INTER-AMERICAN TROPICAL TUNA COMMISSION

WORKSHOP ON REFERENCE POINTS FOR TUNAS AND BILLFISHES

La Jolla, California (USA)
27-29 October 2003

REPORT

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1. Participants

1. Introduction

The IATTC holds an annual mid-year technical workshop on a topic that is of significant importance to the stock assessment of tunas and billfish in the eastern Pacific Ocean (EPO). The topic of the meeting arises from research needs identified in the annual scientific review. In the previous year, the technical workshop addressed the diagnostic requirements for highly-parameterized models such as those used for assessing tunas in the EPO and western-central Pacific Ocean (WCPO) by the IATTC and SPC, respectively. The results of this meeting were used for the assessments of bigeye and yellowfin tuna in the EPO during 2003.

The IATTC has developed several reference points over the last few years, and presents these in its annual Stock Assessment Reports. Reference points are also used by most agencies involved in the management and assessment of tunas and billfishes. However, reference points are less well developed for tunas and billfishes than for many other species. In addition, management of world fisheries is trending toward a greater use of reference points. Therefore, it was decided at the IATTC stock assessment review meeting that a mid-year technical workshop on reference points for tunas and billfishes would be of benefit to the assessment and management of these species.

The meeting was organized to provide an opportunity for both presentations and discussions. The presentations were divided into 1) those describing the objectives of organizations and their use of reference points, and 2) those describing research on reference points. In addition, there were presentations on multi-species and ecosystem reference points and management strategy evaluation. A large amount of time was devoted to discussions. The final section of the meeting was used to develop recommendations for reference points for tunas and billfishes in general and specifically for the IATTC.

2. Reports on management objectives and use of reference points

2.1. Inter-American Tropical Tuna Commission (IATTC, R. Allen and M. Maunder)

The 1949 Convention of the IATTC provides the formal management objective for the Commission, which is to keep the populations of fish at levels that will provide the maximum sustainable catch. The species specifically mentioned in the Convention are yellowfin, skipjack, baitfishes, "and other kinds of fish taken by tuna fishing vessels." It is understood that both natural factors and human activities affect the abundance of fish populations.

While this is not a full ecosystem approach, it is a long way beyond what might have been thought of as a mid-twentieth century single-species approach to fisheries management. The management goal ("to keep the populations of fishes covered by this Convention at those levels of abundance which will permit the maximum sustained catch") can be used to define a reference point, which could be seen as either a limit or a target reference point.

While the 1949 Convention provides the formal objectives, the new "Antigua Convention" gives a current perspective on the thinking of the member countries. The management objectives of the Antigua Convention are more specific than those the 1949 Convention, but do not contradict the earlier ones, so it is appropriate to take account of its provisions in thinking about reference points. The Antigua Convention preserves the general objective of maintaining populations of harvested species at levels that can produce the maximum sustainable yield (MSY).

Some of the key new points are:

- Application of the precautionary approach;
- A different objective for species belonging to the same ecosystem;
- A specific reference to measures to prevent excess fishing capacity.

The IATTC considers several reference points and related quantities in its annual Stock Assessment

Reports. Reference points are generally more developed for the main tuna species (yellowfin and bigeye), but are also presented for several species of billfish.

Spawning biomass ratio (SBR) is the ratio of the spawning biomass to the average spawning biomass in the absence of fishing. This quantity is compared to the SBR required to produce the maximum sustainable yield (SBR_{MSY}). SBR is also a quantity that is presented in future projections. The estimates of SBR and its relation to SBR_{MSY} have changed among the assessments due to changes in values used for growth, steepness of the stock-recruitment relationship, fecundity, and values of the age-specific fishing mortality rate.

MSY is calculated based on the current age-specific fishing mortality. It is also calculated using the age-specific fishing mortality based on a single fishery, allowing the comparison of the efficiency of each fishing method in respect to maximum yields. The associated SBR is also presented. MSY and SBR are also calculated for two different productivity regimes for yellowfin tuna.

