REPORT OF THE 2011 JOINT MEETING OF THE ICCAT WORKING GROUP ON STOCK ASSESSMENT METHODS AND BLUEFIN TUNA SPECIES GROUP TO ANALYZE ASSESSMENT METHODS DEVELOPED UNDER THE GBYP AND ELECTRONIC TAGGING

(Madrid, Spain - June 27 to July 1, 2011)

1. Opening, adoption of Agenda and meeting arrangements

Dr. Pilar Pallarés, on behalf of Mr. Driss Meski, ICCAT Executive Secretary, opened the meeting and welcomed participants. The meeting was chaired by Dr. Paul De Bruyn. Dr. De Bruyn welcomed the Working Group participants, reviewed the objectives of the meeting and proceeded to review the Agenda which was adopted without changes (**Appendix 1**).

The List of Participants is attached as **Appendix 2**.

The List of Documents presented at the meeting is attached as **Appendix 3**.

The following participants served as Rapporteurs for various sections of the report:

Section	*Rapporteurs*
1, 7	P. Pallarés
2	L. Kell
3.1	G. Scott
3.2	M. Ortiz
4.1	S. Cass-Calay
4.2	J. Neilson
5, 6	P. De Bruyn

2. Review of current development of stock assessment methods (GBYP)

Dr. Laurence Kell (ICCAT Secretariat) chaired the session and presented some preliminary work being conducted on a management strategy evaluation (MSE) framework to analyze the robustness of the current, VPA-Adapt based implicit management procedure. Current management procedures consider many but not all sources of uncertainty. It was noted that the Kobe Strategy matrix actually provides a generic framework for evaluating the impact of uncertainty on management advice. MSE is also an important way to show how the results from the new research funded by GBYP can be incorporated into new assessment and modeling approaches for providing robust advice

The author presented a generic MSE approach for simulation (SCRS/2011/110) evaluating the robustness of alternative management advice frameworks with respect to various sources of uncertainty. This involved the use of an Operating Model (see Rademeyer, et al. 2007 for definition of terminology) to evaluate the impact of structural uncertainty on the perception of stock status obtained via Adapt-VPA. Structural uncertainty related to population structure (i.e., two subpopulations) and the stock recruitment relationship (i.e., constant recruitment or compensatory dynamics). The authors found that structural assumptions (1 stock versus 2), and the source of various indices (stock 1 or stock 2) were critical assumptions, which had much greater impact than the stock recruitment assumptions. This has important implications for the structure of assessment models and for the development of management procedures that are robust to structural uncertainty and demonstrated the importance of fisheries independent data and a better understanding of stock dynamics as being provided by the GBYP.

Subsequently, the Chair informed about two short-term modeling contracts awarded under the GBYP to Imperial College on risk analysis and to Dr. Justin G. Cooke to develop new alternative methods to provide scientific advice for fisheries management.

A presentation on the work being conducted by Imperial College showed how different risks will be identified and their relative importance determined. The authors had developed a questionnaire to obtain the perception of stakeholders of the importance of uncertainty on management advice, the extent to which this uncertainty is already considered in management advice and how strongly the responders believed this. These characteristics would be important in helping to identify scenarios for quantitative modeling (i.e., with an MSE framework). There was concern that different stakeholders may have varying levels of understanding of the critical assessment factors, leading to differing priorities. However, it was explained that identifying the difference in perceptions about risk was an important aim of the questionnaire and that the results of the survey would be useful general guide for future activities, e.g. to develop better methods of risk communication as well as developing MSE scenarios which would be used to evaluate and subsequently manage the actual risks.

The Group completed the questionnaire in order to allow the contractors to obtain feedback before conducting the actual survey. Following this exercise, suggestions on how to improve the form were made.

The Group felt that the questions were probably too technical for non-scientific stakeholders. However, it was pointed out that restricting the audience to scientists might be appropriate, if the primary objective of the questionnaire is to identify the main uncertainties in the provision of scientific advice. Modifying the questionnaire for different stakeholder groups was out of the scope of the small contract awarded to Imperial College.

The second contract was for the development of a prototype of an alternative assessment and advice framework. The intention is that alternative frameworks will be evaluated using an MSE framework currently under development by the Bluefin Tuna Species Group. This will allow a range of scenarios to be constructed to first evaluate the existing bluefin tuna assessment and management framework and then to compare the performance of alternative frameworks. This will be used to evaluate how well candidate assessment and advice frameworks perform relative to the management objectives specified by the Commission. It is of interest to the SCRS to determine both how the various methods perform: (i) when supplied only with the data used for assessments to date (catch at size/age, abundance indices, growth curves), and (ii) when additionally supplied with data of the kind being collected under the GBYP (e.g. aerial surveys, electronic tagging).

A short presentation was given by Dr. Cooke of the work in progress on one of the two contracts. It involves an assessment method and a harvest control rule, designed to work in tandem which form the management procedure (MP) component of an MSE. The assessment method proposed is broadly similar to that already used for bluefin tuna, but in order to be able to make use of a variety of different kinds of data, and to capture most of the main sources of uncertainty, it is cast in a formal Bayesian form with specific likelihood functions for each kind of data. The choice of prior distributions of parameters is driven primarily by the requirement for good management performance, rather than by prior beliefs about likely values. Prior information about likely ranges for parameter values can be taken into account in the construction of the test scenarios which be used to test all candidate procedures. The conventional management reference points B_o, B_{MSY} and F_{MSY} are used, but defined in a way such that they remain appropriate in the presence of possible regime changes. A simple harvest control rule is proposed: constant F when the stock is above B_{MSY}; F linearly proportional to B/B_{MSY} when $B < B_{MSY}$. The harvest control rule is based on a notional unselective standard fishery. To convert the results to an actual TAC for a real mix of fisheries, weighting factors are determined for each fishery to relate the effect of a unit catch from each fishery to the effect of a unit catch from the notional standard fishery.

In discussion it was noted that under the management objectives being developed by ICCAT and other RFMOs, F_{MSY} and B_{MSY} implicitly become limit rather than target reference points; harvest control rules should preferably be consistent with this. The management targets are expressed in terms of the probabilities of being above or below the applicable limit reference points. The results of the simulation tests of candidate procedures will need to be tabulated or displayed in a form which shows clearly how each procedure performs relative to these targets. Candidate procedures generally have one or more tunable parameters that can be adjusted up or down to make the procedure more or less conservative. The results of the simulation tests can be used to tune procedures to better meet management objectives.

While it is desirable that candidate procedures show robust performance across a broad range of scenarios, it was noted in discussion that the determination of whether a procedure meets quantitatively specified management objectives may depend on the relative weight given to different scenarios. Therefore, even under an MSE approach, the SCRS will not completely escape the necessity, as with conventional stock assessments, to discuss the relative plausibility of different assumptions.

Discussion of the presented approach focused largely upon the structural complexity of the operating models (OM) which serve as the underlying data generating process for the MP. Development of the OM will be a complex task due to the multiple structural, biological and human dimension aspects that could potentially be considered. It was noted that success of the MSE depends upon making the process accessible to all involved parties and making the software widely accessible.

3. Meta-analysis for investigation of key parameters such as steepness, virgin biomass or K, r and M ect

3.1 Feedback from ISSF meeting

A workshop was held to examine two issues that significantly affect scientific management advice and which are not always being treated consistently in tuna stock assessments: (1) Assumptions about the stock-recruitment relationship, and (2) evaluating the implications of changing mortality on juvenile and small tunas. The workshop reviewed available information and conducted several preliminary analyses. With regards to the first issue, many assessments either estimate or fix the value of "steepness", a parameter that determines the degree to which average recruitment depends on parental stock biomass. The Workshop concluded that estimated steepness values from individual assessments should be treated with considerable caution and that meta-analyses of the available data for all tuna stocks be continued in order to provide further advice for the estimation of steepness. In addition, the Workshop made recommendations for scientists to better characterize uncertainty in steepness in their stock status determinations, and for managers to consider Harvest Control Rules that are robust to this uncertainty. With regards to the second issue, the Workshop concluded that tuna stocks that have a high fishing mortality rate on juveniles relative to adults tend to have lower spawner-per-recruit levels. However, in terms of absolute spawning biomass relative to SSB_{MSY}, those stocks that have experienced high juvenile fishing mortality are not necessarily more overfished in comparison to stocks that have not. The Workshop recommended that stock assessment reports routinely include Fishery Impact plots so that the effect that gears with different selectivity have on spawning biomass can be readily evaluated. Finally, the Workshop recommended that future meetings be held to compare the basic life history parameters being used in the tuna stock assessments, with a view to reconcile differences or improve consistency.

