INTER-AMERICAN TROPICAL TUNA COMMISSION

WORKSHOP ON MANAGEMENT STRATEGIES

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REPORT

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1. WELCOME AND INTRODUCTIONS

Dr Allen provided a brief introduction to the workshop and the background for holding it. Dr Maunder provided more detailed information on the topics to be discussed.

Due to the uncertainties in the stock assessments for tunas (*e.g.* about age-specific natural mortality, steepness of the stock-recruitment relationship, regime shifts, and assumptions of proportionality between stock size and catch per unit of effort (CPUE)), developing management strategies and assessment methods that are robust to these uncertainties would be desirable. This requires a comprehensive evaluation of available management strategies. The workshop would review approaches to the evaluation of such strategies for tunas, billfishes, and related species, with particular emphasis on management measures for bigeye tuna in the eastern Pacific Ocean (EPO), which is currently overfished and experiencing overfishing. In particular, due to the large interaction among the main tuna species and bycatch species, multi-species management strategies will be reviewed. The topics to be covered include: A) comprehensive management strategy evaluation (MSE) for tunas and billfishes, including operating models, data collection, assessment methods, harvest rules, and evaluation criteria; B) evaluation of management strategies that use spatial and temporal closures; C) evaluating other management strategies (*e.g.* gear restrictions, vessel catch limits, yield consequences of effort allocation among fishing methods); and D) multi-species MSE.

The first part of the workshop included presentations by participants of the workshop topics; the second part involved an open discussion of these topics.

2. PRESENTATIONS

2.1. Comprehensive management strategy evaluation for tunas and billfishes, including operating models, data collection, assessment methods, harvest rules, and evaluation criteria

Simon Hoyle presented an introduction to MSE. MSE is a way of linking alternative management strategies with their likely outcomes in terms of fishery performance. It is collaboration between decision makers and technical experts. In addition to being useful for answering management and science questions, it is a powerful communication tool and decision aid, to the extent that the performance indicators are relevant to the decision makers.

MSE is a comprehensive method to evaluate the management of a fish stock. It is generally implemented as follows: 1) an operating model reproduces the dynamics of the stocks and fisheries and acts as a representation of the "real world"; 2) a data generation component of the operating model generates data of appropriate types; 3) these data are fed into an assessment model; 4) the results of the assessment are used to make management decisions according to decision rules ('harvest rules'); 5) the management decisions are then applied to the operating model; and, finally, 6) the performance of the management procedures are evaluated using pre-defined criteria.

Performance indicators are outputs from the operating models that decision makers will use to compare management strategies. These performance indicators are defined so as to represent management objectives. Consultation with decision makers is vital in defining performance indicators. A suite of performance indicators might include 3 types: yield, variation in yield, and risk; for example, average catch by fishery and region, annual variation in catch by fishery and region, and probability of spawning biomass falling below a defined proportion of unfished spawning biomass.

Steven Hare presented information on the operating model used in support of the harvest policy at the International Pacific Halibut Commission[1]. The dynamics of the population are modeled as realistically as possible. Interaction of the fishery with the population is an integral part of the fish population

[1] Clark, W.G. and Hare, S.R. 2006. Assessment and management of Pacific halibut: data, methods, and policy. Int. Pac. Halibut Comm. Sci. Rep. 83: 104 pp.

dynamics. Within the operating model many of the uncertainties about stock dynamics and fishery performance are incorporated. The most important dynamics of the halibut operating model are those relating to recruitment and growth. Based on 70 years of data, recruitment is modeled as a regime shift process, alternating between high and low productivity periods of 25-35 years' duration. Average recruitment during productive periods is more than double average recruitment during unproductive regimes. Growth is modeled as a density-dependent process, with growth rates moderated by the number of adult halibut in the ocean. Size at age among the oldest halibut has varied by a factor of three (*e.g.*, a 20 year old female halibut currently weighs about 30% of what it weighed 30 years ago). The halibut operating model also considers such biological factors as temporal changes in maturity at age, variability in natural mortality rate, migration among areas and fishery factors such as variable selectivity schedules, sublegal hooking mortality and different size limits. Ultimately, a harvest policy is chosen that, across the uncertainties in the operating model, minimizes risk to the spawning biomass while achieving a large fraction of the total available yield.

Kevin Piner presented preliminary work done in collaboration with Mark Maunder (IATTC) and Ian Stewart (NOAA, NWFSC) to develop a framework for using the Stock Synthesis II model (SS2) for MSE. The automatic parametric bootstrap option of SS2 facilitates its development as an operating model for MSE analyses; however, considerable code must still be written to integrate output of generated data from the operating model into the assessment model, and subsequently the harvest strategy results from the assessment back into the operating model. A method to introduce process error into the operating model in addition to the parametric error generated in the bootstrap operation has been developed, but the forms of process error to introduce are still under discussion. Preliminary simulations indicate that the computer time needed to evaluate a suite of harvest strategies will be considerable, and that a dedicated cluster of computers may be required.

2.2. Evaluation of management strategies that use spatial and temporal closures, with emphasis on bigeye tuna in the EPO

Alain Fonteneau presented a discussion of the use of temporarily or permanently closed areas (marine protected areas, MPAs) as a management tool for tuna fisheries. Such well-selected areas can be established in a multispecies context with a combination of goals such as: 1) protecting juveniles by closing nursery areas in order to increase the yield per recruit (YPR); 2) protecting spawning stock abundance by closing spawning areas; and 3) protecting sensitive components of the pelagic ecosystems (biological "hot spots") and targeting restoration of overfished ecosystems.

