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CONSIDERATION OF THE EFFECTS OF THE TUNA FISHERIES OF THE EASTERN PACIFIC OCEAN UPON THE PELAGIC ECOSYSTEM

Introduction

The FAO Code of Conduct for Responsible Fisheries provides that management of fisheries should ensure the conservation not only of target species, but also of the other species belonging to the same ecosystem. In 2001, the Reykjavik Declaration on Responsible Fisheries in the Ecosystem elaborated this standard with a commitment to incorporate ecosystem considerations into fisheries management.

The IATTC has taken account of ecosystem issues in many of its decisions, but it has not often focused its attention on the entire ecosystem in which the target species, the tunas and billfishes, reside. The IATTC staff has prepared this Background Paper to provide a coherent view, summarizing what is known about the impact of the fisheries upon all species of the ecosystem. It is proposed that a similar review be presented to the Commission each year, so that when it considers the status of the tuna and billfish stocks it is provided with the opportunity to consider the ecosystem as a whole as part of its consideration of management measures.

This first Background Paper on the subject is descriptive, and does not suggest objectives for the incorporation of ecosystem considerations into the management of tuna or billfish fisheries or any new management measures. Rather, its prime purpose is to offer the Commission the opportunity to ensure that ecosystem considerations are clearly seen as part of its agenda.

This paper is intended to give a broad view of the effects of the fisheries upon the ecosystem. As such, it provides information from other reports, without describing their background or providing details about the precision of the estimates or how they may be qualified. It is important also to remember that the view that we have of the ecosystem is based on the recent past, and that the environment is subject to change on a variety of time scales, including the well known El Niño-Southern Oscillation (ENSO) fluctuations and more recently recognized longer-term changes, such as the Pacific Decadal Oscillation and some other longer-term climate changes.

In addition to reporting the catches of the principal species of tunas and billfishes, the IATTC staff has reported the bycatches of other species that are normally discarded. In this paper these bycatches are presented in the context of the effect of the fishery on the ecosystem. Unfortunately, information for the entire fishery is not available. Relatively good information is available for tunas and billfishes (Background Paper A1). The information is comprehensive for large purse seiners that carry observers, and information on retained catches is also reported for other purse seiners, pole-and-line vessels, and the much of the longline fleet. Some information is available on sharks that are retained by parts of the longline fleet. Information on bycatches and discards is also available for the large purse seine vessels that carry AIDCP observers and for some smaller purse-seiners. There is little information on bycatches and discards for other fishing vessels.

1. ANALYSIS OF THE IMPACT OF CATCHES

1.1. Single-species assessments

This section provides a summary of current information on the effect of the tuna fisheries on stocks of single species as IATTC staff or other scientists studying fisheries for tuna or tuna-like species in the EPO have estimated it. The section focuses on the current biomass of each stock considered compared to what it might have been in the absence of a fishery. The intention is to give a view of how the fishery may have altered the components of the ecosystem, rather than the detailed assessments, which for the most part can be found in other Commission documents. The section below frequently refers to comparisons with the unexploited stock size. There are no direct measurements of this, and in any case it would vary from year-to-year. What is normally meant is the stock size that would be produced in the absence of a fishery with the average recruitment observed during the period in which the stock was assessed.

1.1.1. Tunas

1.1.1.a Yellowfin

Since 1984 the yellowfin stock has been at or above the level that will provide the average maximum sustainable yield. To meet this objective, the stock size must be kept above 36% of its unexploited size. One estimate of the effect of this reduced stock size is that the predation by yellowfin on other parts of the ecosystem is reduced to about 30% of what it was in the absence of a fishery.

1.1.1.b Bigeye

Up to 1993 bigeye were taken mostly by longline fishing. By 1993 the stock size was estimated to be 62% of its unexploited size. After 1993, purse seining for tunas associated with fish-aggregating devices (FADs) took significant quantities of small and medium-sized bigeye. Currently, after several years of poor recruitment, the stock size is estimated to be at about 28% of its unexploited size.

