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**ECOSYSTEM CONSIDERATIONS**

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**1. 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 an ecosystem approach into fisheries management.

The IATTC has taken account of ecosystem issues in many of its decisions, and this report on the offshore pelagic ecosystem of the tropical and subtropical Pacific Ocean, which is the habitat of tunas and billfishes, has been available since 2003 to assist in making its management decisions. This section provides a coherent view, summarizing what is known about the direct impact of the fisheries upon various species and species groups of the ecosystem, and reviews what is known about the environment and about other species that are not directly impacted by the fisheries but may be indirectly impacted by means of predator-prey interactions in the food web.

This review does not suggest objectives for the incorporation of ecosystem considerations into the management of tuna or billfish fisheries, nor any new management measures. Rather, its prime purpose is to offer the Commission the opportunity to ensure that ecosystem considerations are part of its agenda.

It is important to remember that the view that we have of the ecosystem is based on the recent past; we have almost no information about the ecosystem before exploitation began. Also, the environment is subject to change on a variety of time scales, including the well-known El Niño fluctuations and more recently recognized longer-term changes, such as the Pacific Decadal Oscillation and other climate changes.

In addition to reporting the catches of the principal species of tunas and billfishes, the staff has reported the bycatches of non-target species that are either retained or discarded. In this section, data on these bycatches are presented in the context of the effect of the fishery on the ecosystem. Unfortunately, while relatively good information is available for the tunas and billfishes, information for the entire fishery is not available. The information is comprehensive for large (carrying capacity greater than 363 metric tons) purse seiners that carry observers under the Agreement on the International Dolphin

Conservation Program (AIDCP), and information on retained catches is also reported for other purse seiners, pole-and-line vessels, and much of the longline fleet. Some information is available on sharks that are retained by parts of the longline fleet. Information on retained and discarded non-target species is reported for large purse-seiners, and is available for very few trips of smaller ones. There is little information available on the bycatches and discards for other fishing vessels.

## **2. IMPACT OF CATCHES**

### **2.1. Single-species assessments**

Current information on the effects of the tuna fisheries on the stocks of individual species in the eastern Pacific Ocean (EPO) and the detailed assessments are found in this document. An ecosystem perspective requires a focus on how the fishery may have altered various components of the ecosystem. Sections 2.2 and 2.3 of this report refer to information on the current biomass of each stock considered, compared to estimates of what it might have been in the absence of a fishery. There are no direct measurements of the stock size before the fishery began, and, in any case, the stocks would have varied from year to year. In addition, the unexploited stock size may be influenced by predator and prey abundance, which is not included in the single-species analyses.

### **2.2. Tunas**

Information on the effects of the fisheries on yellowfin, bigeye, and skipjack tunas is found in Documents SAC-05-[07](#), [08a](#), and [09a](#), respectively, and Pacific bluefin tuna is addressed in Document SAC-05-[10a](#) and the [report of the ISC Working Group](#). Albacore tuna will be addressed at this meeting and a report of the complete stock assessment is expected to be finished by the ISC Northern Albacore Working Group during the first semester of 2014.

### **2.3. Billfishes**

Information on the effects of the tuna fisheries on swordfish, blue marlin, striped marlin, and sailfish is presented in Sections G-J of IATTC [Fishery Status Report 11](#).

#### **2.3.1. Black marlin and shortbill spearfish**

No recent stock assessments have been made for these species, although there are some data published jointly by scientists of the National Research Institute of Far Seas Fisheries (NRIFSF) of Japan and the IATTC in the IATTC Bulletin series that show trends in catches, effort, and catches per unit of effort (CPUEs).

### **2.4. Summary**

Preliminary estimates of the catches (including purse-seine discards), in metric tons, of tunas, bonitos, and billfishes during 2013 in the EPO are found in Tables A-2a and A-2b of Document [SAC-05-06](#).

### **2.5. Marine mammals**

Marine mammals, especially spotted dolphins (*Stenella attenuata*), spinner dolphins (*S. longirostris*), and common dolphins (*Delphinus delphis*), are frequently found associated with yellowfin tuna in the size range of about 10 to 40 kg in the EPO. Purse-seine fishermen have found that their catches of yellowfin in the EPO can be maximized by setting their nets around herds of dolphins and the associated schools of tunas, and then releasing the dolphins while retaining the tunas. The incidental mortality of dolphins in this operation was high during the early years of the fishery, and the populations of dolphins were reduced from their unexploited levels during the 1960s and 1970s. After the late 1980s the incidental mortality decreased precipitously, and there is now evidence that the populations are recovering. Preliminary mortality estimates of dolphins in the fishery in 2013 are shown in Table 1.

Studies of the association of tunas with dolphins have been an important component of the staff's long-term approach to understanding key interactions in the ecosystem. The extent to which yellowfin tuna and dolphins compete for resources, whether either or both of them benefits from the interaction, why the tuna

are most often found with spotted dolphins versus other dolphins, and why the species associate most strongly in the eastern tropical Pacific, remain critical pieces of information, given the large biomasses of both groups and their high rates of prey consumption. Three studies were conducted to address these hypotheses: a simultaneous tracking study of spotted dolphins and yellowfin tuna, a trophic interactions study comparing their prey and daily foraging patterns, and a spatial study of oceanographic features correlated with the tuna dolphin association. These studies demonstrated that the association is neither permanent nor obligatory, and that the benefits of the association are not based on feeding advantages. The studies support the hypothesis that one or both species reduce the risk of predation by forming large, mixed-species groups. The association is most prevalent where the habitat of the tuna is compressed to the warm, shallow, surface waters of the mixed layer by the oxygen minimum zone, a thick layer of oxygen-poor waters underlying the mixed layer. The association has been observed in areas with similar oceanographic conditions in other oceans, but it is most prevalent and consistent in the eastern tropical Pacific, where the oxygen minimum zone is the most hypoxic and extensive in the world.

During August-December 2006, scientists of the U.S. National Marine Fisheries Service (NMFS) conducted the latest in a series of research cruises under the *Stenella* Abundance Research (STAR) project. The primary objective of the multi-year study is to investigate trends in population size of the dolphins that have been taken as incidental catch by the purse-seine fishery in the EPO. Data on cetacean distribution, herd size, and herd composition were collected from the large-scale line-transect surveys to estimate dolphin abundance. Oceanographic data are collected to characterize habitat and its variation over time. Data on distribution and abundance of prey fishes and squids, seabirds, and sea turtles further characterize the ecosystem in which these dolphins live. The 2006 survey covered the same areas and used the same methods as past surveys. Data from the 2006 survey produced new abundance estimates, and previous data were re-analyzed to produce revised estimates for 10 dolphin species and/or stocks in the EPO between 1986 and 2006. The 2006 estimates for northeastern offshore spotted dolphins were somewhat greater, and for eastern spinner dolphins substantially greater, than the estimates for 1998-2000. Estimates of population growth for these two depleted stocks and the depleted coastal spotted

dolphin stock may indicate they are recovering, but the western-southern offshore spotted dolphin stock may be declining. The 1998-2006 abundance estimates for coastal spotted, whitebelly spinner, and rough-toothed (*Steno bredanensis*) dolphins showed an increasing trend, while those for the striped (*S. coeruleoalba*), short-beaked common (*Delphinus delphis*), bottlenose (*Tursiops truncatus*), and Risso's (*Grampus griseus*) dolphins were generally similar to previous estimates obtained with the same methods.

Scientists of the NMFS have made estimates of the abundances of several other species of marine mammals based on data from research cruises made between 1986 and 2000 in the EPO. The STAR 2003 and 2006 cruises will provide further estimates of abundance of these mammals. Of

**TABLE 1.** Mortality of dolphins and other marine mammals caused by the fishery in the EPO during 2013

Species and stock	Incidental mortality	
	Number	Metric tons
Offshore spotted dolphin		
Northeastern	158	10.3
Western-southern	145	9.5
Spinner dolphin		
Eastern	303	13.4
Whitebelly	111	6.7
Common dolphin		
Northern	69	4.9
Central	0	0
Southern	8	0.6
Other mammals*	7	1.0
<b>Total</b>	<b>801</b>	<b>46.4</b>

\*"Other mammals" includes the following species and stocks, whose observed mortalities were as follows: Central American spinner dolphins (*Stenella longirostris centroamericana*) 2 (0.1 t); bottlenose dolphins (*Tursiops truncatus*) 2 (0.2 t), unidentified dolphins 2 (0.1 t); shortfin pilot whale (*Globicephala macrorhynchus*) 1 (0.6 t).

the species not significantly affected by the tuna fishery, short-finned pilot whales (*Globicephala*

*macrorhynchus*) and three stocks of common dolphins showed increasing trends in abundance during that 15-year period. The apparent increased abundance of these mammals may have caused a decrease in the carrying capacity of the EPO for other predators that overlap in diet, including spotted dolphins. Bryde’s whales (*Balaenoptera edeni*) also increased in estimated abundance, but there is very little diet overlap between these baleen whales and the upper-level predators impacted by the fisheries. The abundance estimates for sperm whales (*Physeter macrocephalus*) tended to decrease during 1986-2000.

Some marine mammals are adversely affected by reduced food availability during El Niño events, especially in coastal ecosystems. Examples that have been documented include dolphins, pinnipeds, and Bryde’s whales off Peru, and pinnipeds around the Galapagos Islands. Large whales are able to move in response to changes in prey productivity and distribution.

## 2.6. Sea turtles

Sea turtles are caught on longlines when they take the bait on hooks, are snagged accidentally by hooks, or are entangled in the lines. Estimates of incidental mortality of turtles due to longline and gillnet fishing are few. At the [4th meeting of the IATTC Working Group on Bycatch](#) in January 2004, it was reported that 166 leatherback (*Dermochelys coriacea*) and 6,000 other turtle species, mostly olive Ridley (*Lepidochelys olivacea*), were incidentally caught by Japan’s longline fishery in the EPO during 2000, and that, of these, 25 and 3,000, respectively, were dead. At the [6th meeting of the Working Group](#) in February 2007, it was reported that the Spanish longline fleet targeting swordfish in the EPO averaged 65 interactions and 8 mortalities per million hooks during 1990-2005. The mortality rates due to longlining in the EPO are likely to be similar for other fleets targeting bigeye tuna, and possibly greater for those that set their lines at shallower depths for albacore and swordfish. About 23 million of the 200 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 artisanal longline vessels that fish for tunas, billfishes, sharks, and dorado (*Coryphaena* spp.) in the EPO. Since 2005, staff members of the IATTC and some other organizations, together with the governments of several coastal Latin American nations, have been engaged in a program to reduce the hooking rates and mortalities of sea turtles in these fisheries. Additional information on this program can be found in Section 9.2.