The potential benefits of such areas remain difficult to estimate, as they are widely dependent on tuna movements in and out of the MPA, natural mortality at age, size of the closed area, *etc*, plus the unpredictable new fishing patterns that might be developed by the fisheries after the closure of the area. It was noted that when there is already excess fishing capacity, the closure of a large area could produce negative impacts on both the tunas and the bycatch species in the areas that are still open to fisheries. If MPAs are envisaged, their choice should be based on a careful analysis of fishery and observer data. *Ad hoc* modelling should also be developed in order to evaluate the potential consequences of the planned MPAs on the target species and the pelagic ecosystems, and also on the various tuna fisheries (purse seine and longline). The global recommendation is that these prospects of closed areas are interesting to envisage and that they should be more actively studied.

Good fishing maps, by 1° area, are essential to select the best potential closed areas, as 5° areas are most often too large and too heterogeneous. These maps should show the real fishing activities of the various fleets with circles proportional to the weights of the catches. To illustrate the time and space variability of catches in the envisaged area, time and space diagrams of catches by species are generated (Figures 1 and 2). Similar diagrams showing the monthly sizes taken each year in the selected area can also be generated (Figure 3).

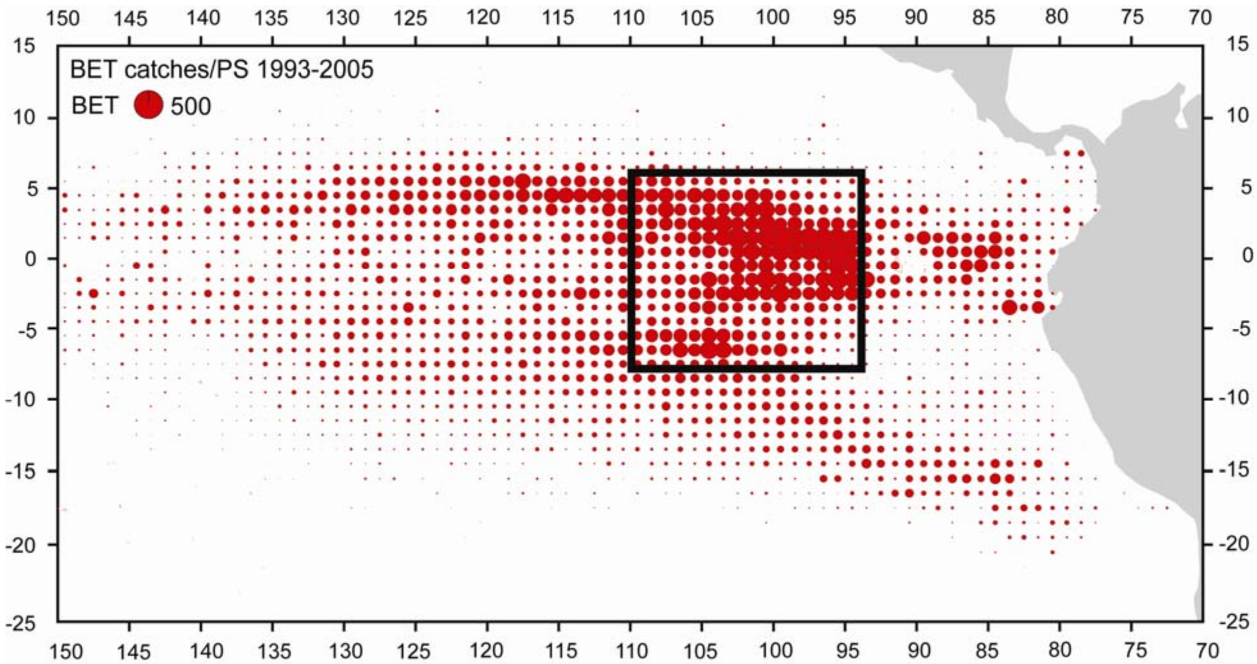

FIGURE 1. Average purse-seine catches of bigeye by 1° square, 1993-2005, and potential area closed to reduce the catches of juvenile bigeye. During 2000-2005, 12% of purse-seine effort was exerted in this area, where 7% of yellowfin catches, 20% of skipjack catches, and 40% of bigeye catches have been taken.