1.1.1.c Skipjack

Skipjack assessments are far less certain than those for yellowfin and bigeye, in part because the fishery does not appear to be having much impact on the stock. However, it appears that fluctuations in recruitment cause large variations in stock size. The current estimated stock size is 23% of the average unexploited stock size.

1.1.1.d Albacore

Albacore have generally been considered as northern and southern stocks. The southern stock is thought to be at about 60% of its unexploited size, while the northern stock appears to be at about 30% of its unexploited size.

1.1.2. Billfishes

1.1.2.a Swordfish

The variations in swordfish catch per unit of effort in the EPO show no trend, suggesting that catches to date have not affected the stock significantly. The stock size is likely to be near the unexploited size.

1.1.2.b Blue marlin

Recent stock assessments of blue marlin have suggested a range of values between 50 and 90% for the ratio between the current stock size and the unexploited stock size.

1.1.2.c Striped marlin

The ratio of current striped marlin stock size to its unexploited size was estimated to have increased from about 30% to nearly 60% during 1991-1998

1.1.2.d Black marlin and sailfish

No formal stock assessment has been made for these species, although there are some data showing trends in catches which have been presented in a bulletin series published jointly be IATTC staff and Japanese scientists.

1.1.3. Dolphins

The size of the stocks of dolphins and the effects of the incidental mortality caused by the purse-seine fishery are currently being re-evaluated by the U.S. National Marine Fisheries Service (NMFS). Table 1 shows the mortality in 2001 and the most recently available NMFS estimate of stock size. Studies of the association of tunas with dolphins have been an important component of the IATTC staff's long-term approach to understanding key interactions of the ecosystem. The extent to which yellowfin tuna and dolphins compete for resources, or whether one or both of them benefits from the interaction, remain critical pieces of information to include in ecosystem models, given the large biomasses of both groups, and their high consumption of prey.

1.1.4. Sea turtles

Olive ridley turtles are, by far, the dominant species of sea turtle taken by purse seiners. They are followed by the green sea turtle, and, very occasionally, by loggerhead and hawksbill turtles. Only one leatherback mortality has been recorded during the nine years of the program. Some of the turtles are unidentified because they were too far from the vessel or it was too dark for the observer to identify them, or some similar reason. Sea turtles at times become entangled in the webbing under FADs. The average annual mortalities of turtles caused by large purse-seine vessels during 1993-2001 were as follows:

	Set type		
	Floating object	**Unassociated**	**Dolphin**
Olive ridley	55.2	21.8	11.8
Green	6.8	4.7	0.9
Loggerhead	0.7	1.4	0.1
Hawksbill	0.7	0.2	0.2
Leatherback	0.1	0.0	0.0
Unidentified	25.6	12.0	4.7
Average number of sets	4,230	5,116	8,503

The mortalities of sea turtles due to purse seining for tunas are probably much less than those due to other types of human activity.

There is no comprehensive information available on bycatches of turtles by longliners. However, based on information from other parts of the world, the mortality rates due to longlining are likely to be greater than those due to purse seining, particularly for shallow longlines targeting species such as swordfish. About 23 million of the 100 million hooks set each year in the EPO by distant-water longline vessels target swordfish with shallow longlines. In addition, there is a sizeable fleet of locally-based longline vessels that fish for tunas and billfishes.

The populations of green, loggerhead, and olive ridley turtles of the EPO are threatened, and the leatherback is endangered. The lack of comprehensive information concerning the impact of the fishery on turtles is probably the most serious weakness in understanding the effects of the fisheries for tunas and billfish on the offshore pelagic ecosystem of the EPO.

1.1.5. Sharks and other large fish

Sharks and other large fish are taken by both purse-seine and longline vessels. Some information is available on shark catches by the Japanese longline fleet, but its usefulness, except for blue shark, is doubtful. The IATTC staff has recently begun a program to obtain discard data from longline vessels, and future reports may contain estimates of these bycatches.

The average annual discards of sharks and other large fish during 1995-2000 (other than those discussed above) by large purse-seine vessels are as follows:

	Set type		
	Floating object	**Unassociated**	**Dolphin**
Dorado	534,838	11,815	311
Wahoo	261,442	412	614
Yellowtail	55,644	26,846	1,526
Rainbow runner	72,477	1,990	13
Sharks and rays	45,215	7,938	5,134

In general, there are no stock assessments available for these species in the EPO, and hence the impact of the bycatch on the stocks is not known.