Plots of the biomass trajectory are compared to plots of the biomass that would have been expected if no fishing had occurred. These plots show the depletion level, while taking into consideration the time trajectory of recruitment, and may be more informative than comparisons to equilibrium unexploited biomass, as used in SBR.

The critical age is a theoretical concept that maximizes the yield from a cohort that would result from removing all the individuals at a single age. The weight corresponding to critical age is compared to the average weight in the total catch and the average weight in each fishery, as predicted by the stock assessment model. The weight corresponding to the critical age may provide information on the status of the stock and the efficiency of the different fishing methods with respect to maximizing yields.

The lifetime reproductive potential for each age class is calculated to give an indication of the effect of each fishing method on the spawning potential of the population. The calculation is based on both a marginal change in numbers and a marginal change in weight to reflect the difference a fish of each age contributes to the catch due to differences in weight.

MSY_{ref} which is an approximation of the global MSY, is calculated as the highest sustainable yield when capturing only fish at a single age. It is calculated to illustrate the potential yields from the stock and to provide a measure of the efficiency of each fishing method with respect to maximizing yield. SBR_{ref} is the SBR associated with MSY_{ref}.

Retrospective analysis is used to show that estimates of current SBR are highly uncertain. Sensitivity analyses, particularly to the steepness of the stock-recruitment relationship, are used to show the sensitivity of the reference points and indicators.

2.2. International Commission for the Conservation of Atlantic Tunas (ICCAT, V. Restrepo)

The ICCAT Convention specifies as one of its objectives the "maintenance of the populations ... at levels which will permit the maximum sustainable catch and which will ensure the effective exploitation of these fishes in a manner consistent with this catch." Thus, the implicit target is a biomass around the biomass corresponding to MSY (B_{MSY}) and/or the fishing mortality corresponding to MSY (F_{MSY}). In practice, ICCAT has mandated rebuilding plans for several overfished stocks; in these cases, the target has been to reach B_{MSY} by a given year with a probability of 50% or greater.

ICCAT assessment working groups thus attempt to estimate B_{MSY}- and F_{MSY}-related benchmarks (or proxies) with a variety of methods. More attention is paid to ratio statistics (*e.g.* B_t/B_{MSY}, where B_t is the biomass at time t), than to absolute quantities. Traditional production models are used primarily, followed by a variety of age-structured analyses. In terms of expressing uncertainty in these estimates, common statistical procedures, such as bootstrapping, are used. However, a variety of results may be taken into consideration together when communicating uncertainty to the Commission.

The guidelines for limits and targets in the 1995 UN Fish Stocks Agreement are potentially in conflict with ICCAT's implicit F_{MSY} target. ICCAT scientists have recommended that management control rules that define both limits and targets be identified and evaluated for various stocks. It has been recommended that the specification of alternatives be made jointly by scientists and managers and that the evaluations be carried out with simulation studies.

2.3. Secretariat of the Pacific Community (SPC, J. Hampton)

The Western and Central Pacific Fisheries Convention requires the use of reference points in developing scientific advice and the precautionary approach for designing and implementing management measures. Key guidance from the Convention is the objective to "… maintain or restore stocks at levels capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors …". This indicates that MSY-based reference points – B_{MSY} and F_{MSY} – will be strongly featured in future management advice to the WCPF Commission. The adoption of the precautionary approach will possibly mean that target reference points will be set such that there is a reasonably small probability of the limit reference point being exceeded. In addition to the above, the Convention also requires that "… members of the Commission shall … ensure long-term sustainability of highly migratory fish stocks in the Convention Area and promote the objective of their optimum utilization." This implies that there will be a need to at least monitor variables such as yield per recruit and average weight in relation to critical weight, so that advice with respect to optimum utilization can be provided.