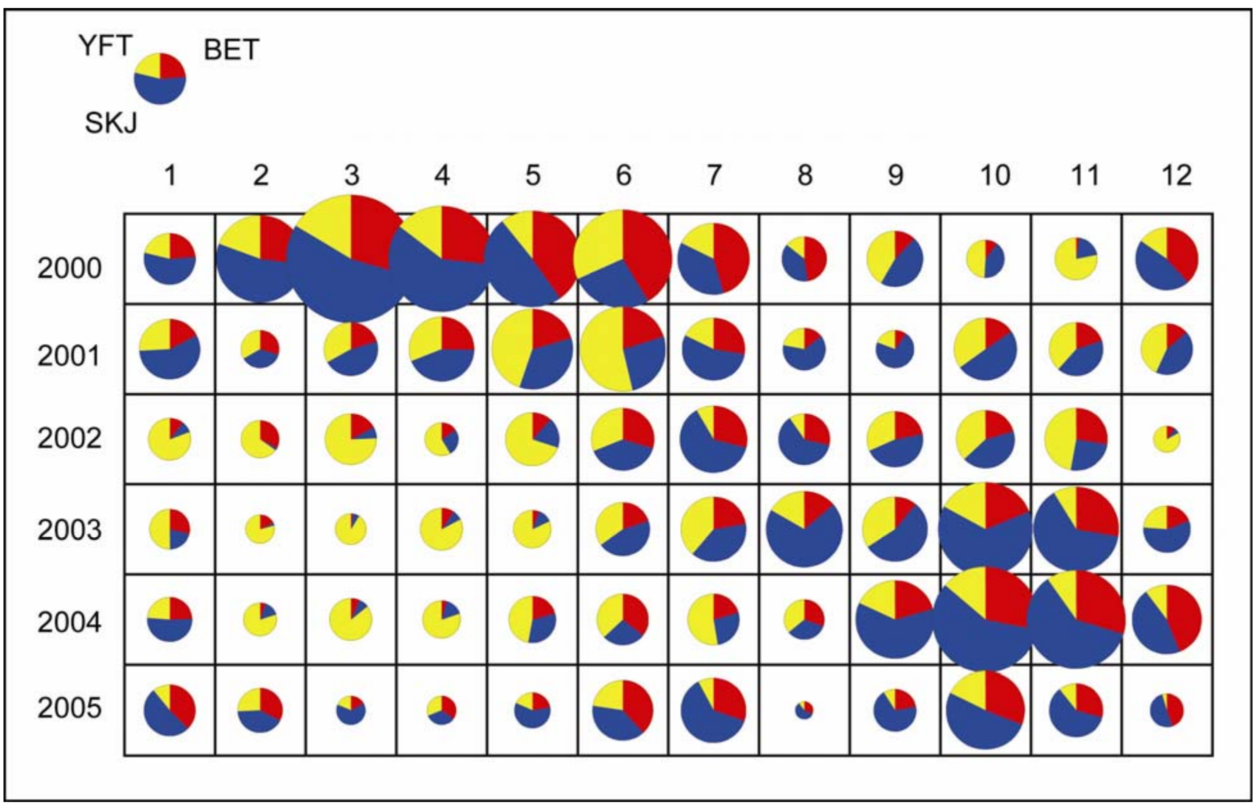

FIGURE 2. Monthly catches of yellowfin, skipjack, and bigeye by purse seiners in the potentially closed area shown on Figure 1 during 2000-2005.

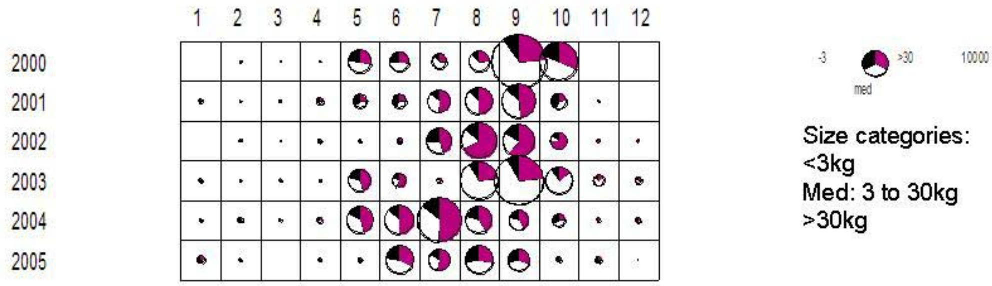

FIGURE 3. Monthly catches of yellowfin taken in the Cap Lopez area in the Atlantic Ocean, by size class.

Michel Dreyfus described methods to analyze the redistribution of effort during fishery closures. Effort allocation is an economically-driven process. In case of a closure, part of the effort is reallocated, and it is necessary to analyze where effort could be reallocated to determine the range of effects from implementing a closure. In some cases a closure could result in an allocation of effort whose effects are worse than if no management was implemented. In the case of a spatial closure, effort will shift not only spatially, but could shift temporally, especially if the area closed generates good profits.

Where will the effort be reallocated during a temporal closure? Probably where it is allocated normally during the open period, since fishers are already trying to optimize the distribution of their effort. If a closure is implemented in all areas, vessels can use this time for maintenance and repairs minimizing the effect of the regulation.

Effort redistribution can be modeled through artificial neural networks, as has been done previously, or some other optimization method. It is useful to consider which fleets or vessels are going to be affected because area of redistribution is related to the port(s) of departure, autonomy (size), mode of fishing, and target species. It is also necessary to consider the "quality" of the areas (catch, catch rates, variability *etc*.) These attributes can be used to define potential areas for effort redistribution.

Mark Maunder described the work of Harley and Suter (in press), who analyzed historical catch rates for the EPO purse-seine fishery to search for time-area "hotspots" for bigeye catches and predict the impact of closing these areas. The "hotspots" were defined by the ratio of bigeye catch to skipjack catch. Set-by-set catch and effort data from floating-object and unassociated purse-seine sets in the EPO, grouped by 5º area by quarter, were used in the analysis. Reallocation of effort from the closed area was in proportion to the effort in each of the open areas. The catch of each species was based on the new effort and CPUE of each species in each area. The calculations were repeated for each year of the 1995–2002 period to evaluate the potential variability in the effect of a closure due to interannual variation in the spatial distribution of the fish and fishing effort. The performances of the two closed areas for each quarter and year were compared. The first closed area corresponded to the "hotspots", the second closed area approximated the "hotspot" closure, but with a more practical, continuous region (5°N–10°S, 90°–120°W). The greatest reductions in bigeye catch were associated with second- and third-quarter closures. Results for both closures suggest that a closure during the second or third quarters is optimal. Because the predicted variability in performance was greater for a second-quarter closure than a third-quarter closure, the latter was preferred. Simulation of a practical closure predicted that moderate average reductions in bigeye catch (11.5%) could be achieved with lesser average reductions in skipjack catches (4.9%), but if a closure took place in a larger area for a longer time, the losses in skipjack catches will quickly outweigh the reductions in bigeye catches.