The general themes and outcomes of the ISSF meeting were welcomed by the group, although there were questions regarding the approaches undertaken, particularly regarding the fixed natural mortality vectors and their implications for the meta-analysis outcomes, the identification of regime shifts and the utility of impact analysis as a scientific rather than quota bargaining tool. It was pointed out that the analyses conducted at the meeting where very preliminary and further analysis is required and was encouraged. The Working Group noted that part of this continued work should focus on possible common, but not yet evident, bias in the data used for the preliminary meta-analysis. It was also asked as to whether the recommendations made during the ISSF meeting would be presented formally within ICCAT. It was clarified that a document including many of the recommendations had been developed and that it would be presented at the Kobe meeting in La Jolla in 2011. The document was reviewed by the Group and its recommendations were endorsed.

3.2 Alternative approaches

Much information exists on life history characteristics that are not routinely used in stock assessment. Using such information and assessments from information-rich or similar species, it may be possible to inform assessments of information-poor species (termed a “Robin Hood” approach in Australia). Allowing stocks from one ICCAT area to “learn” from stocks in other ICCAT or other RFMO areas and the generic nature of tools and frameworks proposed for use under the European Common Fisheries Policy and tested prior to implementation. Application of such an approach would thus provide reference points and advice for the stocks which do not have them (e.g., Mediterranean Albacore or by caught species). A problem with traditional hierarchical meta-analysis is that “data” such as stock-recruit are actually outputs from assessment models conditional on assumptions about fixed parameters (e.g. natural mortality, growth and maturity) and dynamics and may carry common, but undetected bias, therefore the development of methods for meta-analysis that are performed on the actual data (e.g., catch and CPUE) will be valuable.

A presentation on the "Robin-hood" approach (SCRS/2011/111) was made to the Group as an example of what could be applied for information-poor ICCAT stocks. In a Bayesian approach priors are "borrowed" from better known, but similar species. The method permits characterization of uncertainty in key aspects needed for providing management advice.

The Working Group noted that hierarchical Bayesian analysis such as this can have some important affect on the outcomes of such evaluations. In the case of tunas, as noted above, differences between tropical and temperate species should be considered when borrowing information sets. But it was also noted that such restrictions can quickly result in few species/stocks from which to borrow information. Estimates of SRR, natural mortality, stock productivity, and other influential parameters are commonly poorly determined for many tuna stocks worldwide and there may be little information available to borrow. Furthermore, even for "information rich" species, the degree of certainty in many of these parameters can be quite low. In these cases, using plausible ranges across parameters may be the only reasonable method available to better capture uncertainty.

The Working Group noted the need to carry out simulation analyses to evaluate the Robin-Hood approach, before implementation, of how the resulting estimates of uncertainty in key parameters carry forward into management recommendations.

A brief summary was given of ECOKNOWS (http://www.ecoknows.eu/), an ongoing project from EU that addresses several common points for meta-analysis and evaluations of multi-stocks designed to improve understanding of temporal changes in stock productivity. Several of the objectives of this project are common to the evaluation of uncertainty of key parameters and the outcomes may be useful in further guiding SCRS on better characterization of uncertainties. The Working Group noted interest in keeping abreast of progress in this project.

4. Limit, threshold and target reference points as part of HCRs to manage risk

4.1 Generic Harvest Control Rules

The Working Group previously considered generic HCRs and the precautionary management frameworks of several nations and RFMOs including IATTC, WCPFC, ICES, NAFO, the Multilateral High-Level Conference (MHLC), Canada and the United States (Anon. 2010). The working group also noted that it proposed a generic HCR to the SCRS in 2010 (**Figure 1**), and that this control rule is described in the Report of the 2010 ICCAT Working Group on Stock Assessment Methods (Anon. 2011).

A new methodology was presented to the working group, and is described in SCRS/2011/105. The authors explore a potential harvest control rule (HCR) for depleted stocks ($B<B_{MSY}$) which is defined as the TAC that results from an X% probability of further stock decline where the probability is chosen to be extremely low (likely in the range of 1-5%). Typically, biological reference points are used to construct management targets and/or limits for stock biomass and fishing mortality. However, in many cases these reference points are poorly estimated or based upon unquantifiable assumptions. For instance, reference points based upon maximum sustainable yield (B_{MSY} and F_{MSY}) often require a stock recruitment relationship for which the critical steepness parameter is extremely difficult to estimate. The authors describe a preliminary exploration of the performance of the proposed HCR using the 2010 western Atlantic bluefin tuna base model, and various assumed stock-recruitment relationships. They found that despite substantial differences in the assumed stock recruitment relationship, the proposed harvest control rule, evaluated at a 1% or 5% risk of further depletion, could provide fairly consistent short-term harvest advice for western Atlantic bluefin tuna across the different assumptions regarding spawning stock biomass. They recognized the need for further development and simulation testing of this HCR to determine its general usefulness.

The Group debated the utility of a risk-of-depletion based HCR and emphasized the importance of simulation testing any HCR using a management strategy evaluation (MSE) to ensure that the HCR performs as intended (e.g. converges to the desired objective). The group generally agreed that, given successful simulation testing, a risk-of-depletion based HCR could operate in conjunction with conventional MSY (or proxy)-based management frameworks.

The Working Group also examined the formulation of the ICES generic HCR (**Figure 2**). In the ICES context F_{MSY} is used as a generic term for a robust estimate (e.g., $F_{0.1}$) of a fishing mortality rate associated with high long-term yield (ICES, 2010). Thus the MSY-based HCR is specified such that F_{MSY} is the fishing mortality that will maximize yield in the long-term, and MSY $B_{trigger}$ is a biomass reference point that triggers a “cautious response” that will maintain the stock at a level capable of producing MSY. ICES intends to recover depleted stocks to levels greater than or equal to the MSY $B_{trigger}$ by 2012. In order to achieve this objective, a transition strategy was designed to estimate the allowable fishing mortality during 2013-2015. The ICES framework also includes two exceptions: (1) when the stock biomass is much less than $B_{trigger}$ the fishing mortality will be set at a "suitable alternative", and (2) when the stock biomass is below $B_{trigger}$ and the recruitment is low, the allowable F could be set considering only F_{MSY} or both $F_{MSY-HCR}$ and $F_{MSY-transition}$ (**Figure 2)**. This generic HCR is also described in (ICES, 2010).

The Group expressed several concerns regarding the application of the ICES HCR in an ICCAT context. The SCRS has advised that consistent with the precautionary approach, F_{MSY} be considered an F limit, and that an F target lower than F_{MSY} be defined to ensure a low risk of overfishing given scientific uncertainty. Therefore it appears that the ICES HCR is inconsistent with SCRS advice. Furthermore, using the ICES HCR, natural variability in recruitment could allow an overfished condition to occur and/or persist even when fishing mortality was maintained below F_{MSY}. The Group noted that current SCRS advice endorses are more precautionary level (e.g. 75%F_{MSY}) of fishing mortality intended to ensure that the stock biomass remains at a level consistent with convention objectives despite natural variability. The Group also noted that the generic HCR with transition is also designed to limit the possible reduction in F from one year to another. While this objective may be most desirable from an economic perspective, it may be incompatible with the management objective to allow recovery to above $B_{trigger}$ within the intended timeframe. The Group also cautioned that management advice must be conditioned on the intent of the management regulations to be applied, and that simulation testing with an MSE is necessary to ensure proper performance of any HCR.

The Group also discussed the guidance of the Commission's Working Group on the Future of ICCAT with regard to the development of HCRs and precautionary management advice. Previously, the SCRS advised the Commission that:

1) *The Commission should establish management measures which result in a low probability of exceeding F_{MSY} (or other proxy), in cases of stocks for which status is consistent with the Convention objective; and*

2) *For stocks with biomass below the level defined by F_{MSY} (or other proxy), the Commission should establish management measures which result in rebuilding of biomass within a short a time period as biologically feasible and which have a high probability of success.*

To that end, the Working Group on the Future of ICCAT considered and expressed broad support for the concepts contained in the following text. The missing values in the text, referring to X% or less probability of overfishing, X% or greater chance of ending overfishing immediately, and an X year period for rebuilding will be discussed and ratified by the Commission in the near future.