Sea turtles are occasionally caught in purse seines in the EPO tuna fishery. Most interactions occur when the turtles associate with floating objects, and are captured when the object is encircled. In other cases, nets set around unassociated schools of tunas or schools associated with dolphins may capture sea turtles that happen to be at those locations. The olive Ridley turtle is, by far, the species of sea turtle taken most often by purse seiners. It is followed by green sea turtles (*Chelonia mydas*), and, very occasionally, by loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) turtles.

From 1990, when IATTC observers began recording this information, through 2013, only three mortalities of leatherback turtles have been recorded. 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. Sea turtles, at times, become entangled in the webbing under fish-aggregating devices (FADs) and drown. In some cases, they are entangled by the fishing gear and may be injured or killed. Preliminary estimates of the mortalities (in numbers) of turtles caused by large purse-seine vessels during 2013, by set type (on floating objects (OBJ), unassociated schools

**TABLE 2.** Numbers of turtle mortalities caused by large purse-seine vessels in the EPO during 2013

	Set type			Total
	OBJ	NOA	DEL	
Olive Ridley	7	1	-	8
Eastern Pacific green	1	-	-	1
Loggerhead	-	-	-	-
Hawksbill	1	-	-	1
Leatherback	-	-	-	-
Unidentified	2	-	-	2
<b>Total</b>	<b>11</b>	<b>1</b>	<b>0</b>	<b>12</b>

(NOA), and dolphins (DEL)), are shown in Table 2.

The mortalities of sea turtles due to purse seining for tunas are probably less than those due to other types of human activity, which include exploitation of eggs and adults, beach development, pollution, entanglement in and ingestion of marine debris, and impacts of other fisheries.

The populations of olive Ridley, green, and loggerhead turtles are designated as endangered, and those of hawksbill and leatherback turtles as critically endangered, by the International Union for the Conservation of Nature.

## **2.7. Sharks and other large fishes**

Sharks and other large fishes are taken by both purse-seine and longline vessels. Silky sharks (*Carcharhinus falciformis*) are the most commonly-caught species of shark in the purse-seine fishery, followed by oceanic whitetip sharks (*C. longimanus*). The longline fisheries also take silky sharks. A Pacific-wide analysis of longline and purse-seine fishing is necessary to estimate the impact of fishing on the stock(s). Estimated indices of relative abundance of silky sharks, based on data for purse-seine sets on floating objects, showed decreasing trends for large (>150 cm total length) and medium-sized sharks (90-150 cm total length) during 1994-2004, and remained relatively constant for large sharks and increased slightly for medium sharks between 2005 and 2009. The trends in unstandardized bycatch per set were similar for the other two types of purse-seine sets (standardized trends are not yet available). The unstandardized average bycatches per set of oceanic whitetip sharks also showed decreasing trends for all three set types during the same period. It is not known whether these decreasing trends were due to incidental capture by the fisheries, changes in the environment (perhaps associated with the 1997-1998 El Niño event), or other factors. The decreasing trends do not appear to be due to changes in the density of floating objects.

Apart from blue and silky sharks, there are no stock assessments available for shark species in the EPO, and hence the impacts of the bycatches on the stocks are unknown. Progress on a stock assessment for the silky shark in the EPO was achieved at the IATTC 4<sup>th</sup> Technical Meeting on Sharks in February 2013 and continued throughout the year.

A stock assessment for blue sharks (*Prionace glauca*) in the North Pacific Ocean has been conducted by scientists of the NMFS and the NRIFSF. Preliminary results provided a range of plausible values for MSY of 1.8 to nearly 4 times the 2001 catch of blue sharks per year. A more recent assessment that used catch and effort data for 1971-2002 showed a decline in abundance in the 1980s, followed by a recovery to above the level of 1971. It was assumed that the blue shark population in 2009 was close to MSY level, and that fishing mortality may be approaching the MSY level in the future.

A project was conducted during May 2007–June 2008 by scientists of the IATTC and the NMFS to collect and archive tissue samples of sharks, rays, and other large fishes for genetics analysis. Data from the archived samples are being used in studies of large-scale stock structure of these taxa in the EPO, information that is vital for stock assessments and is generally lacking throughout the Pacific Ocean. The preliminary results of an analysis for silky sharks showed two stocks, one north and one south of the equator.

Preliminary estimates of the catches (including purse-seine discards), in metric tons, of sharks and other large fishes in the EPO during 2013, other than those mentioned above, by large purse-seine vessels are shown in Table 3. Complete data are not available for small purse-seine, longline, and other types of vessels.

The catch rates of species other than tunas in the purse-seine fishery are different for each type of set. With a few exceptions, the bycatch rates are greatest in sets on floating objects, followed by unassociated sets and, at a much lower level, dolphin sets. Dolphin bycatch rates are greatest for dolphin sets, followed by unassociated sets and, at a much lower level, floating-object sets. The bycatch rates of sailfish

**TABLE 3.** Catches, in tons, of sharks and other large fishes by large purse-seine vessels with observers aboard in the EPO, 2013

	Set type			Total
	OBJ	NOA	DEL	
Silky shark ( <i>Carcharhinus falciformis</i> )	212	55	38	305
Oceanic whitetip shark ( <i>C. longimanus</i> )	<1	<1	0	<1
Hammerhead sharks ( <i>Sphyrna</i> spp.)	79	6	1	86
Thresher sharks ( <i>Alopias</i> spp.)	2	2	6	10
Other sharks	58	5	4	67
Manta rays (Mobulidae)	5	35	28	69
Pelagic sting rays (Dasyatidae)	<1	<1	<1	1
Dorado ( <i>Coryphaena</i> spp.)	1912	26	<1	1939
Wahoo ( <i>Acanthocybium solandri</i> )	786	2	<1	787
Rainbow runner ( <i>Elagatis bipinnulata</i> ) and yellowtail ( <i>Seriola lalandi</i> )	31	2	<1	34
Other large fishes	176	545	3	723

(*Istiophorus platypterus*), manta rays (Mobulidae), and stingrays (Dasyatidae) are greatest in unassociated sets, followed by dolphin sets, and lowest in 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 estimated numbers of purse-seine sets of each type in the EPO during 1997-2013 are shown in Table A-7 of Document [SAC-05-06](#).

The reduction of bycatches is a goal of ecosystem-based fisheries management. A recently-published study analyzed the ratio of bycatch to target catch across a range of set size-classes (in tons). The study demonstrated that the ratios of total bycatch to tuna catch and silky shark bycatch to tuna catch decreased as set size increased. The greatest bycatch ratios occurred in sets catching <20 t.

In October 2006, the NMFS hosted a workshop on bycatch reduction in the EPO purse-seine fishery. The attendees supported a proposal for research on methods to reduce bycatches of sharks by attracting them away from floating objects prior to setting the purse seine. They also supported a suite of field experiments on bycatch reduction devices and techniques; these would include FAD modifications and manipulations, assessing behavioral and physiological indicators of stress, and removing living animals from the seine and deck (e.g. sorting grids, bubble gates, and vacuum pumps). A third idea was to use IATTC data to determine if spatial, temporal, and environmental factors can be used to predict bycatches in FAD sets and to determine to what extent time/area closures would be effective in reducing bycatches.

Scientists at the University of Washington have conducted an analysis of the temporal frequency of areas of high bycatches of silky sharks in purse-seine sets on floating objects, which will be useful for determining the effectiveness of area-time closures as a means of reducing shark bycatch. Results show that both model predictions and observed data tend to indicate that these bycatches occurred most frequently north of 4°N and west of 100-105°W. However, due to large tuna catches south of 5°N, the greatest reduction in bycatch from sets on floating objects with the least loss of tuna catch would be achieved north of approximately 6°N.

### 3. OTHER FAUNA

#### 3.1. Seabirds

There are approximately 100 species of seabirds in the tropical EPO. Some seabirds associate with epipelagic predators near the sea surface, such as fishes (especially tunas) and marine mammals. Subsurface predators often drive prey to the surface to trap them against the air-water interface, where the prey becomes available to the birds. Most species of seabirds take prey within a half meter of the sea

surface or in the air (flyingfishes (Exocoetidae) and squids (primarily Ommastrephidae)). In addition to driving the prey to the surface, subsurface predators make prey available to the birds by injuring or disorienting the prey, and by leaving scraps after feeding on large prey. Feeding opportunities for some seabird species are dependent on the presence of tuna schools feeding near the surface.

Seabirds are affected by the variability of the ocean environment. During the 1982-1983 El Niño event, seabird populations throughout the tropical and northeastern Pacific Ocean experienced breeding failures and mass mortalities, or migrated elsewhere in search of food. Some species, however, are apparently not affected by El Niño episodes. In general, seabirds that forage in upwelling areas of the tropical EPO and Peru Current suffer reproductive failures and mortalities due to food shortage during El Niño events, while seabirds that forage in areas less affected by El Niño episodes may be relatively unaffected.

According to the *Report of the Scientific Research Program under the U.S. International Dolphin Conservation Program Act*, prepared by the NMFS in September 2002, there were no significant temporal trends in abundance estimates over the 1986-2000 period for any species of seabird, except for a downward trend for the Tahiti petrel (*Pseudobulweria rostrata*), in the tropical EPO. Population status and trends are currently under review for waved (*Phoebastria irrorata*), black-footed (*P. nigripes*), and Laysan (*P. immutabilis*) albatrosses.

