**INTER-AMERICAN TROPICAL TUNA COMMISSION**

# BYCATCH WORKING GROUP

# 2nd MEETING

**4-6 April 2000**
**La Jolla, California, USA**

# CHAIRMAN'S REPORT

## AGENDA

1. Welcome, introductions, consideration of agenda
2. Introduction
    a. Meeting objectives and terms of reference for the working group
    b. Background to concerns about bycatch
    c. Resolution on bycatch of the 65th Meeting, October 1999
    d. Incidence and distribution of bycatch in the purse-seine fishery
3. Results of the ecological studies and modeling subgroup
4. Results of the technology and fishing techniques subgroup
5. Review and evaluation of modification of fishing practices and gear
    a. Avoiding capture of determined species
    b. Release of determined species
6. Review and evaluation of management options
    a. Time-area closures
    b. Catch, set limits
    c. Incentives
    d. Other options
7. Management recommendations
8. Other business
9. Adjournment

## DOCUMENTS

1. Terms of reference
2. Chairman's Report, 1st Meeting of the Bycatch Working Group (July 1998)
3. Report of the 1st Meeting of the Subgroup on Technology and Fishing Techniques (March 1999)
4. Report of the 1st Meeting of the Subgroup on Ecological Studies and Modeling (April 1999)
5. Options for reduction of bycatches in the tuna purse-seine fishery of the eastern Pacific Ocean
6. Resolution on bycatch, 65th Meeting of the IATTC, October 1999

## APPENDICES

1. List of attendees
2. Progress Report: Subgroup on Ecological Studies and Modeling
3. Summary of Simulations: Subgroup on Ecological Studies and Modeling
4. Recommendation on measures to reduce bycatch in the tuna purse-seine fishery of the eastern

Pacific Ocean.

## 1. Welcome, introductions, consideration of agenda

The second meeting of the Bycatch Working Group was held in La Jolla, California on 4-6 April 2000. Dr. Robin Allen, Director of the IATTC, welcomed the participants and called for candidates to serve as Chair of the meeting, and Mr. William Gibbons-Fly, of the United States, was duly elected. The provisional agenda was approved as presented. A list of participants is attached as Appendix 1.

## 2. Introduction

Dr. Allen introduced the bycatch[1] problems in the tuna fishery of the eastern Pacific Ocean (EPO) and noted that bycatch reduction is a worldwide concern. The Working Group was established in 1997 to address bycatch problems in the purse-seine fishery of the EPO. One of the concerns leading to its establishment was possible interaction between this fishery and the artisanal fisheries of Central America. Dr. Allen explained the three terms of reference for this group, noting that the first two (to define relationships among bycatch and target species, and to develop gear technology for bycatch reduction) have been addressed by meetings of the subgroups on ecological studies and modeling and of technology and fishing techniques. The third term of reference, "*to formulate and evaluate management schemes for reducing bycatch*" has largely not been considered and is therefore the objective of this meeting. Dr. Allen also explained the relevant points in the resolution on bycatch of the 65th meeting of the IATTC in October 1999.

Dr. Martín Hall, of the IATTC staff, then discussed the incidence and distribution of bycatches in purse-seine sets by vessels of 363 metric tons carrying capacity and larger. He described the spatial and temporal patterns of sets on dolphins, unassociated tunas, and floating objects, and of bycatches of tunas and other species.

Maps of catches and bycatch/catch ratios presented showed differences in the spatial and temporal concentration of bycatches of the three main tuna species (yellowfin, skipjack, and bigeye). Bycatches associated with floating objects had increased, especially since 1993 and, for all species, tended to be composed of smaller individuals than those of other set types. Some features of the patterns changed during the 1997-1998 ENSO (El Niño-Southern Oscillation) event. Bycatches of the three main tuna species tended to be greater south of 6°N, and much higher in sets on floating objects than on unassociated schools and dolphins (27,133 mt, 2,551 mt and 747 mt during 1998, respectively).

Participants discussed the effect of market conditions on recorded tuna bycatch, the need to include bycatch by vessels smaller than 363 metric tons carrying capacity, and whether closures of selected areas with certain patterns of skipjack catch and tuna bycatch could reduce bycatches.

Maps of bycatches, in estimated number of animals, of the main groups of species other than tunas (sea turtles, sharks, billfish, mahimahi, other large fish, and manta rays) showed different patterns for different species. Most of the bycatch of sharks consists of silky sharks, although there are some problems with the identification of this and other shark species. Olive ridley turtles account for the majority of the bycatches of sea turtles, but other species were also included. Bycatches of mahimahi show clear temporal and spatial patterns. Bycatches of blue marlin are most common south of 3°N, and those of manta rays are concentrated in three coastal regions.

[1] "Bycatch" is defined as all animals caught during fishing operations which are discarded dead or in a condition in which they may be expected to die in the short term.

As was the case with tunas, sets on floating objects produce the greatest bycatches, in some cases (large fishes, sharks) almost an order of magnitude greater than those for sets on dolphins or unassociated schools. Attention was focused on groups that included species of slow growth and low reproductive rates (sharks, sea turtles, billfishes and manta rays) and might therefore be more seriously affected by such bycatches; however, it was noted that information on population abundance for these groups was very limited, and that this generalization was useful but not always correct: for example, some sharks have a relatively high reproductive rate. Most bycatch of this group of species is taken south of 7°N but, when scaled by purse-seine tuna catch (numbers of animals/tuna tonnage caught), the area north of 7°N has a higher bycatch rate.

The Working Group noted the relatively low bycatches of the purse-seine fishery compared with fisheries that use other gears worldwide, and considered the possibility of prohibiting tuna discards as a regulatory measure. The question of the impact of bycatches of yellowfin, skipjack and bigeye on the stocks of these species was deferred to the Scientific Working Group.

Mexico presented a method for estimating bycatches by vessels of less than 363 metric tons carrying capacity. The Working Group discussed this procedure, and made some suggestions on how it might be made more accurate and precise.