Mark Maunder presented an analysis of IATTC Resolution C-04-09 on the conservation of tuna in the

EPO, which implemented a 6-week closure during the third or fourth quarter of the year for purse-seine fisheries, and restricted longline catches to not exceed 2001 levels, during 2004-2006. The effectiveness of this measure was investigated by (1) examining the changes in purse-seine fishing effort and longline catches of bigeye in 2004 and 2005, and (2) simulating the effect of assumed purse-seine effort and longline catch in the absence of the Resolution, using forward projections of the A-SCALA stock assessment model. The spatial differences in selectivity and catchability (as different fleets chose different quarters to implement the closure) were taken into consideration, but no reallocation of effort was required, as the vessels were assumed not to fish during the closures. As expected, without the restriction the abundances of both yellowfin and bigeye tuna would be lower. Catches without restrictions would initially be greater during the first few years, but then, as the populations declined, the catches would be less. However, the reduction in effort caused by the closure was less than expected, due probably to the increased fishing capacity of the fleet and the use of closures for maintenance and repairs.

Simon Hoyle presented an approach for modelling tuna movement with Multifan-CL, which estimates quarterly transition rates by age class between regions defined in the model. If the regions can be defined at the scale of potential spatial closures, it may be possible to include the effect of tuna movement when investigating the effectiveness of such closures.

However, some aspects of the movement estimation process need further investigation. In seeking to maximize the tag-recapture, CPUE, and length-frequency likelihoods, the model may move fish around in biologically unlikely ways, particularly in strata with insufficient tag-recapture data to constrain results. The most reliable information about movement comes from the tag-recapture data. Further tagging will improve consistency, as will further investigation of biologically realistic prior distributions for movement parameters.

Another area that requires further investigation is inter-annual variation in movement rates, since, due to limitations of the data, movements are currently modeled as time-invariant seasonal rates.

Stock projections under alternative management strategies, based on the above approach using Multifan-CL, were presented for yellowfin and bigeye tuna in the western and central Pacific Ocean[2] ('. These projections, used to investigate the consequences of potential management measures, were simplistic but offer a “first look” at the relative merits of various types of management measures. A number of management measures were examined, including spatio-temporal closure of single regions for one quarter at a time.

The most important points to emerge relevant to this workshop were: 1) for bigeye, switching effort from floating-object to unassociated sets was the most effective measure investigated for the purse-seine fishery; for yellowfin, a simulated 50% reduction in floating-object set catchability provided somewhat greater biomass gains; 2) quarterly closures in individual regions were not particularly effective when effort is allowed to transfer to the neighbouring region during the closure, with the possible exception of longline closures for bigeye in the central tropical Pacific (Region 4).

2.3. Evaluating other management strategies, with a focus on bigeye tuna in the EPO

Kurt Schaefer described research done, in collaboration with Daniel Fuller, on the acoustic detection and behavior of bigeye and skipjack tunas, and potential applications of that research toward meeting the management objective of reducing the catch of small bigeye tuna in the purse-seine fishery on floating objects in the EPO.

The air-filled swimbladders of bigeye, which extend the length of the body cavity, provide a very strong, dense, acoustic signature, whereas skipjack lack a swimbladder and have a very different acoustic signature. The presence of bigeye within aggregations associated with floating objects can be detected

[2] Estimates of sustainable catch and effort levels for target species and the impacts on stocks of potential management measures, WCPFC - SC1, Hampton *et al.* 2005

with the commercial echosounders aboard purse-seine vessels. Although the proportions of bigeye and skipjack within mixed aggregations cannot be precisely determined with echosounders alone, in conjunction with sonars and visual observations from the vessel and helicopter, based on differences in color spots and the behavior of schools, fishing captains can make fairly accurate estimates of the quantities and proportions by species before they make a set.

Four sets of observations, consisting of the concurrent monitoring of pairs of skipjack and/or bigeye with implanted acoustic tags within large multispecies aggregations associated with floating objects in the EPO, were conducted in May of 2002 and 2003. The pairs of acoustically-tagged skipjack and bigeye, and the entire aggregations, were primarily upcurrent of a moored buoy and downcurrent of the drifting tagging vessel during the day. At night the aggregations were more diffuse, and were feeding on prey organisms of the deep-scattering layer. Both bigeye and skipjack showed concurrent changes in depth records, occupying significantly greater mean depths at night than during the day. The concurrent horizontal and vertical distributions of both species observed were quite similar in this study.

Archival tags recovered from five skipjack provided 9.3 to 10.1 days of depth and temperature data for each fish. In addition to observed associative behavior with the tagging vessel for the first 2 days, the fish exhibited distinct non-associative repetitive “bounce-diving” behavior between about 50 and 300 m during the day. The greatest number and longest duration of surface-oriented events occurred between 01:00 and 12:00 h and ranged from 10 to 214 minutes. The vertical habitat utilization distributions indicate that the un-associated skipjack remained above the thermocline depth (44 m) 99% of the time during the night, but below the thermocline 38% of the time during the day.