In recent years, stock assessments conducted by the SPC Oceanic Fisheries Programme have attempted to incorporate some of these ideas in advance of the Commission coming into effect. The assessments use the MULTIFAN-CL approach, and integrate Beverton and Holt stock-recruitment parameter estimation and yield estimation into the model. MSY and associated *B*- and *F*-based reference points are estimated conditioned on assumptions regarding stock-recruitment steepness and the overall age-specific selectivity of the combined fisheries. Confidence intervals for the ratios of B_{current} to B_{MSY} and F_{current} to F_{MSY} are estimated using both likelihood profile and normal approximation.

2.4. U.S. National Marine Fisheries Service (NMFS)

2.4.1. Pacific Islands Fisheries Science Center (PIFSC, P. Kleiber)

The management objectives of the U.S. National Marine Fisheries Service (NMFS) in the Pacific islands region are governed, as in other regions, by the the 1996 version of the Magnuson-Stevens Fishery Conservation and Management Act (M-SFCMA), with modifications in accordance with the Endangered Species Act and the Marine Mammal Protection Act. The overarching objective defined by the M-SFCMA is to manage fishery resources "for the greatest benefit of the Nation." Specific exhortations are embodied in "National Standards 1" (NS1) of the M-SFCMA. These include achieving an "optimum yield" on a "continuing basis" while preventing overfishing and keeping resource stocks out of an overfished state.

To comply with requirements of the NS1, NMFS created a set of guidelines to help refine under various circumstances the concepts of optimum yield, overfishing, and overfished state and to define rules for examining the situation of a fish stock with respect to those concepts and to rules for management action whenever the situation needs to be changed. Unfortunately, NS1, and the guidelines in particular, have not fit well with the nature, particularly the international nature, of the pelagic fishes and fisheries in the Pacific Island region, with the result that the Western Pacific Regional Fishery Management Council (WPRFMC) has found it difficult to promulgate rules that pass muster with the guidelines. Eventually, the WPRFMC adopted the approach behind the rules already approved for the U.S. east coast pelagic fisheries, which are also embedded in an international situation. The new preferred rules for the Pacific Island region have now been accepted.

Meanwhile, it appears that other regions have also had difficulty in conforming to the guidelines, and in February 2003 NMFS proposed a new set of NS1 guidelines to ameliorate some of the problems. The new guidelines are controversial, and have not yet been formally adopted. Predictably, non government organizations (NGOs) argue that the guidelines should, if anything, promulgate stricter rules, while industry argues for guidelines producing more relaxed rules.

Research on reference points and control rules has not been conducted by the WPRFMC or PIFSC. However, outside the hurly-burly and contention of determining acceptable reference point rules and guidelines thereto, PIFSC scientists have been collaborating with other regional and international institutions in the Pacific to conduct stock assessments and develop stock assessment methodologies. This, after all, is where information on status of fish and fisheries is gleaned from fishery and other data, regardless of whether that status information is then viewed through the prism of reference point rules. This work is not without controversy either, but it deals with more fundamental, or more cogent, questions such as whether there has been a true trend in recruitment or "regime shift" with possible implications for the long-term sustainability of current harvest levels.

2.4.2. Southwest Fisheries Science Center (SWFSC, P. Crone)

The Pacific Fishery Management Council (PFMC) serves as one of eight regional fishery Councils of the NMFS. The PFMC's jurisdiction is largely the Exclusive Economic Zone off the west coast of the continental United States. Each Council is mandated by law to adhere generally to stipulations of the M-SFCMA and, in particular, to technical guidance documented in NS1 of the legislative act. In general, management approaches are founded on MSY theory and application and, more recently, the concept of "optimum yield" (OY), which are folded into formal Fishery Management Plans (FMPs). Optimum exploitation strategies inherently consider "precautionary" principles and essentially, define target levels more conservative than those recommended in MSY-based approaches, *e.g.*, 0.75(F_{MSY}).