The catch rates of other species in the purse-seine fishery are different for each type of set. With a few exceptions, the bycatch rates are higher in sets on floating objects, followed by unassociated sets and, at a much lower level, dolphin sets. Dolphin bycatch rates are highest for dolphin sets, followed by unassociated sets and, at a much lower level, floating-object sets. Sailfish, manta rays, and stingrays have higher bycatch rates in unassociated sets, followed by dolphin sets and then floating-object sets. Because of these differences, it is necessary to follow the changes in frequency of the different types of sets to interpret the changes in bycatch figures. The following table shows the number of sets during 1993-2001 by purse seiners that carried observers:

	Set type		
	Floating object	**Unassociated**	**Dolphin**
1993	2,063	6,267	6,953
1994	2,770	5,070	7,804
1995	3,568	5,124	7,187
1996	4,160	5,387	7,483
1997	5,828	4,977	8,995
1998	5,481	4,631	10,644
1999	4,620	6,143	8,648
2000	3,916	5,482	9,235
2001	5,660	2,963	9,578

1.2. Ecosystem effects

It is clear that the different components of an ecosystem interact. The best way to describe the relationships and explore their effects is through ecosystem modeling. Our understanding of this complex maze of connections is at an early stage, and, consequently, the current ecosystem models are most useful as descriptive devices for exploring the effects of a mix of hypotheses and established connections among the ecosystem components. Ecosystem models must be compromises between simplistic representations on the one hand and unmanageable complexity on the other.

The staff of the IATTC has developed a model of the pelagic ecosystem in the tropical EPO to explore how fishing and climate variation might affect the animals at middle and upper trophic levels. The ecosystem model has 36 components, including the principal exploited species (*e.g.* tunas), functional groups (*e.g.* sharks and flyingfishes), and sensitive species (*e.g.* sea turtles). Some taxa are further separated into categories (*e.g.* large and small marlins). In general, the model has finer taxonomic resolution at the upper trophic levels, but most of the system's biomass is contained in the middle and lower trophic levels. Fisheries landings and discards were estimated for five fishing "gears," pole-and-line, longline, dolphin sets by purse seiners, floating-object sets by purse seiners, and sets on unassociated schools by purse seiners. The model focuses on the pelagic regions; localized, coastal ecosystems are not adequately described by the model.

The ecosystem model was developed using *Ecopath with Ecosim* (EwE). The information required to parameterize the model in *Ecopath* includes, for each component of the ecosystem, estimates of diet composition, biomass, production-to-biomass ratio (*P/B*), consumption-to-biomass ratio, ecotrophic efficiency, and various parameters that determine the rates at which the animals grow and reproduce. *Ecosim* provides a tool to explore hypothesized changes in fishing and climate by means of dynamic simulations.

Most of the information describing inter-specific interactions in the model comes from a joint IATTC-NMFS project, which included studies of the food habits of co-occurring yellowfin, bigeye, and skipjack tuna, dolphins, pelagic sharks, billfishes, dorado, wahoo, rainbow runner, and others. The impetus of the project was to contribute to the understanding of the tuna-dolphin association, and a community-level sampling design was adopted. During 1992-1994 observers of the IATTC Tuna-Dolphin Program sampled the stomach contents of more than 8,200 predators from about 320 purse-seine sets of all three types. The samples included over 6,200 tunas of 5 taxa, 570 dolphins of 4 taxa, 540 dorado of 2 taxa, 500 sharks of at least 9 taxa, 235 wahoo, 110 billfishes of at least 4 taxa, and 48 rainbow runners, and were collected during all months of the year and over the entire range of the fishery during those years. The data from that study supplied much of the diet information for the ecosystem model.