1. *For stocks managed by ICCAT that are not overfished and not subject to overfishing (i.e., "healthy" stocks in the green quadrant of the Kobe plot), management measures shall be designed to result in a low (e.g., X% or less) probability of overfishing.*

2. *For stocks that are not overfished, but are subject to overfishing, (i.e., stocks in the upper right yellow quadrant of the Kobe plot), the Commission shall adopt management measures designed to result in a[moderately] high (e.g., X% or greater) probability of ending overfishing immediately and in a low (e.g., X% or less) probability of resuming overfishing within an X year period.*

3. *For overfished stocks that are subject to overfishing (i.e., stocks in the red quadrant of the Kobe plot), the Commission shall adopt management measures designed to result in a high (e.g., X% or greater) probability of ending overfishing immediately. In addition, the Commission shall adopt a plan to rebuild the stock to levels consistent with the Convention Objective within X years. A longer rebuilding period may be adopted if SCRS determines a X year rebuilding program is not possible given the biological productivity of the stock.*

4. *For overfished stocks that are not subject to overfishing (i.e. stocks in the lower left yellow quadrant of the Kobe plot), the Commission shall adopt management measures designed to rebuild the stock to levels consistent with the Convention Objective within X years and to result in a low (e.g., X% or less) probability of overfishing. A longer rebuilding period may be adopted if SCRS determines a X year rebuilding program is not possible given the biological productivity of the stock.*

The Methods Working Group agreed that HCRs considered by the SCRS should conform to this guidance and that reiterated that MSE simulations must be conducted to confirm that proposed HCRs perform as expected.

4.2 Species specific case studies

The Group reviewed ongoing work being conducted for N. Atlantic albacore, where Multifan-CL had been used to evaluate uncertainty due to choices made during stock assessment. MFCL had been fitted to the same data set but different but equally plausible assumptions about life history parameters and patterns of fishing had been made. This resulted in 10 different estimates of historic stock status, productivity and reference points. The intention was to take one of the more complex ICCAT assessments, and use it to evaluate robustness of current methods used for advice, particularly for data-poor stocks and simpler stock assessment methods for use as part of HCRs.

To simulate the data-poor situation, a range of life history parameters were varied. The results showed recruitment varied on a decadal scale, possibly indicating regime shifts. However, limitations of using Multifan-based assessments for this type of analyses were discussed. Yield-per-recruit combined with spawner-per-recruit results was then shown. Reference points change based on assumptions, with the steepness of the stock-recruitment relationship having a particularly large impact. Changing growth assumptions also had a large impact on these length-based assessments. Kobe phase plots showed considerable variation in the stock trajectories among the scenarios attempted. It was pointed out that some extreme examples, such as constant selection, could be ruled out. It was also noted that combining results of different scenarios using different modeling approaches would be more problematic. Projections showed predictable responses, with stock recovery related to quotas. Adding an HCR similar to the ICES approach, output was generated comparable to a Management Strategy Evaluation. It was noted that another potential use of the exercise was that as a kind of sensitivity analyses, the impacts of varying life history parameters can give guidance on the most appropriate research investments. It was noted that development of plausible hypotheses are often more important than the Harvest Control Rule. The Group noted that future harvest control rules should be consistent with policy developed from ICCAT groups such as the Future of ICCAT Working Group (see Section 4.1).

A presentation describing the Canadian policy regarding the Precautionary Approach was provided. The Canadian approach defines three levels of stock status: critical, cautious and healthy. A limit reference point defined the boundary between the critical and cautious zones, and an upper stock reference defined the boundary between cautious and healthy zones. It was noted that Canada recently applied their Precautionary Approach framework to a number of domestic Atlantic Canadian stocks. Important lessons learned included involvement of fishery managers and scientists in a joint panel that attempted to apply the framework in a consistent fashion. The assignment of reference points was basically ad hoc, and the limit reference and upper stock reference points were set at 40 and 80% of the B_{MSY} level, respectively.

The presentation continued with a possible approach for responding to the Commission's request for the development of a limit reference point (see Rec. 10-02) for North Atlantic swordfish, that built on observations of the stock's recovery from a depleted state, and past work of the Stock Assessment Methods Working Group that demonstrated substantial benefits of incremental gain in SSB of North Atlantic swordfish with reduced (0.75 F_{MSY}) exploitation rates, with only marginally reducing equilibrium yield (Anon. 2010). The Group noted that the calculations supporting those conclusions were derived from a VPA, but the main advice on stock status for North Atlantic swordfish is derived from a surplus production model. The Group advised that the calculations could be updated using additional modeling approaches.

The Group also recalled that the Future of ICCAT Working Group has considered and given broad support for policy on harvest control rules (see Section 5). That, if adopted by the Commission, has implications for the definition of limit reference points and harvest control rules that will guide the work of the SCRS in this regard.

The experience in the EU has shown that during simulation testing of Harvest Control Rules (HCR), choices often have to be made when coding that were not obvious when the HCR was proposed. For example the relative priority of objectives such as the risk of falling below a biomass limit, catch or variability in catch may not been fully specified initially, and may require further dialogue with managers and policy-makers. Simulation testing will be an important process in identifying any inconsistencies and specifying relative importance of objectives. Even if HCRs have been simulation tested their operation in practice may be less than optimal and therefore they will require regular performance reviews.

5. Other matters

5.1 Google Code

The Group was made aware of an initiative developed for the Joint Working Group on Stock Assessment Methods and GBYP meeting using Google code as a networking and information sharing tool. The site is located at http://code.google.com/p/gbyp-sam/ and has been used to store code written by several scientists collaborating on models and case studies related to management strategy evaluation. The site is available for anyone to access on a read only basis, and permissions can be given by the site administrators for write access. The idea is to post code and work in progress on this site; allowing others to contribute and download the code, data and documents as necessary. A key feature of the Google code site is the svn feature which stores and tracks the different changes in the code, allowing the easy identification of changes (along with who made them) as well as providing the ability to revert back to previous versions. This method of information sharing and collaboration was proposed by Dr. Kell as a powerful tool that could easily be adopted during ICCAT working groups by the scientists who participate in them. This way scientists can collaborate inter-sessionally both in advance and after meetings

5.2 CPUE standardization techniques

Document SCRS/2011/106 was presented. Two-stage models such as the delta-lognormal estimator are some of the most widely used models for CPUE standardization. The variance of these estimators is obtained from the delta or Taylor series approximation which can sometimes lead to negative variance estimates when the correlation between the proportion of positive observations and the lognormal component have a negative correlation. This document provides a derivation of this variance estimate, a more intuitive understanding of its parts, a recommendation for a solution to this incongruous problem as well as a set of unified R and SAS code which could be used by researchers employing two-stage CPUE estimators. The recommendation is to: (1) test the significance of the correlation between the two components, (2) if non-significant, use the Goodman (1960) exact estimator for the product of two independent random variables and, 3) if significant, use equation the delta approximation for the index variance.

As the code used in the model has been included as an appendix to the document, the authors welcomed the utilization and testing of the code along with any identified comments or issues. It was acknowledged that although the code was fairly robust, there are circumstances, such as when negative correlations between zero catches and positive CPUE levels occur, which may cause computational problems. Corrections for these issues have been written and will be made available, probably by linking the software catalogue entry for this code to this document.

Additionally, attention was drawn to an objective method of spatial stratification of CPUE data using the GLMtree model (Ichinokawa and Brodziak, 2010) presented at both the Blue Marlin and Sharks Working Groups. The method performs CPUE standardization and spatial stratification as a joint estimation and there was concern that adding a constant to the log(CPUE) was unnecessary as numerous models exist to more effectively model zero observations such as two-stage or delta lognormal models. It was noted that a potential solution that would avoid any re-coding of the GLMtree model would be to use the GLMtree method to obtain the strata a priori and then use these in a separate CPUE standardization. It might be preferable to use the same strata for both components of a two-stage GLM, however this could lead to unbalance when positive observations might not exist for some areas. The effects of spatial imbalance in observations are considered further, below.