Some seabirds, especially albatrosses and petrels, are susceptible to being caught on baited hooks in pelagic longline fisheries. Satellite tracking and at-sea observation data have identified the importance of the IATTC area for waved, black-footed, Laysan, and black-browed (*Thalassarche melanophrys*) albatrosses, plus several other species that breed in New Zealand, yet forage off the coast of South America. There is particular concern for the waved albatross because it is endemic to the EPO and nests only in the Galapagos Islands. Observer data from artisanal vessels show no interactions with waved albatross during these vessels' fishing operations. Data from the US pelagic longline fishery in the northeastern Pacific Ocean indicate that bycatches of black-footed and Laysan albatrosses occur. Few comparable data for the longline fisheries in the central and southeastern Pacific Ocean are available. At the 6th meeting of the IATTC Working Group on Bycatch in February 2007, it was reported that the Spanish surface longline fleet targeting swordfish in the EPO averaged 40 seabird interactions per million hooks, virtually all resulting in mortality, during 1990-2005. In 2007, the IATTC Stock Assessment Working Group identified areas of vulnerability to industrial longline fishing for several species of albatross and proposed mitigation measures. See also section 9.3.

### **3.2. Forage**

The forage taxa occupying the middle trophic levels in the EPO are obviously important components of the ecosystem, providing a link between primary producers at the base of the food web and the upper-trophic-level predators, such as tunas and billfishes. Indirect effects on those predators caused by environmental variability are transmitted to the upper trophic levels through the forage taxa. Little is known, however, about fluctuations in abundance of the large variety of prey species in the EPO. Scientists from the NMFS have recorded data on the distributions and abundances of common prey groups, including lantern fishes (Myctophidae), flyingfishes, and some squids, in the tropical EPO during 1986-1990 and 1998-2000. Mean abundance estimates for all fish taxa and, to a lesser extent, for squids increased from 1986 through 1990. The estimates were low again in 1998, and then increased through 2000. Their interpretation of this pattern was that El Niño events in 1986-1987 and 1997-1998 had negative effects on these prey populations. More data on these taxa were collected during the NMFS STAR 2003 and 2006 cruises.

Cephalopods, especially squids, play a central role in many, if not most, marine pelagic food webs by linking the massive biomasses of micronekton, particularly myctophid fishes, to many oceanic predators. Given the high trophic flux passing through the squid community, a concerted research effort on squids is thought to be important for understanding their role as key prey and predators. In 2013, a special volume of the journal *Deep Sea Research II Topical Studies in Oceanography* (Vol. 5) was focused on The Role

of Squids in Pelagic Ecosystems. The volume covers six main research areas: squids as prey, squids as predators, the role of squids in marine ecosystems, physiology, climate change, and the Humboldt or jumbo squid (*Dosidicus gigas*) as a recent example of ecological plasticity in a cephalopod species.

Humboldt squid populations in the EPO have increased in size and geographic range in recent years. For example, the squid expanded its range to the north into waters off central California, USA from 2002 to mid-2010. In addition, in 2002 observers on tuna purse-seine vessels reported increased incidental catches of Humboldt squid taken with tunas, primarily skipjack, off Peru. Juvenile stages of these squid are common prey for yellowfin and bigeye tunas, and other predatory fishes, and Humboldt squid are also voracious predators of small fishes and cephalopods throughout their range. Large Humboldt squid have been observed attacking skipjack and yellowfin inside a purse seine. Not only have these squid impacted the ecosystems that they have expanded into, but they are also thought to have the capacity to affect the trophic structure in pelagic regions. Changes in the abundance and geographic range of Humboldt squid could affect the foraging behavior of the tunas and other predators, perhaps changing their vulnerability to capture.

Some small fishes, many of which are forage for the larger predators, are incidentally caught by purse-seine vessels in the EPO. Frigate and bullet tunas (*Auxis* spp.), for example, are a common prey of many of the animals that occupy the upper trophic levels in the tropical EPO. In the tropical EPO ecosystem model (Section 8), frigate and bullet tunas comprise 10% or more of the diet of eight predator categories. Small quantities of frigate and bullet tunas are captured by purse-seine vessels on the high seas and by artisanal fisheries in some coastal regions of Central and South America. The vast majority of frigate and bullet tunas captured by tuna purse-seine vessels is discarded at sea. Preliminary estimates of the catches (including purse-seine discards), in metric tons, of small fishes by large purse-seine vessels with observers aboard in the EPO during 2013 are shown in Table 4.

**TABLE 4.** Catches of small fishes, in tons, by large purse-seine vessels with observers aboard in the EPO, 2013

	Set type			Total
	OBJ	NOA	DEL	
Triggerfishes (Balistidae) and filefishes (Monacanthidae)	228	<1	<1	229
Other small fishes	24	4	<1	29
Frigate and bullet tunas ( <i>Auxis</i> spp.)	385	77	0	461

### 3.3. Larval fishes and plankton

Larval fishes have been collected by manta (surface) net tows in the EPO for many years by personnel of the NMFS Southwest Fisheries Science Center. Of the 314 taxonomic categories identified, 17 were found to be most likely to show the effects of environmental change. The occurrence, abundance, and distribution of these key taxa revealed no consistent temporal trends. Recent research has shown a longitudinal gradient in community structure of the ichthyoplankton assemblages in the eastern Pacific warm pool, with abundance, species richness, and species diversity high in the east (where the thermocline is shallow and primary productivity is high) and low but variable in the west (where the thermocline is deep and primary productivity is low).

The phytoplankton and zooplankton populations in the tropical EPO are variable. For example, chlorophyll concentrations on the sea surface (an indicator of phytoplankton blooms) and the abundance of copepods were markedly reduced during the El Niño event of 1982-1983, especially west of 120°W. Similarly, surface concentrations of chlorophyll decreased during the 1986-1987 El Niño episode and increased during the 1988 La Niña event due to changes in nutrient availability.



The species and size composition of zooplankton is often more variable than the zooplankton biomass. When the water temperatures increase, warm-water species often replace cold-water species at particular locations. The relative abundance of small copepods off northern Chile, for example, increased during the 1997-1998 El Niño event, while the zooplankton biomass did not change.

Copepods often comprise the dominant component of secondary production in marine ecosystems. An analysis of the trophic structure among the community of pelagic copepods in the EPO was conducted by a student of the Centro Interdisciplinario de Ciencias Marinas, Instituto Politécnico Nacional, La Paz, Mexico, using samples collected by scientists of the NMFS STAR project. The stable nitrogen isotope values of omnivorous copepods were used in a separate analysis of the trophic position of yellowfin tuna, by treating the copepods as a proxy for the isotopic variability at the base of the food web (see next section).

#### 4. TROPHIC INTERACTIONS

Tunas and billfishes are wide-ranging, generalist predators with high energy requirements, and, as such, are key components of pelagic ecosystems. The ecological relationships among large pelagic predators, and between them and animals at lower trophic levels, are not well understood. Given the need to evaluate the implications of fishing activities on the underlying ecosystems, it is essential to acquire accurate information on the trophic links and biomass flows through the food web in open-ocean ecosystems, and a basic understanding of the natural variability forced by the environment.

Knowledge of the trophic ecology of predatory fishes has historically been derived from stomach contents analysis, and more recently from chemical indicators. Large pelagic predators are considered efficient biological samplers of micronekton organisms, which are poorly sampled by nets and trawls. Diet studies have revealed many of the key trophic connections in the pelagic EPO, and have formed the basis for representing food-web interactions in an ecosystem model ([IATTC Bulletin, Vol. 22, No. 3](#)) to explore indirect ecosystem effects of fishing. For example, studies in the 1990s and 2000s revealed that the most common prey items of yellowfin tuna caught by purse seines offshore were frigate and bullet tunas, red crabs (*Pleuroncodes planipes*), Humboldt squid, a mesopelagic fish (*Vinciguerria lucetia*), and several epipelagic fishes. Bigeye tuna feed at greater depths than do yellowfin and skipjack, and consume primarily cephalopods and mesopelagic fishes. The most important prey of skipjack overall were reported to be euphausiid crustaceans during the late 1950s, whereas the small mesopelagic fish *V. lucetia* appeared dominant in the diet during the early 1990s. Tunas that feed inshore often utilize different prey than those caught offshore.

Stomach samples of ubiquitous generalist predators, such as the tunas, can be used to infer changes in prey populations by identifying changes in foraging habits over time. Prey populations that support upper-level predators vary over time (see 3.2 Forage), and some prey impart considerable predation pressure on animals that occupy the lower trophic levels (including the early life stages of large fishes). A comprehensive analysis of predation by yellowfin tuna on a decadal scale in the EPO was completed in 2013. Samples from 6,810 fish were taken from 433 purse-seine sets during two 2-year periods separated by a decade. Simultaneously, widespread reductions in biological production, changes in phytoplankton community composition, and a vertical expansion and intensification of the oxygen minimum zone appeared to alter the food webs in tropical and subtropical oceans (see 5. Physical environment). A modified classification tree approach was used to analyze spatial, temporal, environmental, and biological covariates explaining the predation patterns of the yellowfin during 1992-1994 and 2003-2005. For the majority of the yellowfin stock in the EPO, a major diet shift was apparent during the decade. Fishes were more abundant (by weight) during the early 1990s, while cephalopods and crustaceans predominated a decade later. As a group, epipelagic fishes declined from 82% to 31% of the diet, while mesopelagic species increased from 9% to 29% over the decade. Spatial partial dependence plots revealed range expansions by *Vinciguerria lucetia*, Humboldt squid (*Dosidicus gigas*), and *Pleuroncodes planipes*, range contractions by *Auxis* spp. and a boxfish (*Lactoria diaphana*), and a near disappearance of driftfish (*Cubiceps* spp.) from the diet. Evidence from predation rates suggests that biomasses of *V. lucetia* and *D.*

*gigas* have increased in the first half of the 2000s and that the distribution of *D. gigas* apparently expanded offshore as well as poleward (see 3.2 Forage).

Trophic-ecology studies have become focused on understanding entire food webs, initially by describing the inter-specific connections among the predator communities, comprising tunas, sharks, billfishes, dorado, wahoo, rainbow runner, and others. In general, considerable resource partitioning is evident among the components of these communities, and researchers seek to understand the spatial scale of the observable trophic patterns, and also the role of climate variability in influencing the patterns. In 2012, an analysis of predation by a suite of apex predators (including sharks, billfishes, tunas, and other fishes and mammals) on yellowfin and skipjack tunas in the EPO was published. Predation rates on yellowfin and skipjack were high for sharks and billfishes, and those animals consumed a wide size range of tunas, including subadults capable of making a notable contribution to the reproductive output of tuna populations. The tropical tunas in the EPO act as mesopredators more than apex predators.

