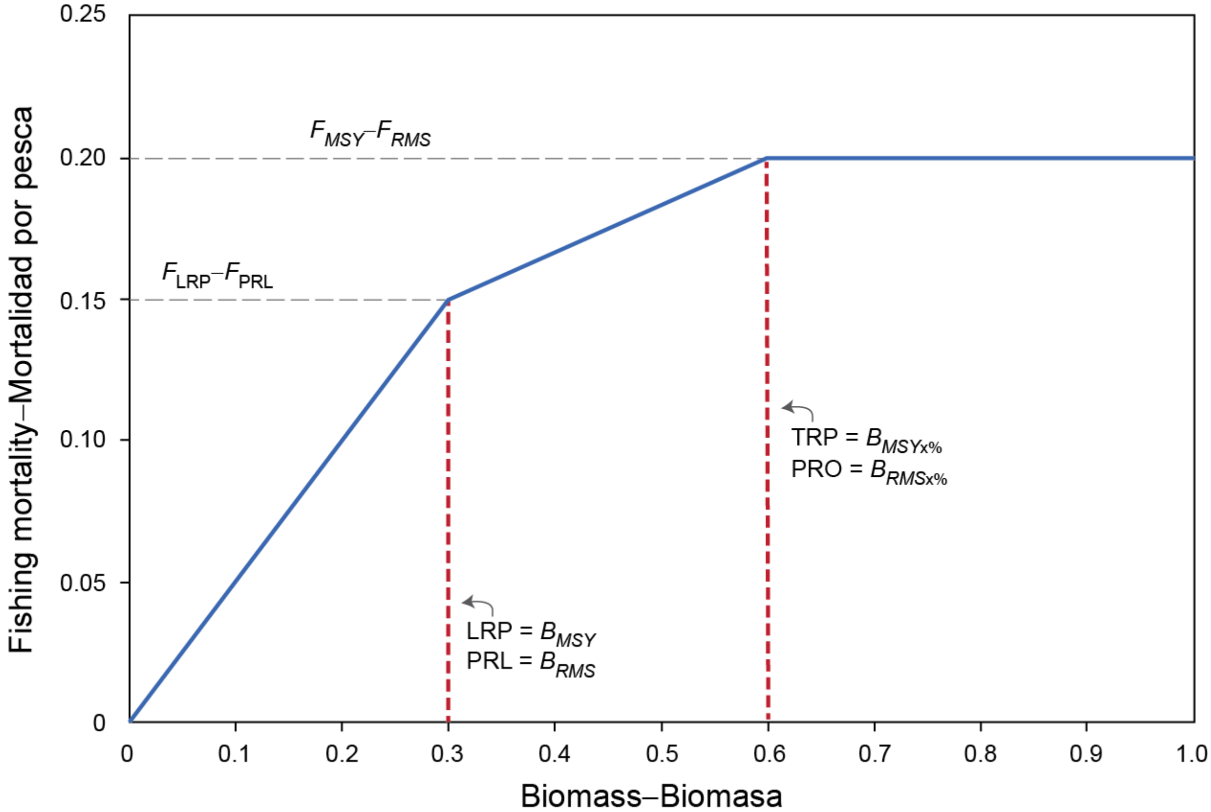

FIGURE 2. Decision rule based on the precautionary approach guidelines. F_{LRP} is the fishing mortality rate at the LRP. $B_{MSYx\%}$ is the (upper) x% of the confidence interval on B_{MSY}.
FIGURA 2. Reglas de decisión basada en las directrices del criterio de precaución. F_{LRP} esta tasa de mortalidad por pesca en el PRL. $B_{RMSx\%}$ es el x% (superior) del intervalo de confianza en B_{RMS}.