## 3. Results of the ecological studies and modeling subgroup

Dr. Robert Olson, of the IATTC staff, talked about the recent research results of this subgroup. An *Ecopath/Ecosim* modeling approach was used in which the fishery (catches of the three purse-seine set types, longlines, and baitboats) is considered as the highest food web component. Modeling was developed as a tool for learning about the relationships among the different components of the ecosystem. Life history, energetics and dynamics are modeled explicitly for a large number of species components of the ecosystem of the tropical EPO. Some aspects of the environment are also modeled.

A report (Appendix 2) provides an update on the modeling done since the meeting of this subgroup in April 1999, discussing validation analysis, and outlines the model's potential application for evaluating bycatch management options.

A series of simulations was presented to illustrate the results of the modeling. The simulations showed the potential results of, among others, changes in fishing effort by longliners and by purse-seiners fishing on dolphins, floating objects, and unassociated schools. The simulations focused on changes in the food web resulting from increased and decreased fishing rates for each fishing method, several combinations of time and area closures, interaction with artisanal fisheries, the use of sorting grids to allow the escape of small fish, and environmental forcing driven by sea surface temperature. A summary of the main results is given in Appendix 3.

The discussion on this topic concentrated on the advisability of developing a spatial version of the model, on careful interpretation of the results, since interactions among species, such as predation, were natural, on the need to subdivide some groups, such as sharks with different life history characteristics, in the analysis, and on the relative effect of long-term environmental variability (*e.g*. ENSO events) versus short-term management actions.

## 4. Results of the technology and fishing techniques subgroup

Dr. Hall presented the results of this subgroup, reported previously in the report of the Bycatch Working Group to the 63rd IATTC meeting in June, 1999, which included a review of options, either already available or which could be developed, to reduce bycatches in the fishery. The first option is to avoid the capture of small individuals of target species and of unwanted species by examining the school prior to setting by acoustic and/or visual means. The second option is the release of unwanted individuals alive after capture, along with active rescue of certain species (sea turtles, some billfishes, and possibly sharks); the most promising approach is this regard is modification of the fishing gear, including the use of sorting grids. The third option is the retention of individuals that die in the set.

No new results are available since the last meeting of this subgroup in March 1999, except for the experimental use of a sorting grid by a purse-seiner currently fishing in the EPO. The discussion centered on the need for a research program to test the feasibility of some of these options and on the importance of industry participation in the program.

### 5 and 6. Review and evaluation of modifications of fishing practices and gear, and management options

Dr. Allen reviewed the management options available. The Commission had assigned the highest priority to dealing with bycatches of tunas, followed by bycatches of endangered or threatened species, and finally to bycatches of other non-target species.

To examine possible management schemes for reducing bycatches of commercial tuna species and selected non-target species, several options were outlined, including absolute and relative limits on bycatches, time and area closures based on absolute or relative estimators, limits on the number or characteristics of sets, especially on floating objects, and incentives and disincentives such as retention of all catches of tuna and/or other species. Regarding technical and procedural options, techniques for avoiding unwanted catches and gear modifications for the quick release of unwanted individuals were emphasized. The Working Group approved a scheme presented for reducing and eventually eliminating bycatches of sea turtles, involving the release of entangled animals by a crewmember on a speedboat as soon as they emerge from the water.

The Working Group noted the lack of direct experience with measures for reducing bycatches, with the exception of incidental dolphin mortality, the need for continued monitoring of bycatch, the lack of estimates of abundance for most non-tuna species in the bycatches, and the advisability of making any measures consistent with international instruments such as the Inter-American Convention for the Protection and Conservation of Sea Turtles and the FAO International Plan of Action for the Conservation and Management of Sharks.

The Working Group discussed possible management recommendations, focusing on long-term measures, research that would address data needs and technological developments, and possible short-term measures, based on available information, to reduce bycatch of tunas and non-target species. The main points on the discussion were:

- **Time and area closures.** This topic was extensively discussed, in particular the possibility of closing the area north of 7°N, in which the bycatch/tuna catch ratio for large vessels was higher and bycatches of some shark species were prominent, to the fishery on floating objects. A series of combinations of area and/or time closures were reviewed, especially the feasibility of closing the purse-seine fishery for the last two months of the year. It was pointed out that, in general, the ecological basis for protecting certain species is not well defined, and that the species in greatest need of protection should be identified. It was noted that the information presented by the staff was not a formal assessment of the possible effects on bycatches of closing certain areas to the fishery, but rather a general indication of some potential consequences, and that therefore any such closures needed to be considered with great care and in consultation with the industry. It was also pointed out that the recent changes in the fishery made interpreting information on the spatial distribution of bycatches difficult.

- **Incentives/disincentives**. The feasibility of a full retention policy (prohibiting discards of tunas) as a bycatch management measure was extensively discussed, and it was agreed that it had potential and could be tested in a pilot program. However, some important concerns were noted, especially in relation to the possible creation of a market or support prices for small tunas.
- **Technological and other long-term developments**. The discussion centered on the development and field-testing of sorting grids and the feasibility of developing acoustic instruments which would allow a school of fish to be examined before a set was made. Ecuador offered the use of a purse-seiner for conducting some of the necessary research.

The Working Group noted the need for a system for collecting data on bycatch of all species by all gears, and of including data from sets on unassociated tunas in the analyses.

## 7. Management recommendations

The Working Group adopted a recommendation for presentation to the IATTC Meeting in June 2000 (Appendix 4).