While diet studies have yielded many insights, stable isotope analysis is a useful complement to stomach contents for delineating the complex structure of marine food webs. Stomach contents represent a sample of only the most-recent several hours of feeding at the time of day an animal is captured, and under the conditions required for its capture. Stable carbon and nitrogen isotopes, however, integrate information on all components of the entire diet into the animal's tissues, providing a recent history of trophic interactions and information on the structure and dynamics of ecological communities. More insight is provided by compound-specific isotope analysis of amino acids (AA-CSIA). In samples of consumer tissues, "source" amino acids (*e.g.* phenylalanine, glycine) retained the isotopic values at the base of the food web, and "trophic" amino acids (*e.g.* glutamic acid) became enriched in <sup>15</sup>N by about 7‰ relative to the baseline. In AA-CSIA, predator tissues alone are adequate for trophic-position estimates, and separate analysis of the isotopic composition of organisms at the base of the food web is not necessary. An analysis of the spatial distribution of stable isotope values of yellowfin tuna in relation to those of copepods showed that the trophic position of yellowfin tuna increased from inshore to offshore in the EPO, a characteristic of the food web never detected in diet data. This is likely a result of differences in food-chain length due to phytoplankton species composition (species with small cell size) in offshore oligotrophic waters versus larger diatom species in the eastern more-productive waters.

## 5. PHYSICAL ENVIRONMENT<sup>1</sup>

Environmental conditions affect marine ecosystems, the dynamics and catchability of tunas and billfishes, and the activities of fishermen. Tunas and billfishes are pelagic during all stages of their lives, and the physical factors that affect the tropical and sub-tropical Pacific Ocean can have important effects on their distribution and abundance. Environmental conditions are thought to cause considerable variability in the recruitment of tunas and billfishes. Stock assessments by the IATTC have often incorporated the assumption that oceanographic conditions might influence recruitment in the EPO.

Different types of climate perturbations may impact fisheries differently. It is thought that a shallow thermocline in the EPO contributes to the success of purse-seine fishing for tunas, perhaps by acting as a thermal barrier to schools of small tunas, keeping them near the sea surface. When the thermocline is deep, as during an El Niño event, tunas seem to be less vulnerable to capture, and the catch rates have declined. Warmer- or cooler-than-average sea-surface temperatures (SSTs) can also cause these mobile fishes to move to more favorable habitats.

The ocean environment varies on a variety of time scales, from seasonal to inter-annual, decadal, and longer (*e.g.* climate phases or regimes). The dominant source of variability in the upper layers of the EPO is known as the El Niño-Southern Oscillation (ENSO). The ENSO is an irregular fluctuation involving the entire tropical Pacific Ocean and global atmosphere. It results in variations of the winds, rainfall,

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<sup>1</sup> Some of the information in this section is from Fiedler, P.C. 2002. Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. *Mar. Ecol. Prog. Ser.* 244: 265-283.

thermocline depth, circulation, biological productivity, and the feeding and reproduction of fishes, birds, and marine mammals. El Niño events occur at 2- to 7-year intervals, and are characterized by weaker trade winds, deeper thermoclines, and abnormally-high SSTs in the equatorial EPO. El Niño's opposite phase, often called La Niña (or anti-El Niño), is characterized by stronger trade winds, shallower thermoclines, and lower SSTs. Research has documented a connection between the ENSO and the rate of primary production, phytoplankton biomass, and phytoplankton species composition. Upwelling of nutrient-rich subsurface water is reduced during El Niño episodes, leading to a marked reduction in primary and secondary production. ENSO also directly affects animals at middle and upper trophic levels. Researchers have concluded that the 1982-1983 El Niño event, for example, deepened the thermocline and nutricline, decreased primary production, reduced zooplankton abundance, and ultimately reduced the growth rates, reproductive successes, and survival of various birds, mammals, and fishes in the EPO. In general, however, the ocean inhabitants recover within short periods because their life histories are adapted to respond to a variable habitat.

The IATTC reports monthly average oceanographic and meteorological data for the EPO, including a summary of current ENSO conditions, on a quarterly basis. There were spots of cool water along the Equator during January-February 2013. During April 2013, there was a narrow band of cool water close to the coast of Peru; during May and June it expanded westward along the equator to slightly west of 120°W, and during July, August, and September retreated eastward. The SSTs were mostly below normal from January through December 2013. The value of 8.00 for the Northern Oscillation Index (NOI) for February 2013 is particularly noteworthy, as it has been exceeded only four times since records began in 1948. According to the Climate Diagnostics Bulletin of the U.S. National Weather Service for December 2013, "ENSO-neutral is expected to continue into the Northern Hemisphere summer 2014."

Variability on a decadal scale (*i.e.* 10 to 30 years) also affects the EPO. During the late 1970s there was a major shift in physical and biological states in the North Pacific Ocean. This climate shift was also detected in the tropical EPO by small increases in SSTs, weakening of the trade winds, and a moderate change in surface chlorophyll levels. Some researchers have reported another major shift in the North Pacific in 1989. Climate-induced variability in the ocean has often been described in terms of "regimes," characterized by relatively stable means and patterns in the physical and biological variables. Analyses by the IATTC staff have indicated that yellowfin tuna in the EPO have experienced regimes of lower (1975-1982) and higher (1983-2001) recruitment, and possibly intermediate (2002-2006) recruitment. The increased recruitment during 1983-2001 is thought to be due to a shift to a higher productivity regime in the Pacific Ocean. Decadal fluctuations in upwelling and water transport are simultaneous to the higher-frequency ENSO pattern, and have basin-wide effects on the SSTs and thermocline slope that are similar to those caused by ENSO, but on longer time scales.

Recent peer-reviewed literature provides strong evidence that large-scale changes in biological production and habitat have resulted from physical forcing in the subtropical and tropical Pacific Ocean. These changes are thought to be capable of affecting prey communities. Primary production has declined over vast oceanic regions in the recent decade(s). A study published in 2008, using "Sea-viewing Wide Field-of-view Sensor" (SeaWiFS) remote-sensed ocean color data, showed that, in the North and South Pacific, the most oligotrophic surface waters have increased in area by 2.2 and 1.4 % per year, respectively, between 1998 and 2006. These statistically-significant increases in the oligotrophic gyres occurred concurrently with significant increases in mean SSTs. In the North Pacific, the direction of expansion was northeast, reaching well into the eastern Pacific to about 120°W and as far south as about 15°N. Net primary productivity also has declined in the tropical and subtropical oceans since 1999. The mechanism is recognized as increased upper-ocean temperature and vertical stratification, influencing the availability of nutrients for phytoplankton growth. Evidence is also strong that primary producers have changed in community composition and size structure in recent decades. Phytoplankton cell size is relevant to predation dynamics of tunas because food webs that have small picophytoplankton at their base require more trophic steps to reach predators of a given size than do food webs that begin with larger

nanophytoplankton (*e.g.* diatoms). Energy transfer efficiency is lower for picophytoplankton-based food webs than for nanophytoplankton-based food webs, *i.e.* for a given amount of primary production less energy will reach a yellowfin of a given size in the former than in the latter because mean annual trophic transfer efficiency at each step is relatively constant. A study published in 2012 used satellite remotely-sensed SSTs and chlorophyll-a concentrations to estimate the monthly size composition of phytoplankton communities during 1998-2007. With the seasonal component removed, the median phytoplankton cell size estimated for the subtropical 10°-30°N and 10°-30°S Pacific declined by 2.2% and 2.3%, respectively, over the 9-year period. Expansion of the oxygen minimum zone (OMZ) is a third factor that demonstrates ecosystem change on a scale capable of affecting prey communities. The OMZ is a thick low-oxygen layer at intermediate depths, which is largely suboxic ( $< \sim 10 \mu\text{mol kg}^{-1}$ ) in the tropical EPO. Time series of dissolved oxygen concentration at depth from 1960 to 2008 revealed a vertical expansion and intensification of the OMZ in the central and eastern tropical Pacific and Atlantic Oceans, and in other regions of the world's oceans. Potential biological consequences of an expanding OMZ are numerous, but for the epipelagic tunas habitat compression can have profound implications. Shoaling of the OMZ restricts the depth distribution of tunas and other pelagic fishes into a narrower surface layer, compressing their foraging habitat and altering forage communities. Enhanced foraging opportunities for all epipelagic predators could alter trophic pathways and affect prey species composition. In addition, with a shoaled OMZ, mesopelagic vertically-migrating prey, such as the phosichthyid fish *Vinciguerria lucetia*, myctophid fishes, and ommastrephid squids, would likely occur at shallower daytime depths and become more vulnerable to epipelagic predators. These are some of the taxa that increased most in the yellowfin diet in the tropical EPO between 1992-1994 and 2003-2005 (see 4, Trophic interactions).

## 6. AGGREGATE INDICATORS

Recognition of the consequences of fishing for marine ecosystems has stimulated considerable research in recent years. Numerous objectives have been proposed to evaluate fishery impacts on ecosystems and to define over-fishing from an ecosystem perspective. Whereas reference points have been used primarily for single-species management of target species, applying performance measures and reference points to non-target species is believed to be a tractable first step. Current examples include incidental mortality limits for dolphins in the EPO purse-seine fishery under the AIDCP. Another area of interest is whether useful performance indicators based on ecosystem-level properties might be developed. Several ecosystem metrics or indicators, including community size structure, diversity indices, species richness and evenness, overlap indices, trophic spectra of catches, relative abundance of an indicator species or group, and numerous environmental indicators, have been proposed. Whereas there is general agreement that multiple system-level indicators should be used, there is concern over whether there is sufficient practical knowledge of the dynamics of such metrics and whether a theoretical basis for identifying precautionary or limit reference points based on ecosystem properties exists. Ecosystem-level metrics are not yet commonly used for managing fisheries.

Relationships between indices of species associations in the catch and environmental characteristics are viewed as potentially valuable information for bycatch mitigation. Preliminary work in 2007-2008, based on novel methods of ordination developed by scientists at the Institute of Statistical Mathematics in Tokyo, Japan, showed clear large-scale spatial patterns in different groupings of target and bycatch species for floating-object sets in the EPO purse-seine fishery and relationships to environmental variables, such as SST, chlorophyll-a density, and mixed layer depth. More work is needed on this or similar approaches.