Numerous observations of large multi-species aggregations associated with drifting fish-aggregating devices (FADs) have been conducted during tagging cruises in the equatorial EPO since 2000. Skipjack schools associated with FADs at night were commonly observed to show mono-specific horizontal separation and breezing behavior near dawn and then move away shortly after dawn, sometimes up to several kilometers, to either return the next night or not at all. The associated bigeye schools would typically remain closer to the FADs throughout the day and cluster tightly around the FADs at night with the other tunas, or also disappear. Neither species commonly remained for more than a few days at a drifting FAD. Although not as easy as the normal technique of setting around FADs about an hour before dawn and catching all the associated skipjack and bigeye along with the associated bycatch species, it seems feasible from discussions with fishing captains of purse-seine vessels that skipjack schools moving away from drifting FADs after dawn could be caught independently of the other species. Experimental fishing by purse-seine vessels during fishing closures for schools of skipjack moving away from drifting FADs is recommended for evaluating this technique as a practical solution to reducing the catch of small bigeye in the FAD fishery in the EPO.

It was noted that the IATTC staff have conducted a survey of fishing captains, which concluded that they were unable to identify bigeye before setting.

Cleridy Lennert-Cody presented a preliminary analysis of the effects of purse-seine gear characteristics on catch of bigeye. The goal of the analysis was to determine if the weights of bigeye caught in floating-object sets varied with gear characteristics, once the effects of other variables had been taken into account. The gear characteristics considered in this analysis were maximum depth of the floating object below the sea surface, maximum fishing depth of purse-seine net, length of the purse-seine net, and the percentage of the floating object covered with fouling organisms. All of these variables showed temporal trends and spatial patterns over the 1996-2005 period. Other variables considered in the analysis included purse-seine set location, bathymetry, month, year, starting time of the set, several measures of local environment (*e.g.* sea surface temperature), a proxy for local object density, and a proxy for the size of the non-tuna community at the floating object. Data on over 28,000 floating-object sets made between 1996 and 2005 were used in the analysis. Data were limited to first sets on floating objects that contained some catch of one of the three target species (yellowfin, bigeye, or skipjack). To relate bigeye catch to gear and other variables, the tree-based method — random forests — was used. Several different response variables were considered: presence or absence of small bigeye, total bigeye catch, presence or absence of bigeye catches greater than 35 metric tons (t), and the ratio of bigeye catch to skipjack catch. Results of analyses based on the last two response variables were similar to those of presence/absence of small bigeye and total catch of bigeye, and thus were not presented. Preliminary results suggest that the importance of gear effects on the catch of bigeye is secondary overall to that of variables describing the location and date of the set, and the local environement. However, the importance of gear effects could be greater on small spatial scales or, for example, in El Niño years. Gear effects were found to be relatively more important in 1998, particularly for the presence or absence of small bigeye, as compared to their importance in the analysis of the pooled data set. For the presence or absence of small bigeye, the effects of object depth and net length were found to be most important among gear characteristics. Ignoring possible spatial and temporal structure in gear effects, the odds of catching small bigeye increased slightly on deeper floating objects; the effect of net length was more variable over its range. For the presence or absence of bigeye catch, net depth and net length were found to be most important among gear characteristics. Ignoring possible spatial and temporal structure in gear effects, the catch of bigeye increased slightly in deeper and longer nets. Future work will focus on studying the spatial and temporal structure of gear effects on bigeye catch to determine if gear effects may be relatively more important locally.

Mark Maunder presented an analysis of the impact of vessel catch limits for bigeye. The current bigeye stock assessment indicates that large reductions in fishing mortality are necessary to allow the stock to rebuild toward a level that would support the average maximum sustainable yield (AMSY). However, this could be difficult to achieve without a substantial reduction in skipjack catch. One method to motivate the capture of skipjack without bigeye is to place limits on the amount of bigeye that vessel is permitted to catch. Historical catch and effort data were used to determine the catch levels that would have been appropriate in previous years, and how many vessels would have been affected by these limits. During 1999-2005, between 11 and 15 vessels took 50% of the bigeye catch, but only about 5% of the yellowfin catch and 18-32% of the skipjack catch. The individual-vessel bigeye catch limits required to reduce the catch to 30% and 50% of the levels in each year are about 660-930 and 350-520 t, respectively, except for 2000, which would have required much higher limits. These limits would have affected 16-26 and 30-40 vessels, respectively, and would have resulted in a reduction of about 7-10% and 15-20%, respectively, of the total catch of all three species in those years.

Vessel quotas for bigeye tuna would hopefully motivate fishers to avoid bigeye. This might be achieved by selecting appropriate areas to fish, using sonar or echosounders to identify schools with high proportions of bigeye, modifying gear (*e.g.* shallower nets, reducing depth of netting attached to FADs), or setting on skipjack when they leave the FAD.

Mark Maunder presented an analysis of restrictions on bigeye less than 60 cm in length (<60 cm). Resolution C-00-02 required that the purse-seine fishery on FADs be closed if the catch of bigeye <60 cm in length reached the level achieved in 1999. The yield per recruit would be increased if the fishing mortality of bigeye <60 cm were reduced. Most of this catch is taken by the floating-object fisheries that have developed since 1993. The amount of bigeye <60 cm caught is generally a function of the strength of the cohorts in the fishery. In the late 1990s and early 2000s there was a substantial drop in the catch of fish <60 cm, corresponding to a period of poor recruitment. Therefore, annual variation in the amount of bigeye <60 cm caught is expected, and any controls on the catch of bigeye <60 cm would reduce fishing mortality rates on these fish in years of high abundance, but not in years of low abundance, when the reduction may be more beneficial. These results are conditioned on the assumed values for age-specific natural mortality. The rate of natural mortality (M) is uncertain, particularly for the younger fish. Changes in yield per recruit would be reduced if the rate of natural mortality for young fish was greater than that currently used in the model.