Both the aforementioned working groups have recommended that the model performance be evaluated for future meetings of the ICCAT Working Group on Stock Assessment Methods. Key areas identified for investigation included the evaluation of robustness of the area stratifications particularly for relatively rare bycatch species. It might be more plausible to use spatial strata obtained from more abundant target species. The second concern regards the potential for spatial imbalance to create data holes in some years as the spatial pattern is obtained from the data aggregated in space across all years. For some years, certain strata may not have observations which could create problems for CPUE modeling and modeling year*area interactions, in particular. It is critical to plot the data to determine whether such gaps occur. The value of this approach is that any data gaps can be explicitly identified and imputation methods (Carruthers et al. 2011) could be employed to fill in these holes. It might also be possible to add a penalty to the likelihood function to ensure that a certain number of observations occur in each stratum in each year. The more global concern is about whether the spatial stratification results in improved CPUE indices. This requires simulation testing using data constructed with a spatial pattern and could use the Goodyear's SEEPA simulation software.

5.3 ICCAT software catalogue

A point was raised that some software/code provided in the ICCAT software catalogue is either incorrectly dated, old or obsolete. It was suggested that it is important to link the catalogue to the most updated code available for each software package. As it was pointed out that changes in version may have significant impacts on the results of past assessments, it was very important to note the version or release of the software package used to conduct each assessment. This may best be achieved by providing this information in the documentation of the stock assessment session. The Secretariat stated that it is working on methods to test outputs from models to determine version differences. For non-proprietary collaborative coding, the previously mentioned Google code site was suggested as a good tool for keeping track of versions and changes between them. The group noted the difficulties involved in validation of software for inclusion in the ICCAT software catalogue and suggested that common protocols be developed with other catalogues (e.g. ICES and NOAA toolbox) should be considered.

6. Recommendations

6.1 Meta-analysis and methods for informing key parameters

It was recommended to pursue Robin Hood approaches in order to evaluate their use for providing management advice and continue pursuing meta-analyses but identifying biases due to model assumptions (see section 3.2).

6.2 HCRs

Simulated HCRs should be based on the advice provided by the 2010 Working Group Stock Assessment Methods and Appendix 6 of the 2011 Future of ICCAT meeting report unless shown otherwise.

Alternative harvest control rules, including empirical rules (ISSF, 2011) should be developed and evaluated, although it thought that these will supplement rather than replace more comprehensive analytical harvest control rules.

Management Strategy Evaluation should be a participative approach involving all stakeholders, from scientists to managers, the industry and the fishing communities. It should be developed for ICCAT tuna fisheries and it is recommended that MSE be actively pursued to develop robust management practices which can achieve the Convention Objectives within time frames and tolerable risks that the Commission decides appropriate. As part of this process, it is necessary to work toward a full characterization of scientific uncertainty in stock status to improve estimates of risk.

7. Other matters

The Blue Marlin and Shark Working Groups requested the Working Group on Stock Assessment Methods to investigate and test GLMtree model for CPUE standardization and especially for use for by-catch species.

8. Adoption of the report and closure

The report was adopted during the meeting.

The Chairman thanked the participants for their hard work.

The meeting was adjourned.

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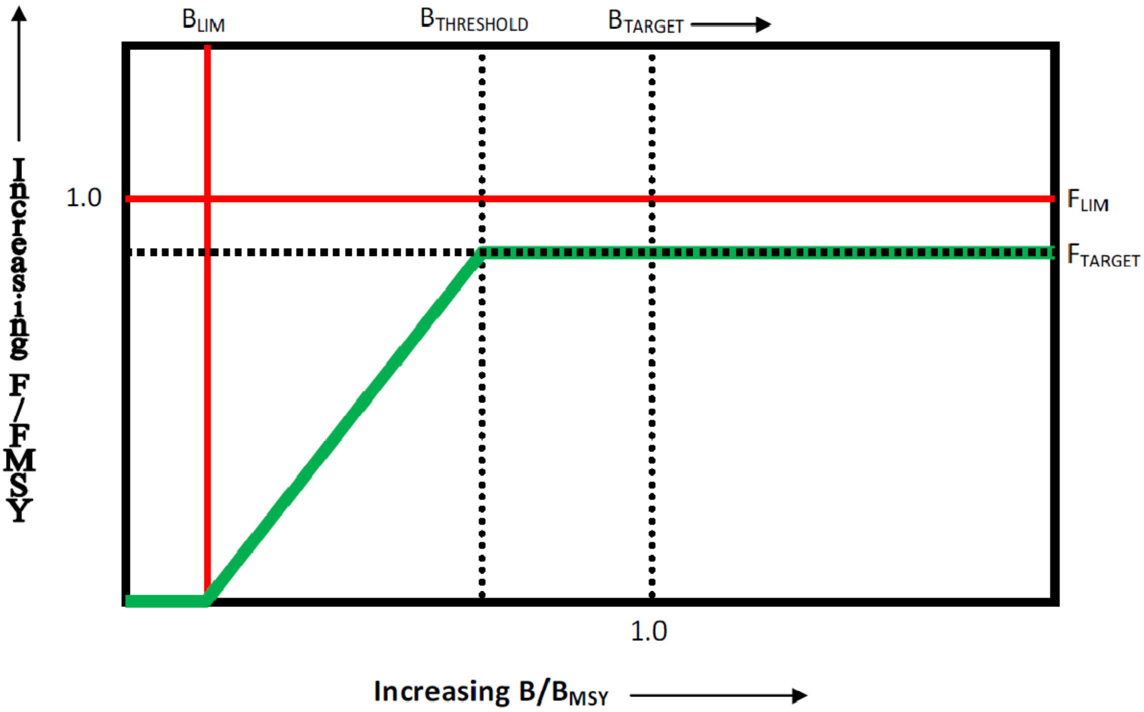

Figure 1. A HCR proposed by the 2010 Methods Working Group, and consistent with current Commission (FUT) guidance. This HCR is described in the 2010 Report of the ICCAT Working Group on Stock Assessment Methods.

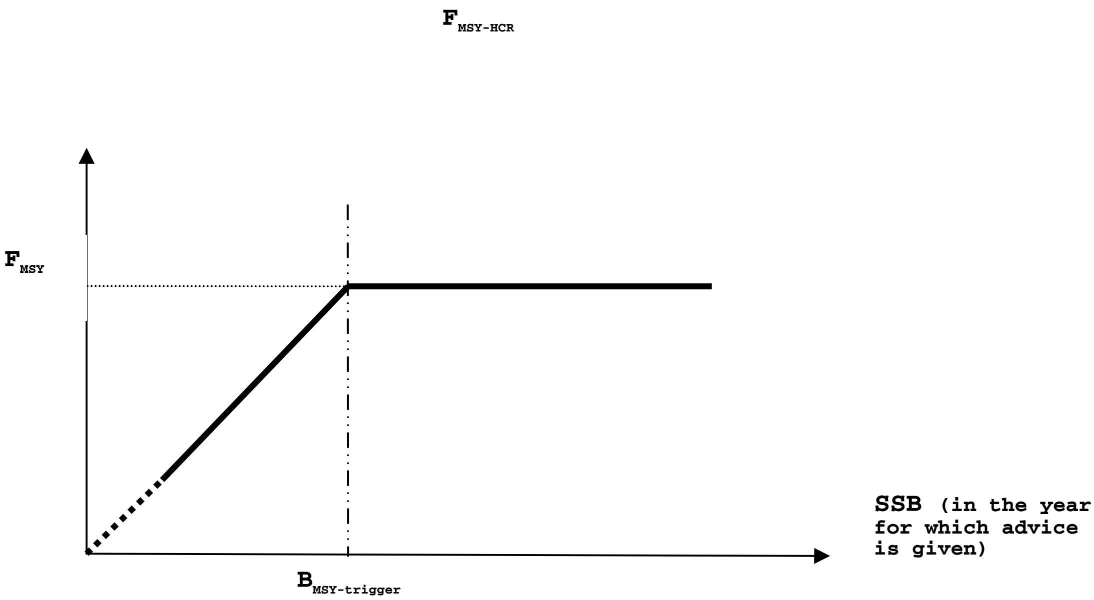

Figure 2. MSY approach shown in Harvest Control Rule (reproduced with permission of ICES; Source: *ICES Advice 2011, Book 1, p.6.*)

Appendix 1

AGENDA

1. Opening, adoption of agenda and meeting arrangements
2. Review of current development of stock assessment methods (GBYP)
3. Meta-analysis for investigation of key parameters such as steepness, virgin biomass or K, r and M

   3.1 Feedback from ISSF meeting
   3.2 Alternative approaches
4. Limit, threshold and target reference points as part of HCRs to manage risk.