## Appendix 1.

# ATTENDEES - ASISTENTES

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**Appendix 2.**

# SUBGROUP ON ECOLOGICAL STUDIES AND MODELING

# PROGRESS REPORT

## 1. Summary

At the meeting of the Ecological Studies and Modeling (ESM) Subgroup of IATTC's Purse-Seine Bycatch Working Group, held on April 26-28, 1999 in La Jolla, the participants discussed various aspects of the pelagic ecosystem in the offshore regions frequented by the tuna purse-seine fishery in the eastern Pacific Ocean (EPO). The assortment of information required to construct simple steady-state and dynamic models of the ecosystem formed the framework for the discussion. The first version of an ecosystem model for the EPO was demonstrated, and recommendations for the model's improvement were made by the participants of the subgroup. The IATTC staff acted upon several of the recommendations during the subsequent year. This report is meant to provide an update to the Bycatch Working Group on the modeling that was done in the interim, to discuss a validation analysis of the model, to outline the model's potential application for evaluating bycatch management options, and to provide general conclusions derived from the EPO model in its current form.

While the IATTC staff conducted most of the analyses, considerable contributions were made by members of another Working Group, "Ecological Implications of Alternative Fishing Strategies for Apex Predators," sponsored by the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, California (www.nceas.ucsb.edu). NCEAS is funded by the U.S National Science Foundation and the State of California.

## 2. Background

There is good evidence that the total fisheries harvest potential of a system is less than the sum of the harvest potentials of the component species when considered separately. Traditional single-species assessments do not take into account the interrelationships among species. Food resources are limited, and the components of an ecosystem are interdependent through predator-prey and competitive interactions represented by the food web. Adequately assessing the status of an ecosystem would require assessments and monitoring of all major species. Fisheries data are not available for most non-target species, scientific surveys are expensive and time-consuming, and ongoing monitoring may be logistically impossible. The best strategy, at this time, is to develop models that represent the various life histories of the principal elements of the ecosystem and describe how biomass flows between them, based on the best available information on who eats whom. The models should be capable of providing answers to "what if" questions regarding the likely outcomes of alternative fishing policies. If the modeling indicates that certain groups or species are more sensitive than others to the ecological effects of fishing (*i.e.* substantial changes in biomass of non-target species resulting from a change in fishing rate), then future studies, including assessments and monitoring, could be focused on those groups. Modeling is a tool for learning about the system, and has the potential to indicate which of several management options available may be the most effective. Alternatively, and perhaps just as valuable, modeling may indicate which management options will be least effective.

With this in mind, the IATTC staff undertook a modeling analysis using the suite of software that includes Ecopath and Ecosim. The participants of the first Purse-Seine Bycatch Working Group meeting, held on 8-9 July, 1998, agreed that Ecopath and Ecosim provide a useful starting point for modeling ecosystem dynamics in the EPO, given the wide use of the approach and the fact that it requires that the analysis include all parts of the system.

## 3. EPO Ecopath model

Characteristics of the ecosystem in the pelagic habitat of the tropical EPO, as represented in the model, are outlined in the report of the first meeting of the ESM Working Group. The information required to assemble the model includes: 1) definition of the spatial scope of the model (20ºN-20ºS, 150ºW-the coastline), 2) definition of the principal species and functional groups of animals, 3) definition of the trophic connections between the model groups (diet matrix), 4) estimates of consumption rates or energy requirements of some of the groups[1], 5) estimates of biomass for some of the groups[1], 6) estimates of production rates for some of the groups[1], 7) estimates of "ecotrophic efficiency" (proportion of production consumed, harvested, or exported from the system) of some of the groups[1], 8) catch data (biomass landed and discarded) for various fleets and set types, 9) immigration and emigration to/from the system, and 10) parameters that govern transition from small to large ontogenetic groups (*i.e.* growth functions, length-weight functions, energetics information, and recruitment parameters). Five "gear types" were included in the model: baitboats, longliners, dolphin sets by purse seiners, floating-object sets by purse seiners, and schoolfish sets by purse seiners.

A number of recommendations for changing the model and for further analyses were made by the participants of the ESM Working Group. These were summarized in two categories: 1) revisions and calibrations that could be addressed within one year, and 2) long-term modeling recommendations for the tropical EPO. The recommendations are listed in the report of the first meeting. The following short-term priorities were addressed by the staff during the intervening period:

- Add model groups for swordfish, bluefin tuna, albacore tuna, and baleen whales (if it was determined that these whales feed substantially in the tropics).
- Incorporate recently-available bycatch data for the longline fishery.
- Incorporate alternative methods of estimating biomasses of some bycatch species.
- Compare previous estimates of the variability of yellowfin tuna recruitment in the EPO with that produced by the model.
- Compare top-down and bottom-up characteristics of the model, to evaluate the relative importance of environmental influences in the EPO ecosystem.
- Redefine the model area (considering, for example, ocean provinces or the main area of the surface fishery).
- Conduct a sensitivity analysis on the Ecosim output

In addition, one of the long-term priorities was acted upon, to incorporate environmental forcing, especially El Niño and La Niña signals. The following summarizes these changes and analyses.

### 3.1. Model changes

***A. Baleen whales.*** Baleen whales were not included in the first draft of the EPO model because the preliminary conclusion was that most species of baleen whales do not feed in tropical regions of the EPO. Some participants questioned that assumption. Apparently, there are resident blue whales (*Balaenoptera*

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[1] Estimates are required for three of the four components: biomass, consumption rates, production rates, or ecotrophic efficiency, for each model group.

*musculus*) in the area of the Costa Rica Dome, year round. Blue whales also reside seasonally in the Gulf of California, and are known to feed there. Bryde's whales (*B. edeni*) are also resident in coastal areas of the EPO. All other baleen whales that occur in the tropical EPO, *e.g.* humpback (*Megaptera novaeangliae*), finback (*B. physalus*), and sei whales (*B. borealis*), do not feed in the tropics.

Baleen whales were added as a group to the model. Abundance estimates, average body sizes, consumption rates, production rates, and diet composition were obtained from the scientific literature. The assumption was made that there are no landings or discards of baleen whales, and that they are not preyed upon, in the tropical EPO.

***B. Swordfish.*** Swordfish (*Xiphias gladius*) were not included in the first draft of the EPO model because they were considered to occur primarily in temperate waters, and to be a minor component in the EPO. Based on a more thorough literature review, however, it appears appropriate to include two size groups of swordfish, small and large, in the model. The two size groups were separated at 150 cm in length, as for the other billfishes, following the standard for IATTC's bycatch database.