Mark Maunder presented a multi-species yield analysis of the tuna fisheries in the EPO. There are several interactions among the fisheries, with some methods capturing more than one species and some species being captured by more than one method. The different fishing methods, if applied in isolation, produce different maximum sustainable yields. Yield analysis was conducted by modifying effort for one method, but leaving the other methods at existing levels. This was repeated for yellowfin and bigeye. Skipjack catch was assumed proportional to effort. In general, reducing purse-seine effort reduces the total catch, and increasing it increases total catch. This relationship is due to the fact that skipjack comprises a large proportion of the catch, and that skipjack catch is assumed proportional to effort. However, increases in floating-object sets decrease the catch of yellowfin and bigeye. Changes in dolphin-associated sets and longline effort cause only small changes in the total catch.

2.4. Multi-species management strategy evaluation

George Watters presented an outline of multi-species management strategy evaluation (msMSE). In the context of ecosystems, utilization and conservation of single species are only proximate issues – the ultimate issue is dealing with trade-offs among fleets, species, *etc*. Two examples were presented: the first, an interaction between sea lions and a squid fishery, showed that fishery closures do not always provide the expected improvements; the second, a spatial model of krill and its predators, showed that the trade-offs may be area-specific. msMSEs that include technical interactions (several species being caught in the fishery) are much easier to develop than those that include biological interactions (*e.g.* predation). It is not clear which species should be included in msMSE when biological interactions are considered. However, biological interactions are important. msMSE that considers ecological interactions is probably not achievable in the near future, and there is a lot of work to do.

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. Management options

Several management options were identified at the workshop, and six of these were discussed in detail. The advantages and disadvantages of each of these, especially with regard to likely success, effectiveness, effect on bycatch, practicality in implementation, and research required to assess their potential, are summarized below. No attempt was made to weight the importance of each advantage or disadvantage. We also outline research that is required to determine if a management option is appropriate and, if so, how it can be implemented. It should be noted that several management options could be combined. For many of the options outlined below, industry would invest or modify its behavior to reduce the effect of the measure on catches, and this should be taken into consideration when implementing any management measure. Management options can modify the information collected from the fishery to manage the stocks, and this should be taken into consideration when deciding on a management option. In this respect, the information about the population dynamics gained from closures in comparison to other management options should be determined. Some of these management options may not appear appropriate as management rules, but may be practical for fishing captains if given the incentive.

3.1.1. Closed season

Closure of the fishery for part of the year. In general, area closures must be total to be effective. However, they may be implemented by gear, vessel flag (as is currently done) or other factors, as long as the vessels do not have an alternative option to fish for tunas in the EPO. However, closures by gear or fishing mode would have additional disadvantages. The timing of a closure must be chosen appropriately to be effective, and should be scientifically determined, rather than based on arbitrary dates. Methods used to determine the effectiveness of a closure should include the population dynamics.

Advantages

- Simple to enforce and monitor;
- Familiar to industry;
- Support for current 6-week closure by purse-seine industry partly due to the positive effect on the

market;
- Fairness;
- Could make commercial vessels available to conduct research during closure;
- May decrease discards and bycatch;
- May provide information to improve assessments (*e.g.* estimation of *M*, due to no fishing in that period causing contrast in data).

Disadvantages

- Long closure may have negative socio-economic impacts;
- May move problem to other areas;
- Does not provide incentive to catch skipjack without catching bigeye;
- Total area closures may be too coarse to address spatial and/or temporal patterns in catches;
- Closure is not species-specific, *i.e.* too long for some species and too short for others. Therefore, closures may need to be combined with other options to adjust for each species;
- May not be practical for the distant-water fleets because their trips are longer;
- Monitoring is not transparent or available for all fleets;
- Results in a loss of other target species.

Research

Research is needed to determine how much of the closure is used for normal maintenance and repairs or other activities (*i.e.* how effective the closure is).

Analyses should be conducted to evaluate the effectiveness of previous closures.

Commercial vessels could be used to conduct research (*e.g.* how to catch skipjack while minimizing catches of bigeye) during the closure.

3.1.2. Spatial closure

Closure of part of the area covered by the fishery. The closure could be restricted by gear or other characteristic, and could be permanent or for a limited period. Closed areas require appropriate enforcement and monitoring to be effective (*e.g.* VMS/observers), and are likely to require longer closures than total area closures. Timing, location, and size of closure need to be chosen appropriately to be effective, and be scientifically determined. The genetic structure of the population should be considered when designing the closed area. Monitoring programs for the stock condition inside the closed area should be considered, particularly for permanently-closed areas. Closures by gear or fishing mode would have additional disadvantages. Spatial closures have been used in the EPO in the past (*e.g.* the CYRA).

Advantages

- Familiar to industry;
- May be used to spatially or temporally avoid species with stable and/or clumped spatial distributions, for which the distribution is different from those of the target species;
- May decrease discards and bycatch;
- May provide opportunities to do research in unfished area (*e.g.* tagging studies);
- May provide information to improve assessments by analyzing closed area (*e.g.* estimation of *M*, due to no fishing in that period causing contrast in data);
- Could be used to increase yield per recruit by protecting small individuals, or spawning biomass by protecting spawning individuals.