   4.1 Generic harvest control rules
   4.2 Species specific case studies.
5. Other matters
6. Recommendations
7. Adoption of the report and closure

Appendix 2

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Appendix 3

LIST OF DOCUMENTS

SCRS/2011/105	A harvest control rule for depleted stocks robust to uncertainty in biological reference points. Cass-Calay, S.L., Walter, J.F. and Brown, C.A.
SCRS/2011/106	Derivation of the delta-lognormal variance estimator and recommendation for approximating variances for two-stage CPUE standardization models. Walters, J. and Ortiz, M.
SCRS/2011/110	A genetic operating model to evaluate the implications of population structure in tuna stocks: A bluefin tuna example. Kell, L.T., Fromentin, J-M., Bonhommeau, S. and Mosqueira, I.
SCRS/2011/111	The Robin Hood Approach, helping the poor at the expense of the rich: An example based on albacore. Kell, L. and Pallarés, P.

Appendix 4

EXCERPTS FROM RELEVANT DOCUMENTS DISCUSSED DURING THE MEETING

A4.1 1999 Meeting of the ICCAT Ad Hoc Working Group on Precautionary Approach

The 1999 Ad Hoc Working Group (Anon. 2000) reviewed several applications and discussions of the precautionary approach in other fora, namely ICES, NAFO, Multilateral High-Level Conference (MHLC), FAO expert consultations and national and regional approaches. This led to discussion regarding how the precautionary approach could be applied to the ICCAT situation with ICES and NAFO in particular being highlighted. ICES had proposed a HCR based on limits for fishing mortality and biomass i.e. F_{lim}, $B_{lim}$and thresholds that are designed to trigger action before the limits are reached i.e. F_{pa} and B_{pa}, While NAFO proposed F_{lim}, B_{lim}, F_{buf} and B_{buf}. The buffers in NAFO are to act in the same was as B_{pa} and F_{pa} in ICES. Depending on the "level of precaution" chosen between F_{lim} and F_{pa} in ICES and between F_{lim} and F_{buf} in NAFO, the two frameworks are comparable. Subsequently ICES realised that an operational HCR also requires the definition of a target and are currently considering the use of F_{MSY} as a target. However, management of stocks is not the responsibility of ICES and MSE has been used by the EU to develop stock specific and generic management plans for many of the stocks assessed by ICES. It was found that these plans and associated harvest control rules had to include many extra elements than originally proposed by ICES and NAFO. For example, NAFO has been applying Management Strategy Evaluation to the task of testing alternative harvest control rules to ensure the precautionary approach is adopted in its management rules (Shelton & Miller, 2009). Seven candidate management strategies were evaluated under a wide range of biological scenarios. A Precautionary Approach strategy was defined based on the break point of a segmented regression stock-recruitment model, with values of fishing mortality being determined as different proportions of $F_{0.1}$, used as implicit target mortality rate.

Different international and national organizations have used the terms "target", "limit", and "threshold" in different ways, resulting in confusion when trying to communicate these concepts (see Gabriel and Mace 1999). Here we define the terms as used by the Committee. All three terms can be used to refer to biological reference points based on either biomass or fishing mortality, or other related quantities.

A limit is a conservation reference point based on a level of biomass (B_{limit}) or a fishing mortality rate (F_{limit}) that should be avoided with high probability because it is believed that the stock may be in danger of recruitment overfishing or depensatory effects if the reference points are violated. However, if the stock falls below the limit biomass or if fishing mortality exceeds the limit F, this does not necessarily imply that the fishery must be shut down. If a stock exceeds the limit fishing mortality, reductions in fishing mortality are required as quickly as possible; if the stock falls below the limit biomass, a rebuilding plan with a specific time horizon may be required. In some other fora, limit biomass has been used in an absolute sense to imply the need to reduce fishing mortality to zero; more commonly, a gradual reduction towards F=0 at some lower biomass or even B=0 is employed. The level chosen to represent "high probability" depends on the severity of the consequences of the violation. The actual probability (risk) levels should be set by managers, in consultation with stock assessment scientists.

A target is a management objective based on a level of biomass (B_{target}) or a fishing mortality rate (F_{target}) that should be achieved with high probability on average. This generally means that the probability of exceeding the reference point should be around 50%. Targets should be set sufficiently far away from limits that they result in only a low probability that the limits will be exceeded. Fishing mortality-based targets have tended to assume more importance than biomass targets (except that the latter may be used as targets of rebuilding plans) because while fishing mortality rates can theoretically be controlled by setting quotas, it is expected that biomass will fluctuate around the corresponding biomass target.

A threshold is a level of biomass (B_{thresh}) or a fishing mortality rate (F_{thresh}) between the limit and target reference points that serves as a "red flag" and may trigger particular management actions designed to reduce fishing mortality. Biomass thresholds are used more commonly than fishing mortality thresholds. Of the four combinations of limit/ target and fishing mortality/ biomass-based reference points, the Committee believes that the most important reference points are targets based on fishing mortality rates (F_{target}) and limits based on biomass levels (B_{limit}).

A4.1.1 Potential candidates for target reference points

Based on language in the ICCAT Convention, F_{MSY} is probably the most appropriate fishing mortality-based target reference point. However, note that the corresponding B_{MSY} is only appropriate as a target in an average or equilibrium sense; i.e. in natural systems where F_{MSY} is the target, biomass should be expected to fluctuate around B_{MSY}, so there should be no unnecessary cause for alarm when biomass falls somewhat below B_{MSY} . Thus, it may make more sense to consider F-targets in conjunction with biomass limits, rather than biomass targets, *per se*. On the other hand, B_{MSY} may be a better rebuilding target than B_{limit}, because this will enhance the probability of rebuilding the age structure as well as the biomass of a previously-depleted stock.

Other potential candidates for target fishing mortality rates include biological reference points that have frequently been used as proxies for F_{MSY}. These include (i) reference points from yield per recruit analysis (e.g. $F_{0.1}$ and F_{max}), (ii) reference points from spawning biomass per recruit analysis (e.g. $F_{20\%}$, $F_{30\%}$, $F_{35\%}$, $F_{40\%}$), (iii) F=M, (iv) F_{med} calculated over a period where the fishery was believed to be in a sustainable mode, (v) empirical reference points (see, for example, Caddy 1998, ref. 10). Average or equilibrium biomass targets include the biomass levels associated with these fishing mortality reference points.

A4.1.2 Potential candidates for limit reference points

Based on paragraph 7 of Annex II of the Straddling Stocks Agreement, F_{MSY} is probably the most appropriate fishing mortality-based limit reference point.

Other potential candidates for limit fishing mortality rates include: (i) F_{crash} (equivalently, $F_{extinction}$), (ii) reference points from yield per recruit analysis (e.g. F_{max}), (iii) reference points from spawning biomass per recruit analysis (e.g. $F_{5\%}$, $F_{10\%}$, $F_{20\%}$), (iv) F_{med} calculated over a period when the fishery was believed to be in an overfished state, (v) empirical reference points (see, for example, Caddy 1998b, ref 10). Potential candidates for limit biomass levels include: B_{limit} = 20% B_0; (1-M)* B_{MSY}; MBAL (ICES 1997, 1998); $B_{MSY} * e^{-1.645\sigma}$ (ICES 1998).

4.1.3 F_{MSY} as a target vs. a limit

Annex II of the Straddling Stocks Agreement states that F_{MSY} should be a minimum standard for a limit reference point. This is potentially in conflict with the objectives of the ICCAT Convention, which imply that F_{MSY} is the target. In fact, there are very few examples where fishing mortality has been limited to F_{MSY} over a significant period of time, even where MSY has been the stated management objective, and the Committee was not aware of any examples where stocks have collapsed despite fishing mortality being maintained near F_{MSY} over a substantial period.