Ecologically-based approaches to fisheries management place renewed emphasis on achieving accurate depictions of trophic links and biomass flows through the food web in exploited systems. The structure of the food web and the interactions among its components have a demonstrable role in determining the dynamics and productivity of ecosystems. Trophic levels (TLs) are used in food-web ecology to characterize the functional role of organisms, to facilitate estimates of energy or mass flow through communities, and for elucidating trophodynamics aspects of ecosystem functioning. A simplified food-

web diagram, with approximate TLs, of the pelagic tropical EPO, is shown in Figure J-1. Toothed whales (Odontoceti, average TL 5.2), large squid predators (large bigeye tuna and swordfish, average TL 5.2), and sharks (average TL 5.0) are top-level predators. Other tunas, large piscivores, dolphins (average TL 4.8), and seabirds (average TL 4.5) occupy slightly lower TLs. Smaller epipelagic fishes (*e.g.* *Auxis* spp. and flyingfishes, average TL 3.2), cephalopods (average TL 4.4), and mesopelagic fishes (average TL 3.4) are the principal forage of many of the upper-level predators in the ecosystem. Small fishes and crustaceans prey on two zooplankton groups, and the herbivorous micro-zooplankton (TL 2) feed on the producers, phytoplankton and bacteria (TL 1).

In exploited pelagic ecosystems, fisheries that target large piscivorous fishes act as the system's apex predators. Over time, fishing can cause the overall size composition of the catch to decrease, and, in general, the TLs of smaller organisms are lower than those of larger organisms. The mean TL of the organisms taken by a fishery is a useful metric of ecosystem change and sustainability because it integrates an array of biological information about the components of the system. There has been increasing attention to analyzing the mean TL of fisheries catches and discards since a study demonstrated that, according to FAO landings statistics, the mean TL of the fishes and invertebrates landed globally had declined between 1950 and 1994, which was hypothesized by the authors of that study to be detrimental to the ecosystems. Some ecosystems, however, have changed in the other direction, from lower to higher TL communities. Given the potential utility of this approach, mean TLs were estimated for a time series of annual catches and discards by species from 1993 to 2010 for three purse-seine fishing modes and the pole-and-line fishery in the EPO. The estimates were made by applying the TL values from the EPO ecosystem model (see Section 8), weighted by the catch data by fishery and year for all model groups from the IATTC tuna, bycatch, and discard data bases. The TLs from the ecosystem model were determined by average diet estimates for all species groups. The mean TLs of the summed catches of all purse-seine and pole-and-line fisheries were fairly constant from year to year, varying by less than 0.1 TL (Figure J-2: Average PS+LP). A slight downward trend for the unassociated sets, amounting to 0.4 TL over the 18-year period, resulted from increasing proportions of skipjack and decreasing proportions of yellowfin or bigeye tunas in the catch, not from increasing catches of low trophic-level species. It is not, therefore, considered an ecologically-detrimental decline. In general, the TLs of the unassociated sets and the pole-and-line fishery were below average and those of the dolphin sets were above average for most years (Figure J-2). The TLs of the floating-object sets varied more than those of the other set types and fisheries, primarily due to the inter-annual variability in the amounts of bigeye and skipjack caught in those sets. The TLs of floating-object sets were positively related to the percentage of the total catch comprised of large bigeye and negatively related to the percentage of the catch comprised of skipjack.

Mean TLs were also estimated separately for the time series of retained and discarded catches of the purse-seine fishery each year from 1993 to 2010 (Figure J-3). The discarded catches were much less than the retained catches, and thus the TL patterns of the total (retained plus discarded) catches (Figure J-2) were determined primarily by the TLs of the retained catches (Figure J-3). The TLs of the discarded catches varied more year-to-year than those of the retained catches, due to the species diversity of the incidental catches. The considerable reduction in the mean TLs of the dolphin-set discards over the 18-year period (Figure J-3), was largely due to an increase in the proportions of discarded prey fishes (bullet and frigate tunas (*Auxis* spp.) and miscellaneous epipelagic fishes) and rays (Rajiformes, mostly manta rays, Mobulidae) with lower trophic levels. For unassociated sets, marked inter-annual reductions in TL were due to increased bycatches of rays (TL 3.68), which feed on plankton and other small animals that occupy low TLs, a reduction in the catches of large sharks (TL 4.93), and an increase in prey fishes (*e.g.* Clupeiformes, Nomeidae, Tetraodontiformes, and *Auxis* spp.; TL 3.19-3.86) in the bycatch. Although prey fishes were lower than 25% in unassociated sets, they reduced the average TLs of the unassociated-set discards substantially, especially when discard proportions of yellowfin tuna were low. For floating-object sets, the discards of bigeye were related to higher mean TLs.

## 7. ECOLOGICAL RISK ASSESSMENT

Long-term ecological sustainability is a requirement of ecosystem-based fisheries management. Fishing directly impacts the populations of not only target species, but also the species incidentally caught as bycatch. The vulnerability to overfishing of many of the stocks incidentally caught in the EPO tuna fisheries is unknown, and biological and fisheries data are severely limited for most of those stocks. Many fisheries managers and scientists are turning to risk assessments to evaluate vulnerability to fishing. Vulnerability is defined here as the potential for the productivity of a stock to be diminished by direct and indirect fishing pressure. The IATTC staff is evaluating established methods for determining the vulnerability of data-poor, non-target species caught by the purse-seine fishery in the EPO. A version of productivity and susceptibility analysis (PSA<sup>2</sup>), used to evaluate other fisheries in recent years, considers a stock's vulnerability as a combination of its productivity and its susceptibility to the fishery. Stock productivity is the capacity of a stock to recover if it is depleted, and is a function of the species' life history traits. Stock susceptibility is the degree to which a fishery can negatively impact a stock, *i.e.* the propensity of a species to be captured by, and incur mortality from, a fishery. Productivity and susceptibility indices of a stock are determined by deriving a score ranging from 1 (low) to 3 (high) for a standardized set of attributes related to each index. The individual attribute scores are then averaged for each factor and graphically displayed on an x-y scatter plot. When scoring the attributes, the data quality associated with each attribute score was assessed, and the attributes were weighted by the data-quality score. Stocks that received a low productivity score ( $p$ ) and high susceptibility score ( $s$ ) were considered to be at a high risk of becoming depleted, while stocks with a high productivity score and low susceptibility score were considered to be at low risk. Vulnerability scores ( $v$ ) were calculated from the  $p$  and  $s$  scores as the Euclidean distance from the origin of the x-y scatter plot and the datum point:

$$v = \sqrt{(p-3)^2 + (s-1)^2}$$

To examine the utility of productivity and susceptibility indices to assess vulnerability of incidentally-caught fishes, mammals, and turtles to overfishing in the EPO, a preliminary evaluation of three purse-seine "fisheries" in the EPO was made. The PSA was focused on 33 species (Table J-1) that comprised the majority of the biomass removed by the purse-seine vessels with carrying capacity greater than 363 metric tons during 2005-2011. Nine productivity and eight susceptibility attributes (Tables J-2 and J-3, respectively) were based on established PSA methodology<sup>2</sup>, and some were modified for more consistency with the tuna fisheries in the EPO.

Information corresponding to the productivity attributes for each species was compiled from a variety of published and unpublished literature sources and EPO fisheries data (*i.e.* not adopted from previous PSAs) to better approximate the distribution of life history characteristics observed in the species found in the EPO. Scoring thresholds for productivity attributes (Table J-2) were derived by dividing the compiled data into 1/3 percentiles. Scoring criteria for the susceptibility attributes (Table J-3) were taken from the example PSA<sup>2</sup> and modified where appropriate to better fit the EPO fisheries. The scores for each index were then averaged. Scatter plots of averaged productivity and susceptibility scores for subsets of the 33 species caught by three purse-seine fisheries (on dolphins, unassociated tunas, and floating objects) are shown in Figure J-4 by group (see Table J-1 for group species composition). The scale of the x-axis on the Figure J-4 is reversed because species/stocks with a high productivity score and a low susceptibility score (*i.e.* at the origin of the plots) are considered to be the least vulnerable.

In general, some of the sharks and the giant manta ray scored the highest in overall vulnerability to overfishing (equation above). The shortfin mako shark, scalloped, great, and smooth hammerhead sharks,

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<sup>2</sup> Patrick, W.S., P. Spencer, J. Link, J. Cope, J. Field, D. Kobayashi, P. Lawson, T. Gedamke, E. Cortés, O. Ormseth, K. Bigelow, and W. Overholtz. 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. *Fish. Bull. U.S.* 108: 305-322.

and bigeye and pelagic thresher sharks had vulnerability scores greater than 2.0 (*i.e.* points to the right side of the semi-circle from susceptibility 3.0 to productivity 1.0 in Figure J-4).

The IATTC staff will continue working to improve and refine the productivity and susceptibility analysis for the EPO during 2014.

## 8. ECOSYSTEM MODELING

It is clear that the different components of an ecosystem interact. Ecosystem-based fisheries management is facilitated through the development of multi-species ecosystem models that represent ecological interactions among species or guilds. Our understanding of the complex maze of connections in open-ocean ecosystems 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 IATTC staff has developed a model of the pelagic ecosystem in the tropical EPO (IATTC Bulletin, [Vol. 22, No. 3](#)) to explore how fishing and climate variation might affect the animals at middle and upper trophic levels. The ecosystem model has 38 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 size categories (*e.g.* large and small marlins). 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, and purse-seine sets on tunas associated with dolphins, with floating objects, and in unassociated schools. The model focuses on the pelagic regions; localized, coastal ecosystems are not adequately described by the model.

Most of the information describing inter-specific interactions in the model came from a joint IATTC-NMFS project, which included studies of the food habits of co-occurring yellowfin, skipjack, and bigeye 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.

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 as proxies for changes in primary production that have been documented during El Niño and La Niña events, and the dynamics of the remaining components of the ecosystem were simulated. 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 were influenced more by fishing than by the environment, and animals with relatively high turnover rates more by the environment than by fishing.