Biomass estimates of swordfish are not available for the model area, so biomasses required for mass-balance were estimated by the Ecopath software. Estimates of consumption rates, production rates (natural mortality + fishing mortality), ecotrophic efficiency, diet composition, predation by other animals on swordfish, and growth rates were obtained from the scientific literature. The landings were determined from two sources. For the purse-seine fleet, the staff used data collected during 1993-1997 by the IATTC's on-board observers. The observers recorded numbers of swordfish caught in three size classes, and these were converted to metric tons by multiplying by average weights per size class. The bycatch data were adjusted by the proportion of total/observed sets to represent bycatches for dolphin sets, floating-object sets, and schoolfish sets for the entire fleet. The staff examined recent records of longline catches of large and small swordfish, in numbers, for Japan, Korea, Taiwan, and French Polynesia. Average lengths for the catches in the two size strata were determined from length-frequency data in the same database and numbers were converted to biomass using a published weight-length relationship.

***C. Bluefin tuna.*** Pacific bluefin tuna (*Thunnus orientalis*) (PBT) were not included in the first draft of the EPO model because they are primarily temperate in distribution when in the EPO, and a minor component of the ecosystem. Based on a more thorough review of the literature, however, one size group of bluefin was included in the model. Conventional tagging data have shown that many PBT make a trans-Pacific migration from the western to the eastern Pacific Oceans when young. The staff estimated that ecological interactions with PBT occur in only 7% of the EPO model area, and assumed they are resident in this region during four months of the year. Biomass of PBT in the western and eastern Pacific during 1966-1982 was estimated based on estimates of abundance from cohort analysis conducted by the IATTC staff, adjusted for the middle of each year, multiplied by estimates of average weights by quarter. Fishing mortality estimates from cohort analysis and a published estimate of natural mortality were summed and a biomass-weighted average total mortality rate was calculated (total mortality rate is equivalent to the production rate (production/biomass)). The diet composition of PBT in the EPO was based on a published study, and 2/3 of the annual consumption was assumed to occur outside of the model area (because of the assumption that they spend only four months per year in the EPO). Predation on PBT while in the EPO was assumed to be comparable to that for small yellowfin tuna. The landings and bycatches of bluefin by purse-seine set type were extracted from the IATTC database. No catches were recorded for baitboats. Numbers of bluefin caught by the Japanese longline fleet during 1993-1997 in the model area (there was no catch by any other longline fleet in this area) were multiplied by the average weight of PBT caught in the area and averaged over those years.

***D. Albacore tuna.*** Albacore (*Thunnus alalunga*) were not included in the first draft of the EPO model because they are primarily temperate in distribution, and a minor component in the tropical EPO. According to a published report, some albacore are caught by surface and longline gear in the northwest corner of the area encompassed by the EPO model. However, the staff decided that albacore should not be included in the EPO model because the food web in the offshore area where albacore mainly occur is considerably different from the food web throughout the main area encompassed by the EPO model (see G. Redefining the model area).

***E. Seabirds.*** In the first draft of the model, estimates of ecotrophic efficiency (EE) were too high, given that seabirds nest outside of the model area, and the vast majority of predation on seabirds occurs at the nesting sites. High EE values resulted in unrealistically high changes in seabird biomass of during Ecosim simulations. Preliminary biomass estimates for the seabirds in the two model groups, "Pursuit Birds" and "Grazing Birds," have been made recently from at-sea surveys in the EPO during 1989 and 1990. Those estimates were substituted in the model, and the new EEs computed by the software were lower and more realistic.

***F. Sharks.*** Recently-available shark bycatch data for the longline fleets of French Polynesia, Korea, Japan and Taiwan were incorporated into the model. Total numbers of sharks caught south of 35°N and east of 150°W during 1993-1997 were summed and converted to biomass. (Thirty-five degrees N is the northern limit of the catch data for tunas used in the model.) Data from Japanese research vessels were used to partition the biomass data into landings and discards of small and large sharks. Updated estimates of fishing mortality based on new catch data were used to improve the estimates of production rates for small and large sharks.

***G. Redefining the model area.*** The staff determined that redefining the model area to closer approximate the EPO surface fishery would not be a useful change. Reducing the model area would eliminate some of the catches of the longline fleet. Enlarging the model area would include temperate animals which do not occur in most of the model area. Many of the tropical species relatively close to the coast north of 20ºN are already represented in the model. These include red crabs, swordfish, tunas (including PBT), billfishes, sharks, and marine mammals. The northern boundary of the model is not drawn at a higher latitude, however, because north of 20ºN some temperate species overlap with some of the tropical species during part of the year. The model best characterizes the system south of 20ºN.

Partitioning the model into several smaller models, which correspond to previously-defined ocean provinces, presents the problem of adequately representing animals which are mobile. Several of the species and functional groups can and do move between ocean provinces. Modeling the EPO on a larger scale minimizes that problem.

### 3.2. Particle-size spectrum analysis

One of the participants of the ESM subgroup, Dr. Daniel Ware, suggested that a particle-size spectrum analysis for the EPO system might be helpful for calibrating the biomass estimates and for estimating biomasses of some of the lesser-known model groups. The staff conducted an analysis, and found the results inconclusive for the EPO model.