Generally speaking, a target refers to a management objective (e.g., maximum sustainable catch, as stated in the ICCAT Convention), while a limit refers to conservation and sustainability considerations. From a theoretical viewpoint and with this general distinction in mind, F_{MSY} has been considered so far by fisheries biologists as an optimization reference point. However, depending on the quality and quantity of available information, a situation may exist where a stock managed at F_{MSY} could encounter sustainability problems: the true fishing mortality, while maintained around a perceived F_{MSY}, could exceed some sustainable limit due to the level of uncertainty in assessments. For tuna stocks, it is not clear whether the quality and quantity of information allows an F_{MSY} management strategy to avoid sustainability problems with sufficiently high probability. Therefore, the Committee decided to investigate this and related problems using a simulation model (specified below).

A4.1.4 Harvest Control rules

A harvest control rule incorporates limit and target (and possibly threshold) reference points into a simple schematic that shows the action to be taken in terms of defining and setting fishing mortality rates or yields (y-axis) depending on the estimated biomass level (x-axis) (**App-Figure 1**). In essence, a harvest control rule can be thought of as a pre-agreed course of management actions dependent on the status of the stock.

Harvest control rules are not new to ICCAT or most other management organizations. They are simply a concise way of specifying how the current management process works conceptually. ICCAT's implicit control rule is that once biomass falls below B_{MSY} and/or fishing mortality substantially exceeds F_{MSY}, regulations (**App-Figure 2)** should be enacted to reduce fishing mortality (by reducing fishing effort or imposing quotas corresponding to reduced levels of fishing mortality and fishing effort). Thus, the Committee is not introducing a new concept; rather it is formalizing existing protocols and, more importantly, suggesting methods for evaluating the performance of these and alternative control rules (see following section on simulation models for evaluating alternative management strategies).

The simplest management strategies consist of fixing either a TAC or a fishing mortality rate for a given period. In the case of a fixed F strategy, the associated harvest control rule would consist of setting a TAC each year corresponding to the target F, based on the most recent estimate of fishing mortality. However, alternative strategies can be envisioned, in particular strategies utilizing a multi-annual basis. In such strategies, gradual changes in fishing mortality can be envisioned, from a given current value of F to the target F. These kinds of strategies may achieve the desired target while, at the same time, avoiding abrupt changes in fishing mortality and therefore in successive TAC values. Thus, it may be particularly useful to examine rebuilding strategies on a multi-annual basis. The performance of harvest control rules can be evaluated through simulation models.

A4.2 ***The precautionary approach as applied by other tuna RFMOs (SCRS/2010/023)***

Some tuna RFMOs, such as the WCPFC and IATTC, make explicit mention of the precautionary approach in their conventions, whilst others, whose conventions either predate these codes or are whose conventions have not been recently revised, are searching for other ways in which to take these codes into consideration.

Based on the case studies presented, best practices for adopting the precautionary approach were identified. Tuna RFMOs with recently adopted conventions which intend adopting the precautionary approach have specifically included reference to the approach in their conventions. This ensures all contracting parties clearly understand the aims and requirements of the approach are legally obliged to fulfil them. For RFMOs with conventions that predate the UN fish stocks agreement, the renegotiation of new conventions may be a costly and time consuming process and thus undesirable. In these cases, the precautionary approach could be formally addressed through the adoption of binding resolutions or recommendations. Again this may not be completely achievable if "opt out" clauses are maintained.

In practical terms, the scientific obligations to Precautionary Approaches are to determine the status of the stock(s) relative to limits and targets, to predict outcomes of management alternatives for reaching the targets and avoiding the limits, and to characterize the uncertainty in both of these. A convenient framework to conduct management evaluations is through the use of control rules, for which managers specify variables under their control through some functions related to the status of the stock under a pre-agreed plan for adjusting management actions. The perceived stock status is reliant upon the development of reference points (either target or limit). The calculation of these reference points requires a suitable quantity and quality of data for the species of concern. With the inclusion of stock projections, rebuilding plans can be developed should a stock be determined as being overexploited. In addition to target species, the monitoring and management of by-catch species is also necessary as is the impact of fishing activities on marine ecosystems and the environment. Socio-economic factors should also be taken into consideration. These considerations may potentially be accommodated in the MSE framework.

From a management perspective, monitoring and compliance is crucial, the latter of which should carry penalties if disregarded. Access or effort controls are also necessary to ensure populations are not unsustainably exploited. If the fishery is perceived to be over capacitated, buy back or capacity reduction schemes should be considered. Of great importance too is the reduction of IUU fishing. The management scheme employed by the RFMO should also be flexible in order to address data poor issues. The management should be able to take action and provide management for species which are data deficient but which have a strong likelihood of being adversely impacted upon by fishing activities. Where TACs are not possible to calculate or implement alternative forms of management such as closed areas or seasons should be considered to reduce fishing pressure on potentially vulnerable stocks.

A4.3 United States: Magnuson-Stevens Fishery Conservation and Management Reauthorization Act (MSRA) of 2006

The United States precautionary management methods are described in the MSRA (Public Law 109-479) and in the National Standard Guidelines (74 FR[1] 3178 (2009-01-16)). The objective of the MSRA can be summarized as follows: *Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery for the United States fishing industry. Section 301(a)(1).*

To that end, the MSRA defined "overfishing" as the level of fishing above that which would produce the maximum sustainable yield (F_{MSY}, or a proxy thereof). It also specifies four reference catch levels (**App-Figure 3**):

- OFL: The overfishing limit is the level of annual catch expected when the best estimate of F_{MSY} is applied to a stock's abundance in any given year. The OFL will be less than MSY to the degree that stock abundance is less than B_{MSY}.
- ABC: The acceptable biological catch is a level of annual catch to be set at or below the OFL based on the level of scientific uncertainty.
- ACL: The annual catch limit is the level of annual catch of a stock that serves as the basis for invoking accountability measures (AMs), defined as management controls to prevent ACLs from being exceeded, and to correct or mitigate overages of the ACL when they occur. The NS Guidelines further state that if catch exceeds the ACL for a given stock or stock complex more than once in the last four years, the system of ACLs and AMs should be re-evaluated and/or modified to improve performance and effectiveness.
- ACT: The annual catch target is the most conservative level of catch. It is recommended in the system of accountability measures to avoid exceeding the ACL (essentially accounting for management uncertainty). The ACT is optional, but regarded as useful for fisheries lacking effective in-season management controls to prevent the ACL from being exceeded. For these fisheries, management plans are advised to set ACTs sufficiently below ACLs that catches are unlikely to exceed the ACL.

A provision of the MSRA is that OFL ≥ ABC ≥ ACL. However, it should be noted that while ACL may be legally set equal to OFL, the U.S. National Marine Fisheries Service has concluded that there are few fisheries for which setting OFL, ABC, and ACL equal to each other would be appropriate.

By law, ACLs must be determined for all stocks in U.S. fisheries management plans by 2011, with the exception of species/stocks identified as "ecosystem components". To be considered for possible "ecosystem component" classification, species should, amongst other considerations:

1. Not be a target of directed fisheries
2. Not be identified as "subject to overfishing", "approaching overfished", or "overfished";
3. Be unlikely to become subject to overfishing (or overfished) according to the best available information
4. Not generally be retained for sale or personal use.

Neither the MSRA not the National Standard Guidelines specify a particular methodology to quantify or incorporate uncertainty for the determination of precautionary catch levels (ABC, ACL, ACT). Instead, the eight

[1] Federal Register.

U.S. Regional Fishery Management Councils are given broad authority to devise precautionary strategies consistent with MSRA objectives regarding the following:

1. Scientific Uncertainty (e.g. measurement error, model specification error, forecast error, environmental variability and uncertainty about overall stock productivity).
   a) ABC control rule: A specified approach to setting the ABC for a stock as a function of the scientific uncertainty in the estimate of OFL and any other scientific uncertainty.
   b) Risk policy is part of ABC control rule: The determination of ABC should be based, when possible, on the probability that an actual catch equal to the stock's ABC would result in overfishing.
   c) This probability that overfishing will occur cannot exceed 50 percent and should be a lower value.
2. Management Uncertainty
   a) Address through a full range of accountability measures.
   b) For fisheries without effective in-season management controls to prevent the ACL from being exceeded, an accountability measure (ACT) should be utilized. ACT should be set sufficiently below ACL so that catches do not exceed the ACL.
3. Overfished stocks:
   a) For overfished stocks and stock complexes, a rebuilding ABC must be set to reflect the annual catch that is consistent with the schedule of fishing mortality rates in the rebuilding plan.
   b) Councils must prepare and implement management measures within two years of the notification of an overfished or "approaching overfished" condition
   c) If the stock is overfished and overfishing is occurring, the rebuilding plan must end overfishing immediately.
   d) The rebuilding time for an overfished stock must be "as short as possible," and may not exceed 10 years + one generation time.