Species managed under the auspices of the PFMC fall generally under four broad assemblage classifications, namely coastal pelagic stocks (*e.g.*, sardine, mackerel, squid, *etc*.), highly-migratory stocks (*e.g.*, tunas, billfishes, sharks, *etc*.), groundfish stocks (*e.g.*, rockfishes, flatfishes, *etc*.), and salmon stocks (*e.g.*, Pacific Northwest and coastal California salmon populations). The biological reference points (BRPs) and harvest control rules (HCRs) for two of these species groups were discussed: coastal pelagic stocks (Pacific sardine); and highly-migratory stocks (North Pacific albacore).

For Pacific sardine, a unique HCR has been established that incorporates various BRPs, including an exploitation fraction based on an oceanographic parameter (sea-surface temperature, T) that is related to F_{MSY}, and to estimates for current stock size (B_t), minimum biomass threshold (*Cutoff*), and distribution of the stock in U.S. waters (*U.S. Distribution*). The general form of the HCR follows:

$$\textit{Harvest Guideline}_{t+1} = (B_t - \textit{Cutoff}\,) \bullet \textit{Fraction} \bullet \textit{U.S. Distribution},$$

where estimable parameters include B_t and *Fraction*, and *Cutoff* (150,000 mt) and *U.S. Distribution* (87% of stock found in U.S. waters) are fixed variables. B_t is determined by conducting a quantitative (peer-reviewed) assessment and *Fraction*, which serves as a proxy for F_{MSY}, is estimated as follows;

$$F_{MSY} \equiv Fraction = 67.4558 - 8.1901(T) + 0.2486(T^2)$$

All highly-migratory species, including North Pacific albacore, are managed according to the "default" MSY Control Rule, as outlined in the M-SFCMA. The MSY Control Rule is quite general, and defines current conditions (stock size and fishing mortality) relative to "target" (B_{MSY} and F_{MSY}) and "limit" (minimum stock size threshold and maximum fishing mortality threshold) reference points. Finally, an extension of the above Control Rule, referred to as the OY Control Rule, is also incorporated in the highly-migratory species FMP, which essentially defines more conservative fishing mortality rates for "vulnerable" (low-productivity) species, such as sharks.

2.4.3. Southeast Fisheries Science Center (SEFSC, M. Ortiz)

For highly-migratory species (HMS) in the Atlantic, the United States manages all of its fisheries for tunas and billfishes following the specifications of the M-SFCMA under the implementations and agreements of ICCAT, of which the United States is a contracting party. Two FMPs apply for highly-migratory species, the Atlantic tuna, swordfish, and sharks FMP and the billfish FMP. The two fundamental objectives of these FMPs are to halt or prevent overfishing and to rebuild overfished fish stocks to ensure the long-term sustainability of the stocks. The FMPs require that reference points for fishing mortality rate (*F*) and for biomass are defined for each stock. These reference points will be used for determining the status of the stock(s). The FMPs defined the control rules of limit reference points for *F* and biomass of each stock that will identify when overfishing is occurring and/or when the stock is overfished. The Minimum Stock Size Threshold (MSST) defines a limit biomass for which biomass levels below will be considered as an overfished stock. The maximum fishing mortality threshold (MFMT) defines the fishing rate above which the stock will be classified as in an overfishing condition. FMPs for both tunas and billfish defined F_{MSY} and corresponding fraction of B_{MSY} as the MFMT and MSST, respectively, for all species under management, with exception of Atlantic bluefin tuna, for which biomass is defined in terms of spawning stock biomass. These FMPs defined MSST fractions as a function of natural mortality rates (*M* – in fact a scalar equal to the annual mortality rate); thus MSST = B_{limit} = (1-M)B_{MSY} when M < 0.5 and MSST = B_{limit} = 0.5 B_{MSY} when $M \geq 0.5$. For the current assessments of tunas and billfish species, only Atlantic yellowfin tuna assessments use *M* value(s) greater of 0.5.