Dr. Ware provided guidance in conducting the analysis, and suggested to use a power factor (equation 1) of between –0.16 and –0.19 for the tropical oceanic region of the EPO model, and a shallower slope for coastal regions. The staff chose –0.16 because the model includes a small proportion of coastal regions. To estimate the proportionality constant ($A$),

$$A = \text{Producer biomass} / W_p^{-0.16} \qquad (1)$$

published estimates of biomass and mean cell weight ($W_p$) for the producers (phytoplankton and bacteria) were used. For comparison, proportionality constants were also computed based on biomass and average body-weight estimates for baleen whales, toothed whales, spotted dolphins, mesopelagic dolphins, yellowfin tuna, bigeye tuna, and mesopelagic fishes. The biomass estimates for these groups were considered to be reliable. The relationship,

$$\log B = \log A - 0.16 \log W, \qquad (2)$$

was used to estimate the biomass ($B$), in tons per million km$^2$, for the other model groups based on estimates of their mean body mass ($W$). The biomass values computed using equation 2 and the biomass estimates considered reliable were compared with those required for mass-balance, computed by Ecopath. To determine if the variability of the estimates solved for by Ecopath was reasonable, standard error statistics for the slopes of calculated biomass spectra for seven other environments published in the literature were utilized. The assumption was made that the standard error (SE) of the slope for the EPO biomass spectrum equals the assumed slope (-0.16) for the EPO multiplied by the mean coefficient of variation (CV) for the seven environments. The bounds for the EPO relationship were plotted as the assumed slope $\pm$ 2 assumed SE. There are few estimates of producer biomass available in the literature, and these estimates are important for positioning the relationship along the y-axis. Only a few groups (small and large sailfish, small and large swordfish, small marlins, and grazing birds) had biomasses estimated by Ecopath that were outside (below) the bounds of the estimates from the particle-size-spectrum . No adjustments of the biomass estimates, based on the particle-size-spectrum relationship, were made in the model because of uncertainty in the independent estimates of phytoplankton and bacteria biomass for the EPO.

### 3.3. Environmental forcing

An analysis was conducted by members of the NCEAS-sponsored Working Group mentioned previously to incorporate environmental forcing in the EPO ecosystem model. The researchers were interested in learning how a marine ecosystem with complex trophic structure responds to physical forcing of the scale of El Niño and La Niña events (El Niño-Southern Oscillation, ENSO). ENSO has been described as the strongest natural interannual climate variation on the planet. The modeling provided information on the relative scale of ecosystem responses to fisheries (top-down) versus bottom-up transfer from the producers to higher trophic levels.

Several studies have documented a close connection between primary production and ENSO events in the EPO. The EPO model, therefore, can be driven by variations in phytoplankton biomass calculated from observed relationships with sea surface temperature (SST) anomalies (average monthly SST deviations from the long-term monthly mean) for the equatorial Pacific, 5ºN to 5ºS and from the Galapagos (90ºW) to the central Pacific (150ºW). Interannual variability of SST is closely related to variability of subsurface temperature, thermocline depth, and surface winds in the tropical Pacific. This physical variability causes interannual variations in primary productivity by modifying nutrient availability via wind-driven upwelling and mixing. For the EPO model area, the relationship between relative phytoplankton biomass (P=1 under average conditions) and the SST anomalies was estimated from three sets of shipboard and satellite phytoplankton pigment data covering three recent warm (El Niño) and cold (La Niña) events. Interannual changes in P versus SST anomalies correspond to –0.047 log P per degree C. This relationship was used as an index to adjust P in Ecosim.

The Ecosim runs of the EPO model incorporating physical forcing clearly demonstrate that changes in fishing pressure by the purse-seine fishery can be detected over and above the interannual variations caused by ENSO. The model also demonstrates, however, that the ecosystem effects of management measures may not become apparent until several years after implementation, depending on the degree of change introduced. One of the motives for developing Ecosim was to give crude predictions of how long it should take for various species or groups to exhibit measurable responses to change.

### 3.4. Model comparisons with IATTC yellowfin stock assessments

The staff performed an analysis which demonstrates that the EPO ecosystem model produces results for yellowfin tuna which approximately agree with previous stock assessment work by the IATTC. This provides validation of the model.

Historical fishing effort and catch per unit effort data for yellowfin, SST anomalies, and hypothesized temperature effects on egg/larval production for yellowfin were incorporated in a simulation to see if the ecosystem model could reproduce the historical trends in biomass observed in the EPO. Fishing effort, in days fishing, for three purse-seine set types and for baitboats, and numbers of hooks for longline gear, for 1961-1997 were standardized to the effort in 1993. The physical-forcing P-SST relationship (above) was used for the same years. The inverse of the environmental forcing trend was used to simulate increased recruitment of yellowfin during warm periods, as indicated by previous research of the IATTC. The simulations resembled quite closely the pattern of Class-6 catch/effort depicted in Figure 31 of the IATTC Annual Report for 1997.

### 3.5. Sensitivity analysis

The staff considered the sensitivity of the EPO model at two levels, the Ecopath mass-balance and the Ecosim dynamic model. The basic input parameters, biomass, production/biomass ratio (P/B), consumption/biomass ratio (Q/B), and ecotrophic efficiency (EE), were varied from –50% to +50%. The effect of the changes of each input parameter on all the parameters for each group that were solved for to achieve mass balance[1] were calculated. Changes to the parameters of two groups, cephalopods and *Auxis* spp., were found to have much greater influence on the system than those for the other groups. Because the sensitivities for those two groups were high, we concentrated the second part of the sensitivity analysis on them.

The staff addressed the sensitivity of the Ecosim trajectories to changes in the basic parameters for cephalopods and *Auxis* spp. P/B, Q/B, and EE for those two groups were changed by 20%, 30%, and 50%, and the fit of the model to catch per day's fishing data for yellowfin tuna (Figure 31 of the IATTC Annual Report for 1997) was evaluated. The sensitivity analysis (Table 1) showed that reductions in the sum of squares (SS) of the fits, indicating an improvement over the initial values, occurred in only a few cases, SS improvements were slight, and in most cases the fits were worse. For the cephalopods, five of the 14 determinations showed negative changes in SS relative to the fit using the initial values, but the maximum change was only –3.3%. Positive changes in SS values, indicating a worse fit, ranged up to 69.7%. For *Auxis* spp., none of the parameter variations produced a better fit to the catch/effort data for yellowfin (Table 1).