A4.4 Proceedings of the 2008 Joint Canada-ICCAT Workshop on the Precautionary Approach for Western Bluefin Tuna (Anon, 2009)

The Canada-ICCAT working group also considered precautionary harvest strategies. The following conclusions were reported.

1. Although population dynamics theory suggests that harvesting at F_{MSY} should be sustainable and would maintain a population at around B_{MSY}, such a policy may not perform as expected because it affords little room for errors of assessment or environmentally driven fluctuations of productivity, particularly if these are correlated over time. Further, the rate of recovery for depleted populations may be slow. Therefore, strategies that reduce fishing mortality below F_{MSY} when the stock biomass is low generally perform better, in relation to both long term yield and conservation of the resource.
2. A practical approach to incorporate the considerations discussed above is to adopt a harvest strategy that specifies a non-constant F_{REF} that is a function of biomass. When biomass becomes low F_{REF} is reduced. Minimally, such a harvest strategy requires specification of an F_{REF} and a B_{REF} at which reduction of the F reference begins. Additionally, a lower B_{REF} below which harvesting should be reduced to the lowest possible level may also be specified. Some candidate forms of harvest strategies are illustrated (**App-Figure 4)**.
3. A precautionary approach requires that uncertainties should be taken into account. The form of the advice should facilitate incorporation of greater precaution for cases with more uncertainty. One alternative is to conduct simulation experiments to determine the value of F_{REF} that results in a low probability (specified by managers) of the biomass falling below B_{MSY}, given the level of uncertainty. Another alternative is for managers to incorporate greater risk adversity when biomass is low, in addition to reducing F_{REF}.
4. Plans for rebuilding biomass to B_{MSY} may specify the rebuilding period. The group recommended that the rebuilding F be periodically updated and warned that delaying updates when there is lack of progress will require an even larger subsequent adjustment.

A4.5 A Fishery Decision-Making Framework Incorporating the Precautionary Approach. Department of Fisheries and Oceans, Canada

This document describes the fishery management policy developed by Canada based on the Precautionary Approach.

Components of the General Decision Framework:

1. Reference points and stock status zones (Healthy, Cautious and Critical).
2. Harvest strategy and harvest decision rules
3. The need to take into account uncertainty and risk when developing reference points and developing and implementing decision rules.

The three stock status zones are created by defining a Limit Reference Point (LRP), an Upper Stock Reference Point (USR) and the Removal Reference for each of the three zones (**App-Figure 5**). The LRP represents the stock status below which serious harm is occurring to the stock, and possibly also the ecosystem, associated species and fishing opportunities. The LRP is based on biological criteria and established by Science through a peer reviewed process. The Removal reference is the maximum acceptable removal rate for the stock. It is normally expressed in terms of fishing mortality (F) or harvest rate. The Removal reference includes all mortality from all types of fishing.

Table 1 provides generalized management actions to apply this decision framework to the management of key harvested stocks. Specific values for individual stock harvest strategies are to be provided through science assessments.

Both scientific uncertainty and uncertainty related to the implementation of a management approach must be explicitly considered for the Precautionary Approach. Uncertainty should be incorporated in the calculation of stock status and biological reference points. It is desirable that scientific uncertainty be quantified to the extent possible and used to assess the probability of achieving a target or of a stock falling to a certain level under a specific management approach.

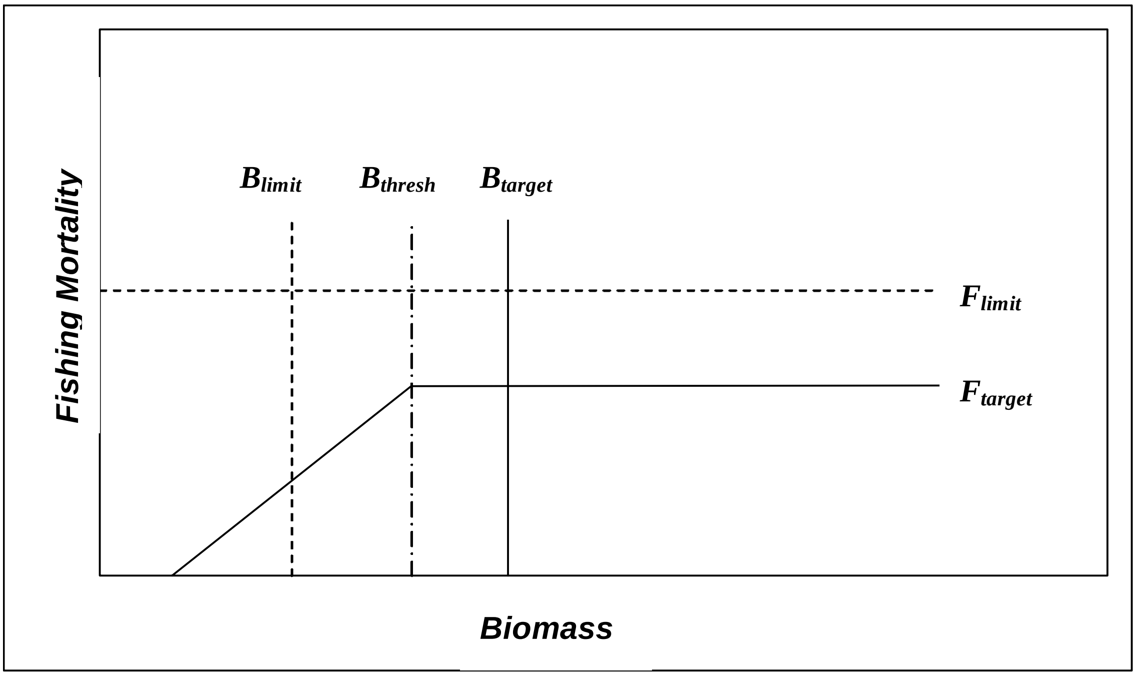
Management decisions should be explicit about the risk of decline associated with a management action by deciding on a risk tolerance for a particular management decision. Management actions would then aim to be consistent with this level of risk tolerance.

When a stock is in the critical zone, management actions must promote stock growth, and removals by all human sources must be kept to the lowest possible level. There should be no tolerance for further preventable decline. When the stock is in the Cautious or Healthy zone, management actions could be differentially considered on the basis of both stock status (e.g. abundance) and trajectory or rate of change in status. For example, management actions might appropriately vary if a stock is in the Cautious zone but clearly improving in status.

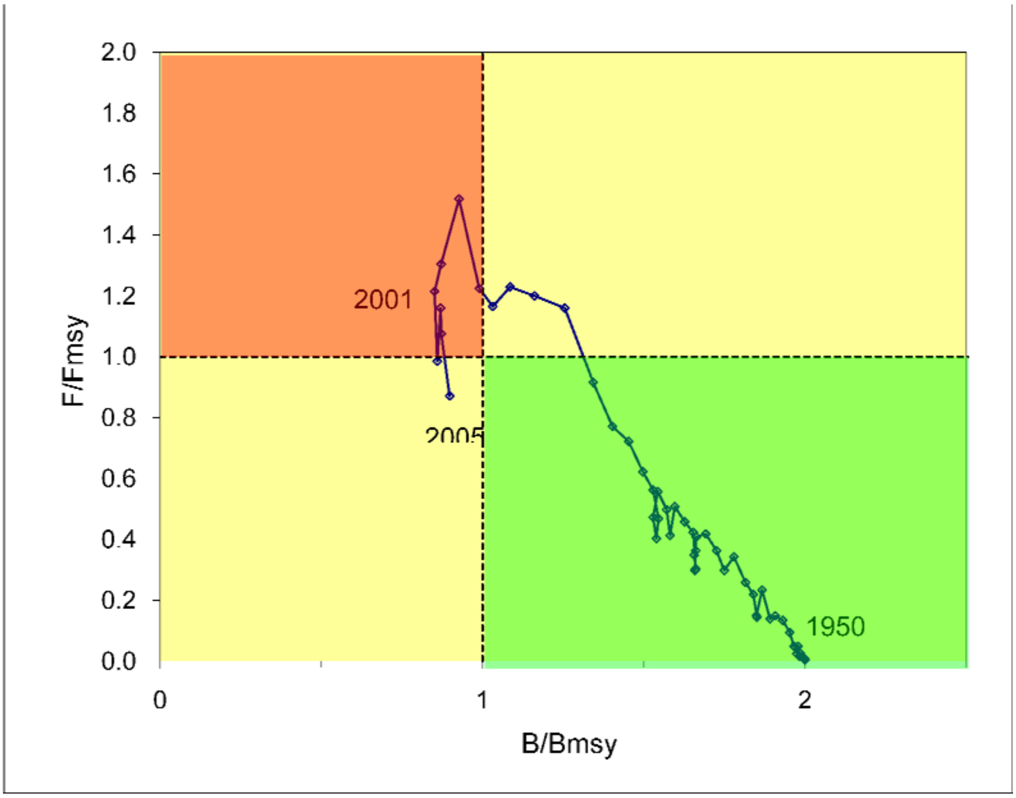
When necessary, the development of a rebuilding plan should be initiated enough in advance to ensure the plan is ready to come into effect at the boundary of the Critical and Cautious zones if a stock has declined and reached the LRP. If a stock is already in the critical zone, a rebuilding plan must be developed and implemented on a priority basis.