A second study, funded by the Pelagic Fisheries Research Program of the University of Hawaii, will commence in 2003. Scientists from four agencies, including the IATTC, will compare the pelagic food web in the EPO with that of the more-oligotrophic western Pacific using two kinds of analyses. Standard stomach-content analysis will be used to quantify the short-term predator-prey interactions at the time the animals are caught. In addition, a more-recent approach, based on stable-isotope ratios of nitrogen and carbon, will provide a longer-term, integrated picture of the pelagic food webs. Stable $^{15}N/^{14}N$ isotope ratios will be used to assess the trophic position of a variety of predators, prey, and plankton. Also, stable $^{13}C/^{12}C$ isotope ratios from the same individuals will be used to trace the sources of primary production, in relation to upwelling and non-upwelling regions that fuel the food webs. This study will provide important information on the trophic position of the forage fishes and cephalopods in the tropical EPO, which is not currently available.

The ecosystem model has been used to evaluate the possible effects of variability in bottom-up forcing by the environment on the middle and upper trophic levels of the pelagic ecosystem. Predetermined time series of producer biomasses were put into the model, and the dynamics of the remaining components of the ecosystem were simulated. The inputted trajectories of producer biomass were intended to be representative of ENSO-scale forcing, using historical sea surface temperature (SST) anomalies as a proxy for changes in primary production that have been documented during El Niño and La Niña events. The model was also used to evaluate the relative contributions of fishing and the environment in shaping ecosystem structure in the tropical pelagic EPO. This was done by using the model to predict which components of the ecosystem might be susceptible to top-down effects of fishing, given the apparent importance of environmental variability in structuring the ecosystem. In general, animals with relatively low turnover rates (*P/B*) were influenced more by fishing than by the environment, and animals with relatively high *P/B* ratios more by the environment than by fishing.

2. ACTIONS BY THE IATTC AND AIDCP ADDRESSING ECOSYSTEM CONSIDERATIONS

Both the IATTC and Agreement on the International Dolphin Conservation Program (AIDCP) have objectives that address the incorporation of ecosystem considerations into the management of the tuna fisheries in the EPO. Actions taken in the past include:

2.1. Dolphins

a. For many years, the impact of the fishery on the dolphin populations has been assessed, and programs to mitigate that impact have met with considerable success.

b. Studies to determine why tunas associate with dolphins have been carried out.

c. The incidental mortality of each stock of dolphins has been limited to levels which are insignificant compared to stock sizes.

2.2. Sea turtles

a. A database on all sea turtle sightings, captures, and mortalities reported by observers has been compiled.

b. A resolution on releasing and handling of sea turtles captured in purse-seine nets has been adopted.

c. A resolution on webbing under FADs has been adopted.

2.3. Other species

A resolution on live release of sharks, rays, and other bycatch species has been adopted.

2.4. All species

a. Data on the bycatches by large purse-seiners have been collected, and plans have been made to expand the activity to smaller vessels and other gears.

b. Data on the spatial distributions of the bycatches and the bycatch/catch ratios have been collected for analyses of policy options to reduce bycatches.

c. Information to evaluate measures to reduce the bycatches, such as closures, effort limits, *etc*., has been collected.

d. Assessments of habitat preferences and the effect of environmental changes have been made.

3. FUTURE DEVELOPMENTS FOR ECOSYSTEM ANALYSES

This section presents some considerations about some of the requirements for characterizing the effects of fishing on the ecosystem and describes some of the complexities of environmental features that must be taken into account in gaining an understanding the ecosystem of the EPO.

It is unlikely, in the near future at least, that there will stock assessments for most of the bycatch species. In lieu of formal assessments, it may be possible to develop indices to assess trends in the status of these species. The staff's experience with dolphins suggests that the task is not trivial if relatively high precision is required.

An array of measures has been proposed to study changes in ecosystem properties. This could include studies of average trophic level, size spectra, dominance, diversity, *etc*., to describe the ecosystem in an aggregate way.

The distributions of the fisheries for tunas and billfishes in the EPO are such that several regions with different ecological characteristics ("Longhurst regions") may be included. Within them, water masses, oceanographic or topographic features, influences from the continent, *etc*., may generate heterogeneity that affects the distributions of the different species and their relative abundances in the catches. It would be desirable to increase our understanding of these ecological strata so that they can be used in our analyses.