## 4. Applications of the EPO ecosystem model

The developers of Ecosim identified, among others, the following potential uses for the model:

- Testing hypotheses about ecosystem functions
- Policy screening of proposed ecosystem management strategies
- Consistency checking for hypotheses about impact of long-term regime shifts

In terms of bycatch management, the staff's goal was to develop an assessment tool for the EPO to help evaluate the likely ecological effects of alternative management policies. The model is capable of addressing the following sorts of options:

- Reducing or increasing fishing effort on dolphin sets by purse seiners, floating-object sets by purse seiners, schoolfish sets by purse seiners, baitboats, and longliners. Simulations of changes in effort can be modeled on any "gear" independently or in combination. This might be used when considering global limits on the number of sets of a particular type or limits on the number of Fish-Aggregating Devices (FADs) that can be deployed.
- Reducing or increasing fishing effort on species or groups, both individually or in unison. This could be used to evaluate the food web responses to seasonal closures directed at species, to catch limits on particular species or suites of species, to using sorting grids in purse-seine nets, and to restrictions on characteristics of FADs (if certain characteristics are correlated with attracting certain species of particular interest).
- Closures on particular set types during certain months of the year. An example would be the moratorium on floating-object sets in late 1999.

The advantage of the model's capability to simulate changes in fishing effort on a set type versus on a species (*i.e.* the distinction between the first two points above) can be illustrated in the following example. The model indicates that the relative effects on the food web of reducing dolphin sets versus further reducing dolphin mortality in the fishery are different. The ecological effects of further reducing mortality are minimal because, according to the parameterization of the model, the dolphin populations do not increase fast enough to have a top-down effect on the food web. Reducing the number of dolphin sets, however, has a greater effect on the ecosystem because fishes with faster turnover rates than the dolphins are affected. In addition, the EPO model might be useful to evaluate the effects of establishing or increasing other types of fisheries (*e.g.* squid) on tuna yield or on the ecosystem.

## 5. General conclusions of the modeling

The following are some of the general patterns indicated by the EPO ecosystem model:

- Substantial changes in fishing effort on the three purse-seine set types affect the relative biomasses of different components of the food web in different ways.
- Substantial changes in fishing effort of longline gear have a greater effect on the food web than other gears and set types.
- Substantial changes in fishing effort for floating-object sets affect bigeye tuna.
- Sharks, marlins, and swordfish are sensitive to substantial changes in fishing.
- Ecosystem effects of management measures may not become apparent until several years after implementation, depending on the degree of change introduced, due to environmental variability.

**TABLE 1.** Results of the sensitivity analysis for the EPO *Ecosim* simulations, including the effect of 20%, 30%, and 50% changes of the P/B, Q/B, and EE parameters for cephalopods and *Auxis* spp. on the sum of squares (SS) of the model's fit to catch per day's fishing data for yellowfin tuna.

**TABLA 1.** Resultados del análisis de sensibilidad para las simulaciones del OPO de *Ecosim*, inclusive el efecto de cambios de 20%, 30%, y 50% en los parámetros P/B, Q/B, y EE para cefalópodos y *Auxis* spp. sobre la suma de cuadrados (SS) del ajuste del modelo a los datos de captura por día de pesca para atún aleta amarilla.

| Parameter | Multiplier | Initial value | Modified value | SS | % change in SS |
|---|---|---|---|---|---|
| Parámetro | Multiplicador | Valor inicial | Valor modificado | SS | Cambio en SS (%) |
| | | Cephalopods - Cefalópodos | | | |
| P/B | +0.2 | 2.0 | 2.4 | 2.2357 | -0.22 |
| P/B | -0.2 | 2.0 | 1.6 | 2.4269 | 8.32 |
| P/B | +0.3 | 2.0 | 2.6 | 2.2392 | -0.06 |
| P/B | -0.3 | 2.0 | 1.4 | 3.8030 | 69.74 |
| P/B | +0.5 | 2.0 | 3.0 | 2.2503 | 0.44 |
| P/B | -0.5 | 2.0 | 1.0 | --[1] | |
| Q/B | +0.2 | 7.0 | 8.4 | 2.2136 | -1.20 |
| Q/B | -0.2 | 7.0 | 5.6 | 2.2614 | 0.93 |
| Q/B | +0.3 | 7.0 | 9.1 | 2.1667 | -3.230 |
| Q/B | -0.3 | 7.0 | 4.9 | 2.2713 | 1.38 |
| Q/B | +0.5 | 7.0 | 10.5 | 3.2558 | 45.31 |
| Q/B | -0.5 | 7.0 | 3.5 | 2.2900 | 2.21 |
| EE | +0.2 | 0.85 | 1.02 | 2.2563 | 0.70 |
| EE | -0.2 | 0.85 | 0.68 | 2.1809 | -2.66 |
| EE | -0.3 | 0.85 | 0.595 | 2.5578 | 14.16 |
| EE | -0.5 | 0.85 | 0.425 | --[1] | |
| | | *Auxis* spp. | | | |
| P/B | +0.2 | 2.5 | 3.0 | 2.3053 | 2.89 |
| P/B | -0.2 | 2.5 | 2.0 | 2.3467 | 4.74 |

| | | | | | |
|---|---|---|---|---|---|
| P/B | +0.3 | 2.5 | 3.25 | 2.3586 | 5.27 |
| P/B | -0.3 | 2.5 | 1.75 | 2.7691 | 23.59 |
| P/B | +0.5 | 2.5 | 3.8 | 2.4959 | 11.40 |
| P/B | -0.5 | 2.5 | 1.3 | --[1] | |
| Q/B | +0.2 | 25.0 | 30 | 2.3224 | 3.65 |
| Q/B | -0.2 | 25.0 | 20 | 2.3234 | 3.70 |
| Q/B | +0.3 | 25.0 | 32.5 | 2.4556 | 9.60 |
| Q/B | -0.3 | 25.0 | 17.5 | 2.4272 | 8.33 |
| Q/B | +0.5 | 25.0 | 37.5 | 3.3352 | 48.86 |
| Q/B | -0.5 | 25.0 | 12.5 | 2.7900 | 24.53 |
| EE | +0.2 | 0.95 | 1.14 | 2.2453 | 0.21 |
| EE | -0.2 | 0.95 | 0.76 | 2.3444 | 4.64 |
| EE | -0.3 | 0.95 | 0.67 | 2.6630 | 18.85 |
| EE | -0.5 | 0.95 | 0.48 | --[1] | |

[1] The model could not balance with this modified parameter value -- El modelo no podía balancear con este valor modificado del parámetro.