Table 1. Three zone Precautionary Approach framework with criteria for management actions for key harvested stocks.

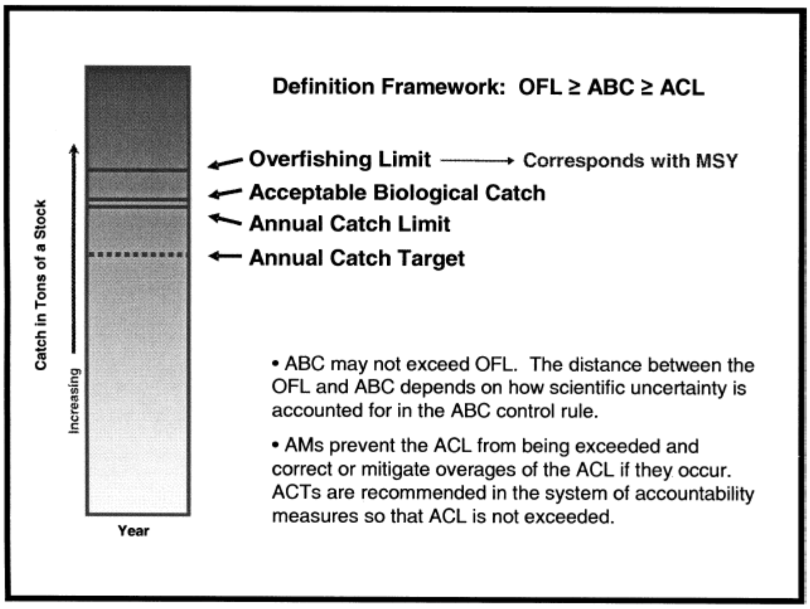
		Stock Status		
		Critical	**Cautious**	**Healthy**
General Approach		Conservation considerations prevail. Management actions cannot be inconsistent with secure recovery	Socio-economic and conservation considerations should be balanced in a manner that reflects location in zone and trajectory	Socio-economic considerations prevail. Conservation measures consistent with sustainable use apply.
Harvest rate strategy		Harvest rate (taking into account all sources of removals) kept to an absolute minimum.	Harvest rate (taking into account all sources of removals) should progressively decrease from the established maximum and should promote stock rebuilding to the Healthy Zone.	Harvest rate (taking into account all sources of removals) not to exceed established maximum.
Recent Stock Trajectory	**Increasing**	Management actions must promote stock growth. Removals from all sources must be kept to the lowest possible level until the stock has cleared the Critical Zone. A rebuilding plan must be in place with the aim of having a high probability of the stock growing out of the Critical zone within a reasonable timeframe[12]. This plan must be associated with appropriate monitoring and assessment of the condition of the stock to confirm the success of rebuilding. The plan must also include additional restrictions on catches, and a provision that application of the measures is mandatory if the evaluation fails to find clear evidence that rebuilding is occurring.	Management actions should promote stock growth to the Healthy Zone within a reasonable time frame. Risk tolerance for preventable decline – low to moderate (if high in zone)	Management actions should be tolerant of normal stock fluctuations. Risk tolerance for preventable decline – high
	Stable[11]		Management actions must encourage stock growth in the short term. Risk tolerance for preventable decline – low to moderate (if high in zone)	
	Declining		Management actions must arrest declines in the short term or immediately if low in the zone. Risk tolerance for preventable decline – very low / low. Development of a rebuilding plan is ready to come into effect if the stock declines further and reaches the critical zone.	Management actions should react to a declining trend that approaches the cautious boundary. Risk tolerance for preventable decline – moderate (if low in zone) to neutral



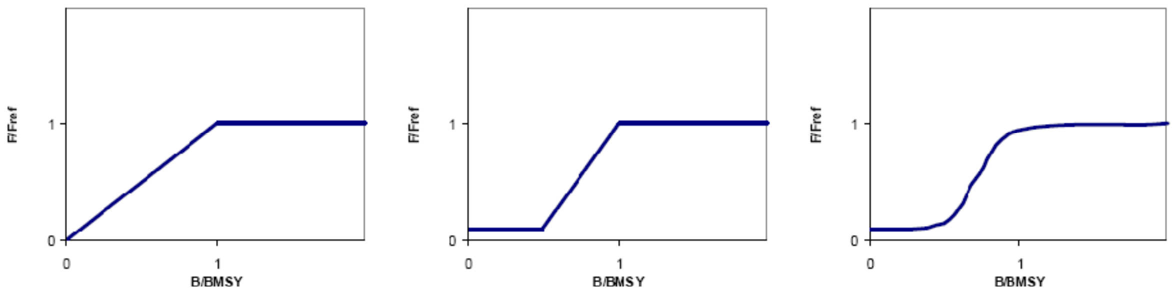
App-Figure 1. Simple example control rule based on the terminology used in this document.



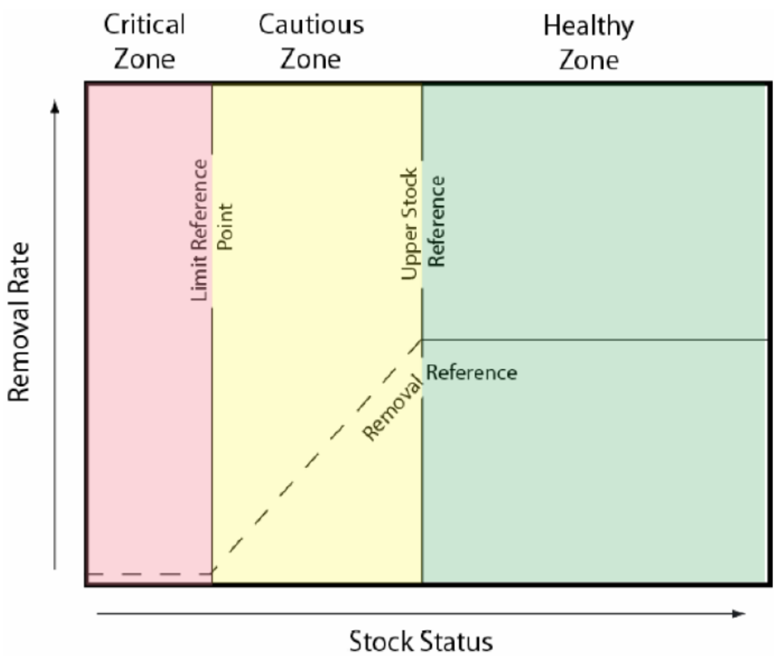
App-Figure 2. An example of the harvest control rule applied to ICCAT stocks (Anon. 2008). Values of $F/F_{MSY} \geq 1$ indicate overfishing. Values of $B/B_{MSY} <1$ indicate an overfished condition. The line shows the annual trajectory of stock status.



App-Figure 3. Description of revised MSRA management targets and limits. The annual catch target (ACT) is optional, but recommended when in-season controls/monitoring of fishing are insufficient to avoid exceeding the ACL.



App-Figure 4. Schematics of various forms of harvest strategy that comply with reduction in F_{ref} when biomass falls below B_{MSY}.



App-Figure 5. Canada's guidelines for a harvest strategy compliant with the Precautionary Approach.