Following these definitions, tuna and billfish stocks are considered “healthy” when the ratios of current B/B_{MSY} is greater than MSST, F/F_{MSY} is less than MFMT, and the stock is NOT in the rebuilding phase. Consistently, the stocks are considered “not healthy” when biomass falls below MSST, in which case *F* must be reduced to a level below F_{MSY} (MFMT) in order to rebuild the stock. When *F* goes above MFMT, overfishing is occurring and must be stopped immediately. It is important to note that for Atlantic tunas and swordfish managed internationally by ICCAT, F_{MSY} is considered as a target reference point, not a limit.

In addition to limit or control rules, the FMP also defined target reference points for which the fishery ought to aim in the long term. When a fishery is “healthy”, managers will try to set *F* so that it produces the optimum yield (OY), resulting in a stock size of B_{OY}. OY is the yield from a fishery that will provide the greatest overall benefit to the nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems. F_{OY} is the F_{MSY} from the fishery, as reduced by any relevant social, economic, or ecological factors. Since F_{OY} cannot exceed F_{MSY}, then B_{OY} (the equilibrium or average *B* associated with F_{OY}) must be equal to or greater than B_{MSY}.

When a stock is defined as “not healthy” the FMP specifies a rebuilding plan. For tunas and billfish, only rebuilding plans that specify a constant-catch scenario are considered.

NMFS will depend on the results of the stock assessment and fishery evaluation (SAFE) report for determining the status of the stock and will follow the framework procedure before changing any management measure. Stocks under a rebuilding phase also have specific biomass and fishing rate targets. Both FMPs have defined the biomass rebuilding target as B_{MSY}. For highly-migratory species, rebuilding management alternatives follow the recommendations and programs defined by the Scientific Committee on Research and Statistics of ICCAT. The FMPs also stated that a level of acceptable probability (certainty) must be set to establish targets and to determine the level of confidence that can be placed in the recovery estimates to ensure that stocks are rebuilding. Any management action under consideration for stocks of highly-migratory species should have at least a 50-percent probability of the desired effect.

3. Multi-species and ecosystem reference points (M. Hall and M. Maunder)

Many fisheries management agencies and researchers are now focusing on fishing effects on multiple species and the environment. Development of multi-species or ecosystem reference points might be appropriate for providing advice to managers about the impacts of a fishery on the ecosystem. There are several types of reference points including 1) single-species reference points applied to multiple species (*e.g.* all species have to be above S/S_0 = 0.2, where *S* is the current spawning biomass and S_0 is the spawning biomass in the absence of fishing), 2) reference points based on combining species (*e.g.* sum of yield from all species = MSY), or 3) ecosystem reference points based on emergent properties (*e.g.* average trophic level).

There has been much less research carried out into the development of multi-species and ecosystem reference points compared to single-species reference points. Numerous problems must still be resolved. For example, ecosystems change naturally with the environment, fisheries may cover multiple ecosystems, how many species should be considered, which species should be considered (keystone species, indicator species), availability of data for unharvested species, should there be upper limits of abundance for some species, and are the measures species-insensitive. Reference points are only part of management, and management measures that reduce ecosystem effects must be developed (*e.g.* what harvest levels should be implemented, and what mitigation measures could be implemented).

4. Research

4.1. Management strategy evaluation of Queensland Spanish mackerel (S. Hoyle)

In management strategy evaluation, the consequences of alternative management strategies are predicted in terms relevant to the decision makers. This manifestation of decision analysis has four essential components: management objectives, performance criteria, management options, and a method for predicting the performance of the options. Decision makers must be directly involved in specifying performance criteria and management options.

The process was illustrated, using the example of the Queensland east coast Spanish mackerel fishery. Key advantages of using this approach, coupled with a Bayesian operating model, include: 1) the approach reports in terms relevant to the decision-maker, so the results are likely to be used; 2) it assesses the management system as a whole, integrating across uncertainty, which increases the accuracy of predictions; 3) performance criteria provide a common currency to assess management alternatives. Performance criteria are better expressed in terms of 'real' objectives (*e.g.* average yield, profit, risk of biomass below critical level) than in derived or surrogate objectives (*e.g.* proximity to B_{MSY}), since these are more likely to be understood and used by decision makers.