The structure of marine ecosystems is generally thought to be controlled by one of two mechanisms: 'bottom-up' control (resource-driven) where the dynamics of primary producers (*e.g.* phytoplankton) controls the production and biomass at higher trophic levels, or 'top-down' control (consumer-driven) where predation by high trophic-level predators controls the abundance and composition of prey at lower trophic levels. In relatively recent years, 'wasp-waist' control of marine ecosystems has also been recognized. 'Wasp-waist' control is a combination of bottom-up and top-down forcing by a small number of abundant, highly productive, and short-lived species at intermediate trophic levels (*e.g.* sardines and anchovies) that form a narrow 'waist' through which energy flow in the system is regulated. These species exert top-down predatory control of energy flows from zooplankton, but also have bottom-up control by providing energy for high trophic-level predators. It has been assumed that wasp-waist control

occurs primarily in highly productive and species-poor coastal systems (e.g. upwelling regions), which can be highly unstable and undergo rapid natural regime shifts in short periods of time. The ecosystem model for the tropical EPO was used in conjunction with a model for a region off the east coast of Australia where tunas and billfishes are caught to examine possible forcing dynamics of these systems. These two large species-rich pelagic ecosystems also showed wasp-waist-like structure, in that short-lived and fast-growing cephalopods and fishes in intermediate trophic levels comprise the vast majority of the biomass. The largest forcing effects were seen when altering the biomasses of mid trophic-level epipelagic and mesopelagic fishes in the models, whereby dramatic trophic cascades occurred both upward and downward in the system. These tropical pelagic ecosystems appear to possess a complex structure whereby several waist groups and alternate trophic pathways from primary producers to apex predators can cause unpredictable effects when the biomasses of particular functional groups are altered. Such models highlight the possible structuring mechanisms in pelagic systems, which have implications for fisheries that exploit these groups, such as squid fisheries, as well as for fisheries of top predators such as tunas and billfishes that prey upon wasp-waist species.

## **9. ACTIONS BY THE IATTC AND THE AIDCP ADDRESSING ECOSYSTEM CONSIDERATIONS**

Both the IATTC convention and the 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:

### **9.1. Dolphins**

- a. For many years, the impact of the fishery on the dolphin populations has been assessed, and programs to reduce or eliminate that impact have met with considerable success.
- b. The incidental mortalities of all stocks of dolphins have been limited to levels that are insignificant relative to stock sizes.

### **9.2. Sea turtles**

- a. A data base on all sea turtle sightings, captures, and mortalities reported by observers has been compiled.
- b. In June 2003 the IATTC adopted a Recommendation on Sea Turtles, which contemplates “the development of a three-year program that could include mitigation of sea turtle bycatch, biological research on sea turtles, improvement of fishing gears, industry education and other techniques to improve sea turtle conservation.” In January 2004, the Working Group on Bycatch drew up a detailed program that includes all these elements, and urges all nations with vessels fishing for tunas in the EPO to provide the IATTC with information on interactions with sea turtles in the EPO, including both incidental and direct catches and other impacts on sea turtle populations. [Resolution C-04-07](#) on a three-year program to mitigate the impact of tuna fishing on sea turtles was adopted by the IATTC in June 2004; it includes requirements for data collection, mitigation measures, industry education, capacity building, and reporting.
- c. [Resolution C-04-05 REV 2](#), adopted by the IATTC in June 2006, contains provisions on releasing and handling of sea turtles captured in purse seines. The resolution also prohibits vessels from disposing of plastic containers and other debris at sea, and instructs the Director to study and formulate recommendations regarding the design of FADs, particularly the use of netting attached underwater to FADs.
- d. [Resolution C-07-03](#), adopted by the IATTC in June 2007, contains provisions on implementing observer programs for fisheries under the purview of the Commission that may have impacts on sea turtles and are not currently being observed. The resolution requires fishermen to foster recovery and resuscitation of comatose or inactive hard-shell sea turtles before returning them to the water. CPCs with purse-seine and longline vessels fishing for species covered by the IATTC Convention in the EPO are directed to avoid encounters with sea turtles, to reduce mortalities using a variety of techniques, and



to conduct research on modifications of FAD designs and longline gear and fishing practices.

- e. In response to a request made by the Subsecretaría de Recursos Pesqueros of Ecuador, a program was established by the World Wildlife Fund, the IATTC, and the government of the United States to mitigate the incidental capture and reduce the mortality of sea turtles due to longline fishing. A key element of this program is the comparison of catch rates of tunas, billfishes, sharks, and dorado caught with J hooks to the catch rates using circle hooks. Circle hooks do not hook as many turtles as the J hooks, which are traditionally used in the longline fishery, and the chance of serious injury to the sea turtles that bite the circle hooks is reduced because the hooks are wider and they tend to hook the lower jaw, rather than the more dangerous deep hookings in the esophagus and other areas, which are more common with the J hooks. Improved procedures and instruments to release hooked and entangled sea turtles have also been disseminated to the longline fleets of the region.

By the end of 2008 the hook-exchange and observer program, which began in Ecuador in 2003, was active in Colombia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama, and Peru and under development in Chile, with workshops taking place in many ports. The program in Ecuador is being carried out in partnership with the government and the Overseas Fishery Cooperation Foundation of Japan, while those in other countries are currently funded by U.S. agencies. Initial results show that, in the fisheries that target tunas, billfishes, and sharks, there was a significant reduction in the hooking rates of sea turtles with the circle hooks, and fewer hooks lodged in the esophagus or other areas detrimental to the turtles. The catch rates of the target species are, in general, similar to the catch rates with the J-hooks. An experiment was also carried out in the dorado fishery using smaller circle hooks. There were reductions in turtle hooking rates, but the reductions were not as great as for the fisheries that target tunas, billfishes, and sharks. In addition, workshops and presentations were conducted by IATTC staff members and others in all of the countries participating in the program.

### 9.3. Seabirds

- a. [Recommendation C-10-02](#) adopted by the IATTC in October 2010, reaffirmed the importance that IATTC Parties and cooperating non-Parties, fishing entities, and regional economic integration organizations implement, if appropriate, the FAO International Plan of Action for Reducing the Incidental Catch of Seabirds in Longline Fisheries (“IPOA-Seabirds”). The governments listed on the Recommendation agreed to report to the IATTC on their implementation of the IPOA-Seabirds, including, as appropriate, the status of their National Plans of Action for reducing incidental catches of seabirds in longline fisheries. It was also agreed that the governments would require their longline vessels that fish for species covered by the IATTC in specific areas (specified in Annex 1 of the Recommendation) to use at least two of a set of eight mitigation measures listed. In addition, members and cooperating non-members of the IATTC were encouraged to establish national programs to place observers aboard longline vessels flying their flags or fishing in their waters, and to adopt measures aimed at ensuring that seabirds captured alive during longline fishing operations are released alive and in the best condition possible
- b. [Resolution C-11-02](#), adopted by the IATTC in July 2011, reaffirmed the importance of implementing the IPOA-Seabirds (see 9.3.a) and provides that Members and cooperating non-Members (CPCs) shall require their longline vessels of more than 20 meters length overall and that fish for species covered by the IATTC in the EPO to use at least two of the specified mitigation measures, and establishes minimum technical standards for the measures. CPCs are encouraged to work, jointly and individually, to undertake research to further develop and refine methods for mitigating seabird bycatch, and to submit to the IATTC any information derived from such efforts. Also, CPCs are encouraged to establish national programs to place observers aboard longline vessels flying their flags or fishing in their waters, for the purpose of, *inter alia*, gathering information on the interactions of seabirds with the longline fisheries.

#### **9.4. Other species**

- a. In June 2000, the IATTC adopted a resolution on live release of sharks, rays, billfishes, dorado, wahoo, and other non-target species.
- b. [Resolution C-04-05](#), adopted by the IATTC in June 2006, instructs the Director to seek funds for reduction of incidental mortality of juvenile tunas, for developing techniques and equipment to facilitate release of billfishes, sharks, and rays from the deck or the net, and to carry out experiments to estimate the survival rates of released billfishes, sharks, and rays.
- c. [Resolution C-11-10](#), adopted by the IATTC in July 2011, prohibits retaining onboard, transshipping, landing, storing, selling, or offering for sale any part or whole carcass of oceanic whitetip sharks in the fisheries covered by the Antigua Convention, and to promptly release unharmed, to the extent practicable, oceanic whitetip sharks when brought alongside the vessel.

#### **9.5. Fish-aggregating devices (FADs)**

- a. [Resolution C-13-04](#), adopted by the IATTC in June 2013, requires all purse-seine vessels fishing on FADs to collect and report FAD information, including an inventory of the FADs present on the vessel, specifying, for each FAD, identification, type, and design characteristics. For every FAD activity, the position, date, hour, FAD identification, and FAD type must be reported. The IATTC staff will analyze the data collected to identify any additional elements for data collection and reporting formats necessary to evaluate the effects of FAD use on the ecosystem, and provide initial recommendations for the management of FADs in the EPO. The Commission will consider adopting management measures based on those recommendations, including a region-wide FAD management plan. Purse-seine vessels are also required to identify all FADs deployed or modified, in accordance with an identification scheme developed by the Director. To reduce entanglement of sharks, sea turtles, or any other species, principles for the design and deployment of FADs are specified. Setting a purse seine on tuna associated with a live whale shark is prohibited, if the animal is sighted prior to the set.

#### **9.6. All species**

- a. Data on the bycatches of large purse-seine vessels are being collected, and governments are urged to provide bycatch information for other vessels.
- 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.
- e. Requirements have been adopted for the CPCs to ensure that, from 1 January 2013, at least 5% of the fishing effort made by its longline vessels greater than 20 m length overall carry a scientific observer.