Environmental conditions affect the target populations, all other components of the ecosystem, and the operations of the fishermen. Very few ocean areas of the world show the changes as dramatic as those that take place in the EPO during an El Niño event. In addition, many less dramatic events are constantly taking place. In broad terms, water temperature controls the horizontal and vertical distributions of the tunas and billfishes. Currents also have an important impact. The drift of floating objects, with their associated communities, depends on the currents. Currents also transport eggs and larvae, determining their location, and their patchiness. Fronts change the productive conditions, and in some cases create areas of attraction for tunas and billfishes. Upwelling brings nutrients from the deeper layers to the surface, and in the EPO the Peru Current is one of the most productive areas of the world. Turbulence, at a very small scale, has a significant impact on the survival of fish larvae. Along the coastline, the contributions of organic matter, fresh water, nutrients, and debris that rivers bring to the ocean are quite significant, and create special conditions that in some cases result in high productivity and areas that are very favorable for the development of the early life stages of many species. Topographic features, such as islands and seamounts, change oceanographic conditions around them, and many constitute very rich habitats. Some species are permanent residents in these locations; others use them as stages in longer migrations. They are usually highly diverse areas. El Niño events, with periodicity of around 4-7 years, change not only water temperature, but also current speed and direction, upwelling intensity, precipitation patterns, and many other components of the environment. Inter-decadal changes were first described for the North Pacific a few years ago, but the most recent observations show that there are also changes with a periodicity of decades that affect the EPO ecosystem. One such shift may have happened in 1976-1978, and many oceanographers believe that 1998 may have been another pivotal year. The recruitment of yellowfin to the fishery was apparently greater during 1985-1999 than during 1975-1984. Because the productivity in the system can change dramatically under different regimes, their effect on all components of the ecosystem is very important. These changes increase the uncertainty about the parameters used to model the target stocks (*i.e.* the carrying capacity is not the same; recruitment, growth and mortality may respond to the changes, *etc.*), the trends observed for all populations, and even the fishing operations (*i.e.* changes in current speeds, depth of the thermocline, *etc.*).

Trends in atmospheric temperature and carbon dioxide have been described for the Central Pacific. The long-term effects are not well understood, but if the water temperatures increase or decrease the ranges of many species will, no doubt, respond to such changes.

This list, although by no means complete, shows the diversity and complexity of the ways in which the environment affects the target species and the rest of the ecosystem. It is, of course, not possible or necessary for the IATTC staff to address more than a small fraction of these. However, priorities should be set, and use made of results of work by national and international research groups that are investigating the same area.

TABLE 1. Preliminary estimates of mortalities of dolphins in 2001, estimates of population abundance pooled for 1986-1990 (from Report of the International Whaling Commission, 43: 477-493), and estimates of relative mortality (with approximate 95-percent confidence intervals), by stock. All the data for 2001 are preliminary.

Stock	Incidental mortality	Population abundance	Relative mortality (%)
Offshore spotted—Manchado de altamar			
Northeastern—Nororiental	588	730,900	0.08 (0.061, 0.101)
Western/southern—Occidental y sureño	311	1,298,400	0.024 (0.019, 0.033)
Spinner dolphin—Tornillo			
Eastern—Oriental	469	631,800	0.08 (0.046, 0.112)
Whitebelly—Panza blanca	372	1,019,300	0.04 (0.023, 0.048)
Common dolphin—Común			
Northern—Norteño	94	476,300	0.02 (0.011, 0.042)
Central	203	406,100	0.05 (0.026, 0.098)
Southern—Sureño	46	2,210,900	<0.01 (0.001, 0.003)
Other dolphins—Otros delfines[1]	46	2,802,300	<0.01 (0.001, 0.002)
Total	2,129	9,576,000	0.02 (0.019, 0.025)

[1] "Other dolphins" includes the following species and stocks, whose observed mortalities were as follows: striped dolphins (*Stenella coeruleoalba*), 3; bottlenose dolphins (*Tursiops truncatus*), 1; and unidentified dolphins, 40.