4.2. Application of spawning biomass per recruit (SBPR) proxies and effects of mis-specifying F_{MSY} for yellowfin and bigeye tuna in the eastern Pacific Ocean (S. Harley and M. Maunder)

In age-structured models many factors contribute to the estimated F_{MSY} and associated MSY and biomass of spawners at MSY (S_{MSY}), *e.g.*, the assumed spawner-recruitment curve and age-specific mortality, maturity, and selectivity. Using data from assessments of bigeye and yellowfin tuna in the EPO, we show that F_{MSY} is sensitive to the steepness (the fraction of virgin recruitment that is produced if the spawning stock size is reduced to 20% of its unexploited level, and it controls how quickly recruitment decreases when the spawning stock size is reduced) of a Beverton-Holt spawner-recruitment curve. Unfortunately, it is difficult to estimate steepness, so there is a good chance that our assumed values are incorrect.

To evaluate the possible consequences of mis-specifying steepness we used simple equilibrium equations for an age-structured model. We estimated the F_{MSY} associated with a given value for steepness and applied that fishing mortality to a population for which the true steepness was different from that assumed. For both bigeye and yellowfin we found that assuming that steepness is 1.0 (as currently assumed) will result in considerable losses in yields and reductions in spawner abundance well below S_{MSY} if the true steepness is less than 1.0. We found that assuming a steepness of around 0.6-0.7 resulted in a fishing mortality that provided yields only slightly less than MSY if true steepness was in the range of 0.5-1.0. This fishing mortality was equivalent to a spawning biomass per recruit (SBPR) of 0.4-0.5. Assuming a steepness of 0.6-0.7 or using a proxy of SBPR = 0.45 will likely result in the maximization of expected yield, given our uncertainty as to the shape of the spawner-recruitment curve.

4.3. Stochastic management strategy evaluation for tuna (S. Hoyle, M. Maunder, and S. Harley)

A stochastic operating model developed for the yellowfin tuna fishery of the EPO was used to carry out management strategy evaluation, with the aim of demonstrating aspects of the process for discussion. Performance criteria based on the management objective of MSY were defined as average yield / MSY (*Y/MSY*), final-year biomass / B_{MSY} (B/B_{MSY}), and the risk of spawning biomass going below 20% of the virgin stock size (S_{min}<20%S_0). Management options were based on alternative assumed values of steepness, $h_{assumed}$, with harvest rate set according to the NFMS Magnuson-Stevens technical guidelines under $h_{assumed}$. The performance of the management strategies was evaluated at a range of values of steepness in the operating model. The model included annual assessment of available biomass with 30% normally-distributed error, implementation error (normal) of 10% in setting harvest rate, and annual lognormal variation in recruitment of 60%. Other parameter values were set at the maximum likelihood estimates from the 2003 yellowfin tuna assessment. Assuming a steepness of 0.6 gave similar *Y/MSY* and better B/B_{MSY}, and S_{min}<20%S_0 than higher values. Steepness of 0.4 gave higher B/B_{MSY} and lower S_{min}<20%S_0 again, but at some cost in *Y/MSY*. The model was also applied to bigeye, starting at the current estimated biomass and projecting forward 5 years.

4.4. Uncertainty in reference points (R. Conser)

The use of biological reference points as a formal basis for management of fish populations has become commonplace in the world's oceans. Fishing mortality rate (*F*)-based reference points (*e.g.* $F_{20\%}$, $F_{40\%}$, $F_{0.1}$, F_{MAX}, *etc.*) are most commonly used, but biomass-based reference points have received increased interest in recent years. However, for most tuna stocks-including North Pacific albacore (*Thunnus alalunga*)-no agreed-upon biological reference point has been adopted as a formal part of the fisheries management process. With international management of tuna stocks in the western and central Pacific Ocean approaching, it is likely that consideration of appropriate biological reference points will receive renewed interest.