**Appendix 3.**

## SUMMARY OF SIMULATIONS

A series of simulations of the eastern Pacific Ocean (EPO) *Ecopath*/*Ecosim* model was presented to illustrate the results of the Ecological Studies and Modeling Subgroup of the IATTC Bycatch Working Group. The simulations encompassed, among others, changes in fishing effort of longliners, dolphin sets by purse seiners, floating-object sets by purse seiners, and schoolfish sets by purse seiners in the EPO. Simulations involving baitboats were not shown because doubling the exploitation rate for baitboats has no effect on the food web in the model. The following modeling scenarios were shown: 1) adding environmental forcing driven by sea-surface temperature (SST) to the base of the food web; 2) a comparison with yellowfin tuna catch-per-day's fishing data; 3) increases in fishing rates for each fishing method; 4) decreases in fishing rates for some of the fishing methods; 5) a prohibition of sets on floating objects during the fourth quarter of each year; 6) a closure of the Commission's Yellowfin Regulatory Area (CYRA) during the fourth quarter of each year; 7) use of a rigid sorting grid in purse-seine sets; and 8) inclusion of unaccounted-for fishing effort for artisanal fisheries. The following summarizes the results of a subset of the simulations.

The relative biomasses predicted by the model for the various components of the system under several scenarios are presented in Table 1 and Figure 1. The *Ecosim* screen images for the runs are shown in Figures 2, 3, and 4. For the first two scenarios, the exploitation rates for purse-seine sets on (a) floating objects and (b) dolphins were increased by 100% at year 10 in simulations lasting 50 years. For the simulation involving increasing floating-object sets, the groups with the greatest percentage increase are Sea Turtles, Lg. and Sm. Sailfish, Misc. Piscivores, and Lg. and Sm. Swordfish; the groups with the greatest percentage decrease are Lg. and Sm. Sharks and Lg. and Sm. Bigeye. For the simulation involving increasing dolphin sets, the groups with the greatest percentage increase are Sea Turtles, Bluefin, and Lg. and Sm. Sailfish; the groups with the greatest percentage decrease are Lg. and Sm. Yellowfin, Lg. and Sm. Sharks, Rays, and Lg. and Sm. Marlins.

For the following two scenarios, the exploitation rates for purse-seine sets on (a) floating objects and (b) dolphins were decreased by 100% at year 10 in simulations lasting 50 years. For the simulation involving reducing floating-object sets, the groups with the greatest percentage increase are Lg. and Sm. Sharks, Lg. and Sm. Bigeye, Lg. and Sm. Sailfish and Lg. and Sm. Swordfish; the groups with the greatest percentage decrease are Sea Turtles, Lg. and Sm. Sailfish, and Lg. and Sm. Swordfish. For the simulation involving reducing dolphin sets, the groups with the greatest percentage increase are Lg. and Sm. Yellowfin, Lg. and Sm. Sharks, and Rays; the groups with the greatest percentage decrease are Bluefin, Sea Turtles, and Lg. and Sm. Sailfish.

Finally, a scenario regarding closure of the CYRA during the fourth quarter of each year was simulated in the model. The assumption was made that this would involve reducing the exploitation rate for sets on schoolfish by 50%, and increasing the exploitation rate for sets on floating objects and dolphins by 25% each. For simulations lasting 50 years, the changes in relative biomass of the system components are slight. Increases of around 5% were observed for Lg. and Sm. Sharks and Rays. The only group that was reduced by 5% or greater was Sea Turtles.

**TABLE 1.** Results of the *Ecosim* simulations of 5 fishing scenarios. The values are relative biomass changes ($B_{end}/B_{initial}$) for the various components of the EPO model.
**TABLA 1**. Resultados de las simulaciones de Ecosim para 5 escenarios de pesca. Los valores son cambios relativos en la biomasa ($B_{end}/B_{initial}$) para los distintos componentes del modelo del OPO.