Disadvantages

- May have uneven affects on different fishers or countries;
- Temporal variability in spatial distribution of species (*e.g.* caused by environmental fluctuations) can reduce the effectiveness of spatial closures;
- Long closure may have negative socio-economic impacts and become less efficient;
- May move problem to other areas or species;
- Does not provide incentive to catch skipjack without catching bigeye;
- May result in a loss of other target species;
- Difficult to optimize throughout the range of species, *i.e.* too long or too large for some species and too short or too small for others. Therefore, may need to combine with other options to adjust for each species;
- Monitoring is not transparent or available for all fleets;
- May not reduce overall effort;
- Difficult to predict effectiveness of closure due to uncertainty in effort reallocation and fish movement rates.

Research

Evaluate the effectiveness of previous closures (*e.g.* CYRA) to help determine if closed areas work as a management tool and to provide advice on the appropriate area closures.

Estimate the movement of relevant species, and include movement in population dynamics models to determine the effectiveness of closures.

Determine the information about the population dynamics gained from closures (e.g. natural mortality) in comparison to other management options.

Investigate alternative methods to determine optimal closures.

Determine appropriate size of closed areas.

Conduct research within closed area during closure (*e.g.* tagging).

Investigate how effort might be reallocated if a spatial closure is implemented.

3.1.3. Catch quotas

Setting a total annual catch. Quotas assigned to each fishery would involve additional allocation issues. Transferable quotas may provide additional advantages.

Advantages

- Specifically targets species;
- Flexible (*e.g.* by species, gear, vessel);
- Familiar to industry;
- May encourage methods to catch skipjack while minimizing the catches of bigeye;

Disadvantages

- Species identification problems;
- Race for fish causing economic inefficiencies (unless there are individual-vessel quotas);
- Compliance problems: under-reporting, high-grading, discarding;
- Quota policies based on constant catch do not work as well with highly-variable stocks (*e.g.* those influenced by the environment, and highly-variable recruitment);

- Difficult to convert harvest rules based on fishing mortality into catch quotas;
- Effectiveness more dependent on the quality of the stock assessments;
- May prevent full utilization of other species;
- Requires knowledge of size distribution of catch, and therefore implies allocation among gears and modes of fishing.

Research

Use MSE to investigate quota-based management (*e.g.* errors in converting harvest rules based on fishing mortality into quotas).

3.1.4. Size limits

Restricting the size of the fish that can be caught or kept. Could also be used as a quota for small fish.

Advantages

- Potential to improve yield per recruit and MSY by limiting catch of small fish;
- Potential to improve spawning biomass;
- Potential to shift the fleet away from areas of small individuals, or modify gear to avoid small individuals;
- Familiar to industry.

Disadvantages

- Discards and discard mortality;
- Requires labor-intensive monitoring;
- Difficulties in application to multi-species gear;
- Quotas on small fish limit catches in years of high recruitment but not in years of low recruitment, which may be counter to desired action;
- Possibility of genetic impacts on growth;
- May lower efficiency of fleets.

Research

Simulation analysis could be used to investigate the benefits of size limits.

MSE could be used to investigate the effect of errors in estimates of year classes on the implementation of quotas for small fish.

Estimation of discard mortality rates is needed to evaluate the effectiveness of size limits..

Gear should be developed that can minimize catches of small fish.

Acoustic methods should be investigated to identify small fish before setting.

Methods could be developed to determine year-class strength at an early age, to adjust levels of quota for small fish.

3.1.5. Particular restrictions on FADs

Restrictions on the number or characteristics of FADs used for aggregating tuna. Options could include: restriction of number of FADs per vessel, restriction on FAD design, seasonal or spatial closures of the FAD fishery, or restricting the FAD fishing process (*e.g.* sets can be made only on skipjack schools when they leave the FAD).

Advantages

- Addresses the method that is causing the greatest problem with bigeye;
- May reduce bycatch and discards (*e.g.* bigeye)

Disadvantages

- Many options also decrease skipjack catch;
- Potential to avoid restrictions due to recording floating object sets as unassociated sets.
- Difficult to monitor.

Research

FAD registration and numbering would greatly improve research on the FAD fishery.

Analyze data to evaluate the influence of fishing gear and FAD characteristics on catch of all species.

Estimate the density of FADs, FAD movement, how FADs influence catch rates, the optimum number of FADs, and other related topics.

Evaluate the change in species composition among consecutive sets, and trends in the number of consecutive sets.

3.1.6. Individual Vessel Quotas

Limits on the amount of fish of a species that a vessel can catch. This option has been recommended in the past, based on a common limit for all vessels, but has not been implemented, since it is viewed as discriminatory by some parties. Vessel quotas based on the proportion of bigeye in the catch may be more appropriate.

Advantages

- Provides an incentive to capture skipjack without catching bigeye;
- Can be used to place a constraint on the minority of the vessels that produce the majority of the problem.

Disadvantages

- Difficult to estimate bigeye catch by vessel;
- A single 'disaster' set (*i.e.* with a large catch of bigeye) could shut the vessel out of the fishery for the whole year.
- Unfairness, because it might penalize the more efficient vessels.

Research

Vessels that capture the most bigeye, or a large proportion of bigeye, should be analyzed in more detail (*e.g.* spatial distribution, gear configuration, and FAD design).

Research methods to improve the onboard estimates of bigeye catch and size distribution.

Prioritize the observer's duties to provide information that can help address current management problems.

3.1.7. Capacity limits

Defined as the ability of the fleet to catch tunas. Over-capacity is one of the fundamental problems in fisheries management, and needs to be considered in combination with all other options. Capacity limits are already being used for the EPO tuna fisheries[3]. Changes in fishing power must be considered in the calculation of appropriate capacity limits. Capacity limits should improve the economics of fishing so long as they do not lead to inappropriate investment in aspects of vessel performance that are not controlled. They are imprecise tools as a primary management mechanism, but can be used effectively to make other restrictions, such as quotas or closures, more practical.