### **10. FUTURE DEVELOPMENTS**

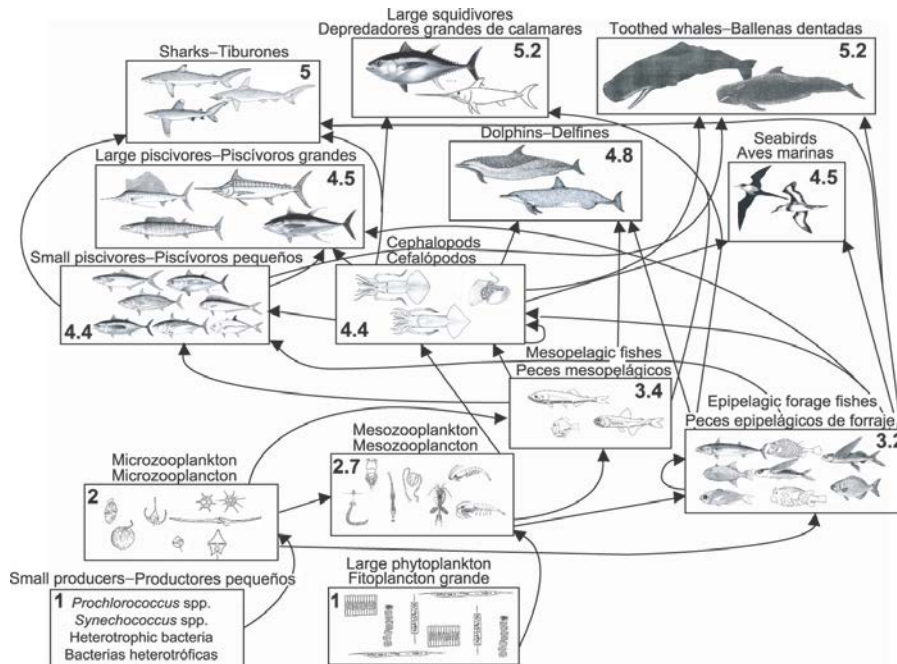
It is unlikely, in the near future at least, that there will be stock assessments for most of the bycatch species. In lieu of formal assessments, it may be possible to develop indices to assess trends in the status of these species. The IATTC staff's experience with dolphins suggests that the task is 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

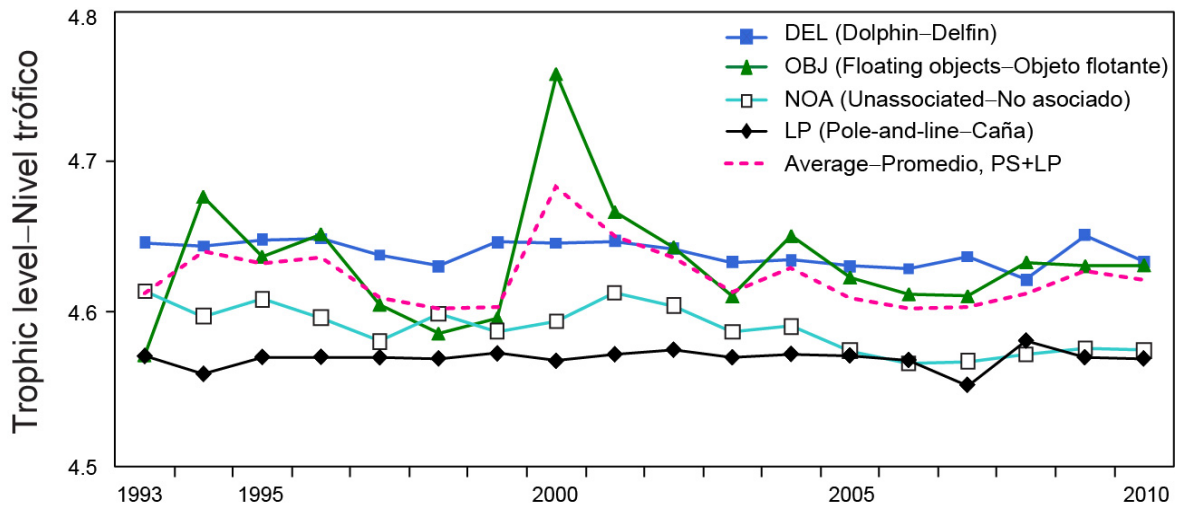
different ecological characteristics may be included. Within them, water masses, oceanographic or topographic features, influences from the continent, *etc.*, may generate heterogeneity that affects the distributions of the different species and their relative abundances in the catches. It would be desirable to increase our understanding of these ecological strata so that they can be used in our analyses.

It is important to continue studies of the ecosystems in the EPO. The power to resolve issues related to fisheries and the ecosystem will increase with the number of habitat variables, taxa, and trophic levels studied and with longer time series of data.



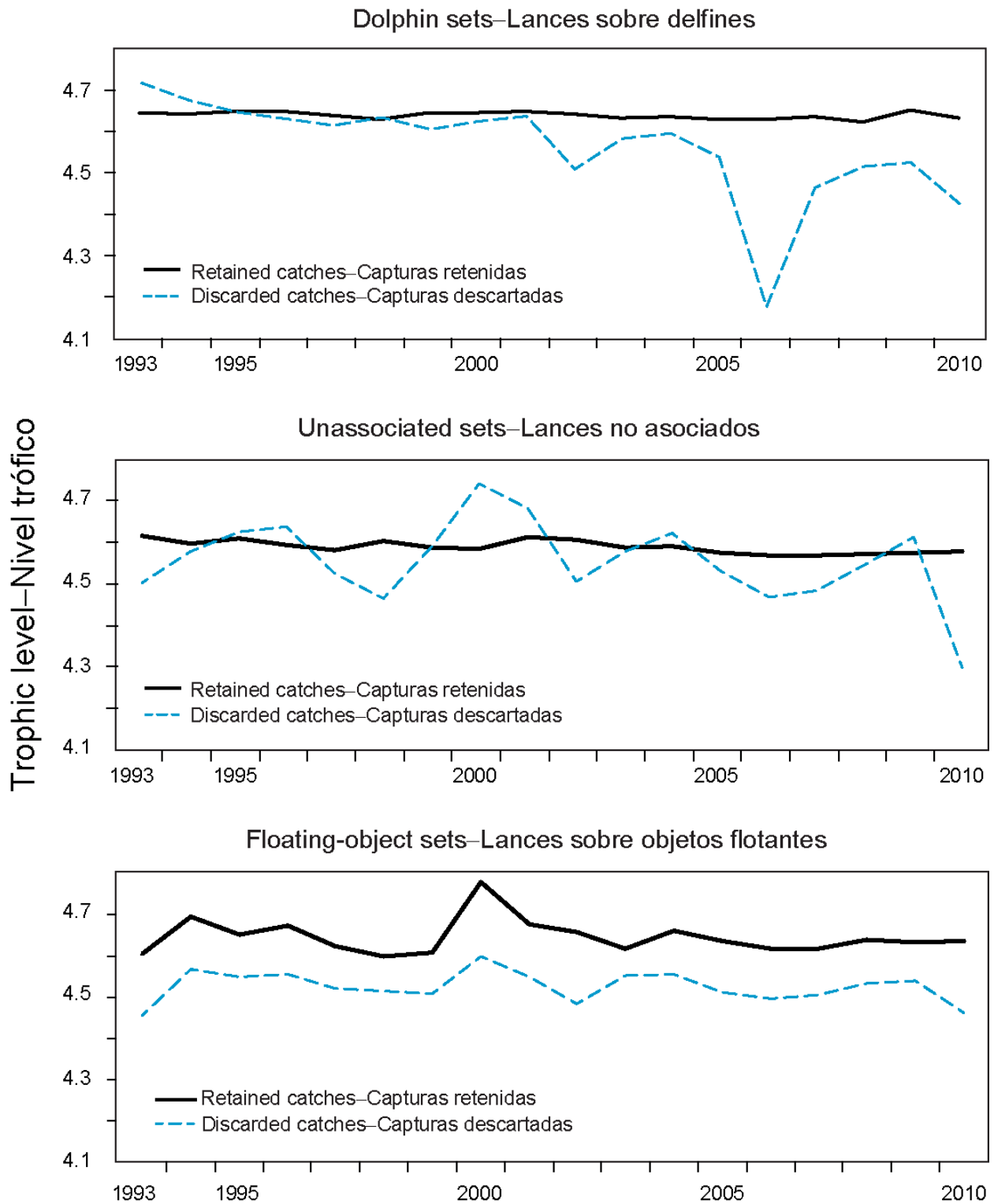
**FIGURE J-1.** Simplified food-web diagram of the pelagic ecosystem in the tropical EPO. The numbers inside the boxes indicate the approximate trophic level of each group.

**FIGURA J-1.** Diagrama simplificado de la red trófica del ecosistema pelágico en el OPO tropical. Los números en los recuadros indican el nivel trófico aproximado de cada grupo.



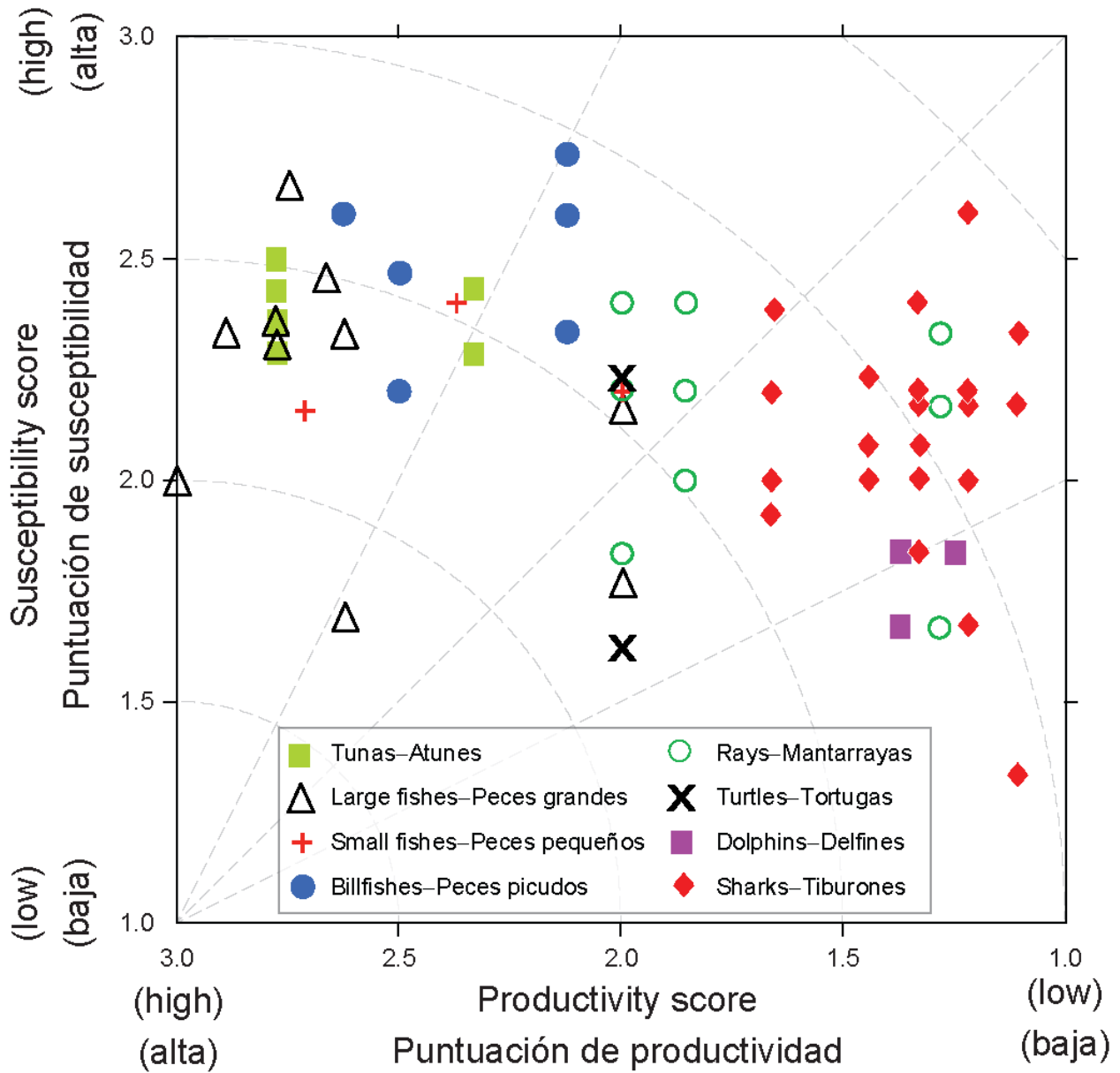
**FIGURE J-2.** Yearly mean trophic level estimates of the catches (retained and discarded) by the purse-seine and pole-and-line fisheries in the tropical EPO, 1993-2010. .