Traditionally, the choice of a biological reference point has been a tradeoff between taking maximum yield from a stock while ensuring its long-term sustainability. In most cases, simple models (*e.g.* spawning biomass per recruit - SBPR) are used to calculate the point estimate of an agreed-upon, *F*-based reference point for comparison with the point estimate of recent *F* from a stock assessment model. Considerable uncertainty is common in both of these point estimates, but it is usually ignored in the process of judging whether recent *F* exceeds an established *F*-based reference point.

Using North Pacific albacore as an example, methods for formally incorporating the stochastic aspects of reference point estimation, recent *F* estimation, and population projections are illustrated. Results indicate that some reference points are more difficult to estimate than others (*i.e.* the precision of the estimates can vary considerably). Consequently, in addition to the traditional tradeoffs used for selecting reference points (*i.e.* yield *vs*. sustainability), consideration of the precision of the estimates may be warranted as well.

4.5. Critical weight as a reference point (M. Maunder)

The IATTC has been presenting critical weight in its Stock Assessment Reports for several years. The critical weight, which is the weight corresponding to critical age, is compared to the average weight in the total catch and the average weight in each fishery, as predicted by the stock assessment model. The critical age is a theoretical concept that maximizes the yield from a cohort by removing all the individuals at a single age. The weight corresponding to the critical age may provide information on the status of the stock and the efficiency of the different fishing methods with respect to maximizing yields. Analyses were carried out to determine the appropriateness of critical weight as a reference point for fisheries management.

Analyses for different values of the steepness of the stock-recruitment relationship, natural mortality, growth rate, and age at maturity showed that the ratio of average weight in the catch at maximum sustainable yield (MSY) to critical weight was relatively insensitive and around 0.8. However, this ratio is very sensitive to the selectivity curve.

Fishing at a level that produces an average weight that is 80% of the critical weight, gives yields close to MSY and is relatively insensitive to the selectivity (age at first vulnerability in knife-edge selectivity) and is robust to small mis-specification in natural mortality or the growth rate. Critical weight did not appear to be a good indicator of stock status.

Eighty percent of critical weight may be a useful reference point for low-information species. Calculation of critical weight requires only estimates of natural mortality and growth rate by age. Evaluation of the stock based on critical weight requires only the measurement of average weight. There are several possible problems with using critical weight as a reference point, including difficulty in estimating the natural mortality rate, and sensitivity of average weight to recruitment fluctuations.

5. Discussions

Numerous discussions among the participants were held after each presentation and in the special sessions at the end of the meeting. In general, these discussions led to the recommendations listed in Section 6. Some of the discussion topics included: which years to use when calculating reference points, dynamic versus equilibrium reference points, presentations of reference points as ratios of indicators to the reference points to include uncertainty, what selectivity to use when creating reference points, reference points for local areas, how to relate fishing method effects on reference points, tradeoff between catchability estimates and recruitment estimates, the relationship between target and limit reference points, difficulties in determining ecosystem reference points, multi-species versus ecosystem reference points, whether B_{MSY} should be a target or a limit, sustainable overfishing, and adoption of the recommendations of the Marine Stewardship Council as a guide for reference points.

One concept that was discussed and needs definition is virgin biomass. This could mean pristine conditions prior to any fishing, conditions at time zero of the data set, or the estimate of current conditions if no fishing had taken place. A similar definition is needed for S_0: is this the spawning biomass at time zero or for zero effort?