3.2. Most promising approach for reducing the catch of bigeye tuna in the EPO purse-seine fishery

The existing 6-week closure is generally acceptable, but insufficient for yellowfin and bigeye conservation because there is too much fishing capacity in the EPO. Therefore, other management action in addition to a seasonal closure is needed; otherwise the required closure will be too long. It is more promising to develop approaches that involve the industry in a proactive rather than punitive way. One approach to developing a positive incentive for the industry to develop methods to reduce bigeye catch is to permit some vessels to fish for skipjack associated with FADs during the closed period. This could require a designed program with scientists and observers on board to test methods that avoid catching bigeye. Another possibility is to allow each vessel to continue fishing after the catch limits have been met, provided its catches of yellowfin or bigeye are kept below an acceptable limit.

3.3. Comprehensive management strategy evaluation

Comprehensive MSE requires designation of the five components: operating model, data collection, assessment method, harvest rule, and evaluation criteria. Each of these has a number of characteristics and options that must be defined; some may be obvious, others may require additional research to determine what is appropriate for the EPO tuna fisheries.

3.3.1. Operating models

All the existing stock assessment models underestimate the uncertainty in our understanding of the population dynamics. The operating model should capture the uncertainty in the states of nature. These include:

a. Spatial structure in population dynamics, selectivity, and biology, including movement
b. Sex structure
c. Uncertainty in catch, both historical and current catches
d. Spawning potential as a function of age
e. Stock-recruitment relationship
f. The shape and temporal variability in the selectivity curves
g. Natural mortality at age and through time
h. Changes in fishing power of vessels
i. Growth by sex and its potential changes over time (*e.g.* the maximum size, aging error)
j. Climatic and oceanographic influences on population dynamics
k. Changes in fishing power of vessels
l. Fleet dynamics, *e.g.* switching from targeting one area or species to another.

Bayesian analysis is probably too computationally intensive to use for representing uncertainty, and the operating model should be used by gridding over major parameters or states, as has been done for

[3] See Appendix VI of the report from the FAO Workshop on the Management of Tuna Fishing Capacity, La Jolla, California, USA, 8-12 May 2006 and the draft statement of the Workshop on Regional Economic Cooperation in the Pacific Fishery for Tropical Tunas.

southern bluefin tuna. Approaches to weighting the different states of nature should be considered. States of nature could be divided into reference cases and robustness trials.

3.3.2. Data collection

Initial analyses should generate the types and sample sizes of data currently used in the stock assessment model. Additional analyses can look at different levels of data collection and/or different types of data (*e.g.* tagging data).

The statistical distributions used to generate the data should be based on those used in the assessment models. However, additional sources of variance (*e.g.* contamination and over-dispersion) of the data should be considered. For example, the current assessments assume that all longline fleets have selectivity similar to that of the Japanese fleet, but this may not be true.

MSE should consider the possible levels of unreported catch and the potential underestimation of historical purse-seine catches of bigeye.

3.3.3. Assessment methods

MSE should, at a minimum, include the current assessment methods, simplified so that the MSEs are practical, but not so that they lose key characteristics or results. Other assessment models that are less complex, such as the Pella-Tomlinson surplus production model, should then be investigated.

Data-based assessment methods should be considered for skipjack tuna and non-target species.

3.3.4. Harvest rules

Initial MSE for tunas should focus on harvest rules based on fishing mortality (F). F_{AMSY}. and other levels of F such as 75% of F_{AMSY} should be considered. Implementation error should be considered. Input from the Commission should be solicited to extend the MSE to other harvest strategies.

3.3.5. Evaluation criteria

Input from the Commission should be solicited to determine appropriate evaluation criteria. Basic criteria should include average catch, variance in catch, and the risk of going below a specified biomass level.

3.4. Multi-species management strategy evaluation (msMSE)

The comprehensive MSE approach applied to single species may not be the most appropriate approach for ecosystems, and alternative approaches should be considered.

Multi-species management strategy evaluation (msMSE) extends MSE to analyze several species at the same time. These analyses may consider just technical interactions (several species being caught in the fishery), or may also include interactions among species (*e.g.* predation).

msMSE is necessary because, in the context of ecosystems, utilization and conservation of single species are only proximate issues – the ultimate issue is dealing with trade-offs among fleets, species, bycatch, *etc*.

At a minimum, msMSE should include species that are utilized or have an IATTC conservation mandate (*e.g.* tunas, billfishes, sharks, marine mammals, sea turtles, and seabirds). More generally, it should include species that are important for maintaining a diverse and resilient system, but current "management objectives" for such species provide no practical guidance.

Species interactions are important because models often predict indirect effects. It is probably not necessary to consider every interaction, and therefore the important interactions should be identified.

The approach for technical interactions seems more tractable and does not require species interactions in the operating models. Operating and assessment models can be based on the single species detailed in 3.3. An msMSE that considers ecological interactions is probably not yet practical, and "ecosystem management objectives" do not seem well defined, so there is little practical guidance about how to approach this. However, there are currently research efforts underway that may make this type of msMSE feasible in the future. The IATTC also has an existing ecosystem model (developed using ECOPATCH and ECOSIM) that has been used for some simple simulations to evaluate the effect of fisheries on the ecosystem, and that could be used as a basis for an operating model.

Input from the Commission should be solicited to determine management objectives with respect to the ecosystem. More research is needed on the technical issues related to ecosystem monitoring and management.

Appendix A.

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