**FIGURA J-2.** Estimaciones anuales del nivel trófico de las capturas (retenidas y descartadas) de las pesquerías cerquera y cañera en el OPO tropical, 1993-2010.



**FIGURE J-3.** Trophic level estimates of the retained catches and discarded catches by purse-seine fishing modes in the tropical EPO, 1993-2010.

**FIGURA J-3.** Estimaciones del nivel trófico de las capturas retenidas y descartadas por modalidad de pesca cerquera en el OPO tropical, 1993-2010.



**FIGURE J-4.** Productivity and susceptibility x-y plot for target and bycatch species caught by the purse-seine fishery of the EPO during 2005-2011. Group species composition is shown in Table J-1.

**FIGURA J-4.** Gráfica x-y de productividad y susceptibilidad de especies objetivo y de captura incidental capturadas por la pesquería de cerco del OPO durante 2005-2011. En la Tabla J-1 se presenta la composición por especies de los grupos.

**TABLE J-1.** Annual bycatch per set (in kilograms) averaged over 2005-2011 for purse-seine vessels with carrying capacity greater than 363 metric tons, by three set methods. “n/a” indicates the tuna species that were included in the PSA analysis, but no values were given because tunas are not bycatches of these fisheries. Only species with a catch value (or n/a) were used in the PSA for the corresponding set type.

Group	Species		Bycatch (kg) per set		
	Common name	Scientific name	DEL	NOA	OBJ
Tunas	Yellowfin tuna	<i>Thunnus albacares</i>	n/a	n/a	n/a
	Bigeye tuna	<i>Thunnus obesus</i>	--	n/a	n/a
	Skipjack tuna	<i>Katsuwonus pelamis</i>	--	n/a	n/a
Billfishes	Black marlin	<i>Makaira indica</i>	1.0	1.1	10.7
	Blue marlin	<i>Makaira nigricans</i> <sup>2</sup>	1.1	1.8	23.3
	Striped marlin	<i>Kajikia audax</i>	1.1	1.6	2.3
	Indo-Pacific sailfish	<i>Istiophorus platypterus</i>	2.3	1.4	--
Dolphins	Spotted dolphin	<i>Stenella attenuata</i>	2.2	--	--
	Spinner dolphin	<i>Stenella longirostris</i>	2.3	--	--
	Common dolphin	<i>Delphinus delphis</i>	1.6	--	--
Large Fishes	Common dolphinfish	<i>Coryphaena hippurus</i>	--	3.2	169.6
	Pompano dolphinfish	<i>Coryphaena equiselis</i>	--	--	10.8
	Wahoo	<i>Acanthocybium solandri</i>	--	--	59.3
	Rainbow runner	<i>Elagatis bipinnulata</i>	--	--	9.5
	Bigeye trevally	<i>Caranx sexfasciatus</i>	--	4.2	--
	Yellowtail amberjack	<i>Seriola lalandi</i>	--	3.5	1.8
	Ocean sunfish	<i>Mola mola</i>	--	5.0	1.4
Rays	Giant manta	<i>Manta birostris</i>	2.6	2.9	0.5
	Spinetail manta	<i>Mobula japanica</i> <sup>4</sup>	1.3	2.7	0.3
	Smoothtail manta	<i>Mobula thurstoni</i> <sup>4</sup>	0.3	1.4	0.1
Sharks	Silky shark	<i>Carcharhinus falciformis</i> <sup>4</sup>	4.1	9.1	55.8
		<i>Carcharhinus longimanus</i> <sup>2</sup>	<0.1	--	0.4
	Oceanic whitetip shark	<i>Alopias superciliosus</i> <sup>2</sup>	0.3	0.6	0.1
	Bigeye thresher shark	<i>Alopias pelagicus</i> <sup>2</sup>	0.3	0.6	0.2
	Pelagic thresher shark	<i>Alopias vulpinus</i> <sup>2</sup>	<0.1	0.2	<0.1
	Common thresher shark	<i>Sphyrna lewini</i> <sup>3</sup>	0.1	0.7	2.3
	Scalloped hammerhead shark	<i>Sphyrna mokarran</i> <sup>3</sup>	<0.1	<0.1	0.2
	Great hammerhead	<i>Sphyrna zygaena</i> <sup>2</sup>	0.1	0.3	4.5
	Smooth hammerhead shark	<i>Isurus oxyrinchus</i> <sup>2</sup>	<0.1	0.3	0.2
Small Fishes	Ocean triggerfish	<i>Canthidermis maculatus</i>	--	--	7.7
	Bluestriped chub	<i>Setator ocyurus</i>	--	--	2.0
	Scrawled filefish	<i>Aluterus scriptus</i> <sup>1</sup>	--	--	0.2
Turtles	Olive Ridley turtle	<i>Lepidochelys olivacea</i> <sup>2</sup>	<0.1	<0.1	<0.1

<sup>1</sup> Included due to numerical importance in bycatch ( $\geq 1$  individual per set)

<sup>2</sup> "Vulnerable" status, IUCN Red List of Threatened Species

<sup>3</sup> "Endangered" status, IUCN Red List of Threatened Species

<sup>4</sup> "Near threatened" status, IUCN Red List of Threatened Species

**TABLE J-2.** Productivity attributes and scoring thresholds used in the IATTC PSA.

**TABLA J-2.** Atributos de productividad y umbrales de puntuación usados en el APS de la CIAT.

Productivity attribute Atributo de productividad	Ranking – Clasificación		
	Low – Bajo (1)	Moderate – Moderado (2)	High – Alto (3)
Intrinsic rate of population growth ( <i>r</i> ) Tasa intrínseca de crecimiento de la población ( <i>r</i> )	≤ 0.1	> 0.1, ≤ 1.3	>1.3
Maximum age (years) Edad máxima (años)	≥ 20	> 11, < 20	≤ 11
Maximum size (cm) Talla máxima (cm)	> 350	> 200, ≤ 350	≤ 200
von Bertalanffy growth coefficient ( <i>k</i> ) Coeficiente de crecimiento de von Bertalanffy ( <i>k</i> )	< 0.095	0.095 – 0.21	> 0.21
Natural mortality ( <i>M</i> ) Mortalidad natural ( <i>M</i> )	< 0.25	0.25 – 0.48	> 0.48
Fecundity (measured) Fecundidad (medida)	< 10	10 – 200,000	> 200,000
Breeding strategy Estrategia de reproducción	≥ 4	1 to-a 3	0
Age at maturity (years) Edad de madurez (años)	≥ 7.0	≥ 2.7, < 7.0	< 2.7
Mean trophic level Nivel trófico medio	> 5.1	4.5 – 5.1	< 4.5



**TABLE J-3.** Susceptibility attributes and scoring thresholds used in the IATTC PSA.

Susceptibility attribute	Ranking		
	Low (1)	Moderate (2)	High (3)
Management strategy	Management and proactive accountability measures in place	Stocks specifically named in conservation resolutions; closely monitored	No management measures; stocks closely monitored
Areal overlap - geographical concentration index	Greatest bycatches outside areas with the most sets <u>and</u> stock not concentrated (or not rare)	Greatest bycatches outside areas with the most sets <u>and</u> stock concentrated (or rare), OR Greatest bycatches in areas with the most sets <u>and</u> stock not concentrated (or not rare)	Greatest bycatches in areas with the most sets <u>and</u> stock concentrated (or rare)
Vertical overlap with gear	< 25% of stock occurs at the depths fished	Between 25% and 50% of the stock occurs at the depths fished	> 50% of the stock occurs in the depths fished
Seasonal migrations	Seasonal migrations decrease overlap with the fishery	Seasonal migrations do not substantially affect the overlap with the fishery	Seasonal migrations increase overlap with the fishery
Schooling/Aggregation and other behavioral responses to gear	Behavioral responses decrease the catchability of the gear	Behavioral responses do not substantially affect the catchability of the gear	Behavioral responses increase the catchability of the gear
Potential survival after capture and release under current fishing practices	Probability of survival > 67%	33% < probability of survival ≤ 67%	Probability of survival < 33%
Desirability/value of catch (percent retention)	Stock is not highly valued or desired by the fishery (< 33% retention)	Stock is moderately valued or desired by the fishery (33-66% retention)	Stock is highly valued or desired by the fishery (> 66% retention)
Catch trends	Catch-per-set increased over time	No catch-per-set trend over time	Catch-per-set decreased over time