| | | Double exploitation rate, year 10, on: | | No fishing, year 10, on: | | CYRA closure |
|---|---|---|---|---|---|---|
| | | Floating objects | Dolphins | Floating objects | Dolphins | |
| Model component | Componente del modelo | Tasa de explotación doble, año 10, sobre: | | Sin pesca, año 10, sobre: | | Veda del ARCAA |
| | | Objetos flotantes | Delfines | Objetos flotantes | Delfines | |
| Pursuit Birds | Aves de Caza | 1.12 | 1.05 | 0.91 | 0.98 | 0.99 |
| Grazing Birds | Aves Forrajeras | 1.10 | 1.06 | 0.92 | 0.96 | 0.99 |
| Baleen Whales | Ballenas Barbadas | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Toothed Whales | Ballenas Dentadas | 1.01 | 1.00 | 0.99 | 1.00 | 1.00 |
| Spotted Dolphin | Delfín Manchado | 1.04 | 1.02 | 0.96 | 0.99 | 0.99 |
| Meso Dolphin | Delfines Meso. | 1.04 | 1.04 | 0.98 | 0.99 | 1.00 |
| Sea Turtles | Tortugas Marinas | 1.45 | 1.33 | 0.69 | 0.82 | 0.95 |
| Lg Yellowfin | Aleta Amarilla Grande | 0.97 | 0.54 | 1.03 | 1.34 | 1.03 |
| Lg Bigeye | Patudo Grande | 0.79 | 1.01 | 1.16 | 0.99 | 1.00 |
| Lg Marlins | Marlines Grandes | 1.01 | 0.88 | 1.01 | 1.09 | 1.01 |
| Lg Sailfish | Pez Vela Grande | 1.17 | 1.14 | 0.86 | 0.90 | 0.99 |
| Lg Swordfish | Pez Espada Grande | 1.13 | 1.04 | 0.88 | 0.97 | 0.99 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Lg Mahimahi | Dorado Grande | 0.97 | 1.02 | 1.03 | 0.99 | 1.00 |
| Lg Wahoo | Peto Grande | 0.99 | 0.96 | 1.01 | 1.03 | 1.00 |
| Lg Sharks | Tiburones Grandes | 0.54 | 0.64 | 1.41 | 1.26 | 1.06 |
| Rays | Rayas | 0.99 | 0.89 | 1.01 | 1.10 | 1.07 |
| Skipjack | Barrilete | 0.91 | 1.01 | 1.09 | 1.00 | 1.01 |
| Auxis | Auxis | 1.02 | 1.09 | 0.98 | 0.93 | 0.99 |
| Bluefin | Aleta Azul | 1.00 | 1.30 | 1.00 | 0.81 | 1.00 |
| Sm Yellowfin | Aleta Amarilla Peq. | 0.97 | 0.56 | 1.03 | 1.25 | 1.02 |
| Sm Bigeye | Patudo Peq. | 0.79 | 1.01 | 1.15 | 0.99 | 1.00 |
| Sm Marlins | Marlines Peq. | 1.03 | 0.91 | 0.99 | 1.06 | 1.00 |
| Sm Sailfish | Pez Vela Peq. | 1.16 | 1.14 | 0.85 | 0.89 | 0.99 |
| Sm Swordfish | Pez Espada Peq. | 1.13 | 1.04 | 0.88 | 0.97 | 0.99 |
| Sm Mahimahi | Dorado Peq. | 0.98 | 1.02 | 1.02 | 0.98 | 1.00 |
| Sm Wahoo | Peto Peq. | 1.01 | 0.97 | 1.00 | 1.02 | 1.00 |
| Sm Sharks | Tiburones Peq. | 0.55 | 0.62 | 1.34 | 1.27 | 1.05 |
| Misc. Pisc | Pisc. Misc. | 1.14 | 1.06 | 0.89 | 0.96 | 0.99 |
| Flying fish | Peces Voladores | 0.97 | 0.97 | 1.02 | 1.02 | 1.00 |
| Misc Epi Fish | Peces Epi. Misc. | 1.00 | 0.98 | 1.00 | 1.02 | 1.00 |
| Misc Meso Fish | Peces Meso. Misc. | 1.00 | 1.01 | 1.00 | 0.99 | 1.00 |
| Cephalopods | Cefalópodos | 1.02 | 1.00 | 0.99 | 1.00 | 1.00 |
| Crabs | Cangrejos | 0.97 | 1.01 | 1.02 | 0.99 | 1.00 |

**Appendix 4.**

## RECOMMENDATION ON MEASURES TO REDUCE BYCATCH IN THE TUNA PURSE-SEINE FISHERY OF THE EASTERN PACIFIC OCEAN

The Bycatch Working Group, meeting in La Jolla, California, on April 4-6, 2000, agrees to recommend that the Commission adopt, at its meeting in June 2000, measures to reduce bycatches of juvenile tunas and non-target species in the purse-seine fishery for tunas in the eastern Pacific Ocean. In particular, the Working Group recommends:

1. That the Commission implement a one-year pilot program to require all purse-seine vessels to retain on board and land all bigeye, skipjack, and yellowfin tuna caught, in order to provide a disincentive to the capture of these small fish. The sole exception shall be the final set of a trip, when there is insufficient well space available to load all the tuna caught in that set. The results of this pilot program shall be evaluated at the end of this period. The Commission should develop appropriate terms of reference for the implementation and evaluation of this program.
2. That fishermen on purse-seine vessels be required to release, as soon as possible and unharmed, to the extent practicable, all sea turtles, sharks, billfishes, rays, mahi-mahi and other non-target species. In this regard, fishermen are encouraged to develop and utilize techniques and equipment to facilitate the rapid and safe release of any such animals.
   - The following additional measures shall apply to sea turtles:
   - Whenever a sea turtle is sighted in the net, a speedboat should be stationed close to the point where the net is lifted out of the water.
   - If a turtle is entangled in the net, net roll should stop as soon as the turtle comes out of the water and should not start again until the turtle has been disentangled and released.
   - If a turtle is brought aboard the vessel, it should, if necessary, be resuscitated before being returned to the water.
3. That the Commission instruct the Director to develop a research program to further evaluate the use of sorting grids as a means of releasing juvenile tunas from purse-seine nets, and facilitate other research to avoid bycatch, including techological innovations such as acoustic instruments, as well as means to implement the requirements of Section 2 above. The Working Group recommends that the Commission consider a program of work and budget for this program at its meeting in June 2000. The industry should also be encouraged to participate in this research program and to continue its efforts to reduce bycatches of all species to the lowest level possible.
4. That the Commission instruct the Director to further evaluate the effectiveness of other measures to reduce bycatch such as: (a) time and area closures in the eastern Pacific Ocean; (b) limits on fishing effort, such as a limit on the number of sets on floating objects and unassociated schools; and (c) limits on catches of juvenile tunas. The Director shall report the results of this evaluation, including analysis of practical ways to implement such measures, for example, quotas such as those used for reducing dolphin mortality, to the Commission by the end of 2000.
5. That the Commission establish, before the end of 2000, a program to obtain data on bycatches by purse-seine vessels not covered by the current observer program and by longline vessels and other tuna-fishing vessels, including an observer program for this purpose.
6. That the Commission consider the development and implementation of additional measures, as appropriate, based on an evaluation of the research conducted pursuant to Sections 3 to 5 above.