6. Recommendations

6.1. General

Several limit reference points, particularly those that are based on probability of exceeding the limit, were recommended for further investigation; for example:

- X probability of the current spawning biomass (S_{cur}) being below $S_{F=FMSY}$
- X probability that current S is above S_{min} where S_{min} is the lower y% confidence limit of $S_{F=FMSY}$
- p($S_{cur} > S_{X\%}$) = Y
- $S_{X\%}$ *e.g.* $S_{20\%}$

Several target reference points were recommended for further investigation; for example:

- S_{MSY}
- No biomass target

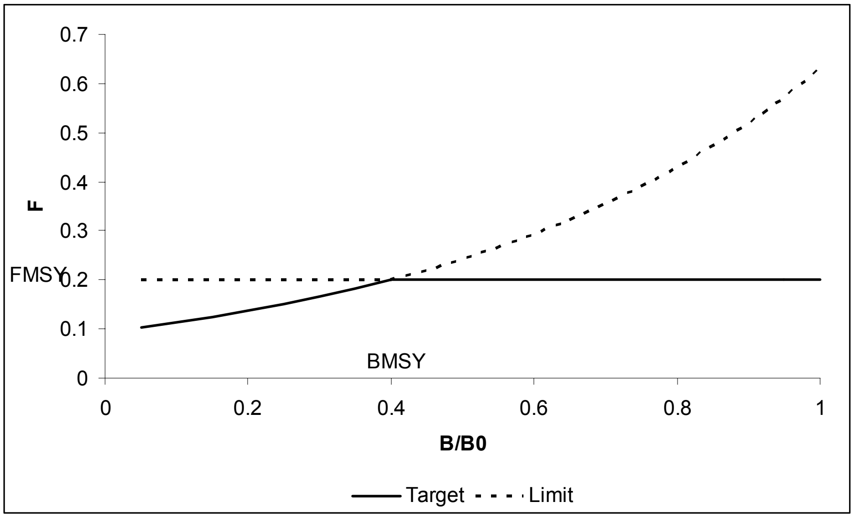
It was recommended that the quantities should be based on current age-specific relative F and that target and limit reference points that are regime-specific or robust to regime changes should be investigated.

Several quantities were recommended as indicators; for example:

- $CPUE/CPUE_{MSY}$ (empirical, model, or equilibrium based)
- *C/MSY*
- Calculation of the impact of each fishery (by region if possible)

- Depletion estimates based on the fished versus unexploited spawning biomass trajectories (by fishery)

It was recommended that a general framework based on an F reference line be investigated. This reference line determines the target as F_{MSY} if spawning biomass is above S_{MSY} and the F that would allow the stock to be at S_{MSY} in one generation if the spawning biomass is below S_{MSY} (see Figure). The limit would be F_{MSY} if the spawning biomass is below S_{MSY} and the F that would allow the stock to be at S_{MSY} in one generation if the spawning biomass is above $S_{MSY.}$ Other forms of the reference line may also be appropriate.



Several recommendations were made regarding the estimation of reference points. Robust reference points or proxies should be determined through simulations, both equilibrium and dynamic. The sensitivity of reference points to assumptions and the estimation uncertainty should be evaluated and communicated. Reference points should be compared to those of similar species. Methods should be developed to detect regime shifts and determine the responses of stocks to regime shifts. The computational requirements for determining reference points should be characterized.

Simulations of the performance and properties of alternative strategies, *e.g.*, control rules based around target and limit reference points, should be carried out.

6.2. IATTC-specific

The reference points and associated quantities presented by the IATTC in its Stock Assessment Reports were evaluated and appropriate changes were recommended.

a. Confidence intervals should be calculated for SBR/SBR_{MSY} (= S/S_{MSY}).

b. The presentation of MSY and associated quantities by fishery should be grouped by fishing method.

c. The no-fishing plots should start from a unexploited condition, and include the stock-recruitment relationship, as appropriate.

d. Fishery-impact graphs similar to those used by the SPC should be presented.

e. The weight should be included on the x-axis of the critical weight plots.

f. The average weight at MSY using the fishery with the highest MSY should be included on the average weight plot.

g. The selectivity of the different fishing methods should be included on the MSY_{ref} plots.

Appendix.

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