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ECOSYSTEM CONSIDERATIONS

CONTENTS

1. INTRODUCTION

The 1995 FAO Code of Conduct for Responsible Fisheries stipulates that States and users of living aquatic resources should conserve aquatic ecosystems and it provides that management of fisheries should ensure the conservation not only of target species, but also of species belonging to the same ecosystem or associated with or dependent upon the target species.[1] In 2001, the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem elaborated these principles with a commitment to incorporate an ecosystem approach into fisheries management.

Consistent with these instruments, one of the functions of the IATTC under the 2003 Antigua Convention is to "adopt, as necessary, conservation and management measures and recommendations for species belonging to the same ecosystem and that are affected by fishing for, or dependent on or associated with, the fish stocks covered by this Convention, with a view to maintaining or restoring populations of such species above levels at which their reproduction may become seriously threatened".

Consequently, 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

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[1] The Code also provides that management measures should ensure that biodiversity of aquatic habitats and ecosystems is conserved and endangered species are protected and that States should assess the impacts of environmental factors on target stocks and species belonging to the same ecosystem or associated with or dependent upon the target stocks, and assess the relationship among the populations in the ecosystem.

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. Furthermore, section 2.2 includes a summary of some recent research conducted on drifting fish aggregating device- (FAD) associated aggregations, including methods which may lead to solutions on how to reduce the fishing mortality on undesirable-sizes of bigeye and yellowfin tunas. 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-07-05b, 05a, and 05c, respectively, and an executive summary of Pacific bluefin tuna will be available at this meeting. The ISC Northern Albacore Working Group completed its stock assessment in 2014 and the next assessment is scheduled for 2017.

IATTC staff recently published two studies that focused on the potential reduction of fishing mortality by purse seine on undesirable sizes of bigeye and yellowfin tunas and other species of concern, while still capturing associated schools of skipjack tuna. The first of these studies evaluated the simultaneous behaviors of skipjack, bigeye, and yellowfin tunas within large multi-species aggregations associated with FADs. The researchers documented spatial and temporal differences in the schooling behavior of the three species of tunas, including depth distributions, and found that the differences did not appear sufficient such that modifications in purse seine fishing practices could effectively avoid the capture of small bigeye and yellowfin, while optimizing the capture of skipjack. The second study assessed a fishing captain's ability to predict species composition, sizes, and quantities of tunas associated with drifting FADs, before encirclement with a purse-seine. The captain's predictions were significantly related to the actual total catch and catch by species, but not to size categories by species. Predictions of species composition were most accurate when estimates of bigeye and yellowfin tuna were combined, indicating the captain was overestimating one species while underestimating the other.

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 13. Stock assessments and/or stock structure analyses for swordfish (2007, structure), eastern Pacific striped marlin (2010, assessment and structure), northeast Pacific striped marlin (2011, assessment), southeast Pacific swordfish (2012, assessment), and eastern Pacific sailfish (2013, assessment) were completed by the IATTC staff. Stock assessments for Pacific blue marlin (2013) and for north Pacific swordfish (2014) and striped marlin (2015) were completed by the billfish working group of the International Scientific Committee (ISC) for Tuna and Tuna-like Species in the North Pacific Ocean.

2.3.1. Black marlin and shortbill spearfish

No 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 2015 in the EPO are found in Tables A-2a and A-2b of Document SAC-07-03a.

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 estimated 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 2015 are shown in Table 1. The IATTC staff is responsible for the assessment of dolphin populations associated with the purse-seine fishery for tunas, as a basis for the dolphin mortality limits established by the Agreement on the International Dolphin Conservation Program (AIDCP).

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. Because there have been no NMFS surveys since 2006, new modelling was conducted during 2014 and 2015 on trends in dolphin relative abundance using purse-seine observer data. That research concluded that indices of relative abundance from purse-seine observer data for species such as dolphins in the EPO that are directly associated with the fishing process are unlikely to be reliable indicators. Not only are such indices susceptible to the usual problems of

TABLE 1. Mortality of dolphins and other marine mammals caused by the fishery in the EPO during 2015

Species and stock	Incidental mortality	
	Number	Metric tons
Offshore spotted dolphin		
Northeastern	191	12.5
Western-southern	158	10.3
Spinner dolphin		
Eastern	196	8.7
Whitebelly	139	8.4
Common dolphin		
Northern	43	3.0
Central	21	1.5
Southern	12	0.8
Other mammals*	5	0.3
Total	**765**	**45.5**

*"Other mammals" includes the following species and stocks, whose observed mortalities were as follows: unidentified dolphins 5 (0.3 t).

changes in fishing behavior, but there is not a clear distinction between indexing the dolphin-tuna association and indexing dolphin abundance. This research, as well as alternative means of monitoring dolphin stocks, was published in 2015.

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. Of 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

TABLE 2. Numbers of turtle mortalities caused by large purse-seine vessels in the EPO during 2015

	Set type			**Total**
	OBJ	**NOA**	**DEL**	
Olive Ridley	2	-	1	3
Eastern Pacific green	-	-	-	-
Loggerhead	-	-	-	-
Hawksbill	-	-	-	-
Leatherback	-	-	-	-
Unidentified	-	4	-	4
Total	**2**	**4**	**1**	**7**

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 2015, only three mortalities of leatherback (*Dermochelys coriacea*) 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 2015, by set type (on floating objects (OBJ), unassociated schools (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 and loggerhead turtles are designated as vulnerable, those of 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 (IUCN).

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. The longline fisheries also take silky sharks. An analysis of longline and purse-seine fishing is necessary to estimate the impact of fishing on the stock(s).

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 that for management purposes, silky sharks in the EPO should be divided into two stocks, one north and one south of the equator. In addition, the results of a mitochondrial-DNA study from 2013 show a slight genetic divergence between silky sharks in the western and eastern Pacific, which supports assessing and managing these two populations separately.

Stock assessments are available for only four shark species in the EPO: silky, blue (*Prionace glauca*), mako (*Isurus oxyrinchus*) and common thresher sharks (*Alopias vulpinus*). The impacts of the bycatches on the stocks of other shark species in the EPO are unknown.

A stock assessment for silky sharks covering the 1993-2010 period was attempted using the Stock Synthesis model. Unfortunately, the model was unable to fit the main index of abundance adequately, and therefore the results were not reliable since relative trends and absolute scale are compromised in the assessment. Results are presented in Document SAC-05 INF-F. The majority of the catches of silky sharks in the EPO is estimated to be taken by longliners, some of them targeting sharks. As an alternative to conventional stock assessment models, a suite of possible stock status (or stability) indicators (SSIs), which could be considered for managing the northern and southern stocks of silky sharks in the EPO, are provided in Document SAC-05-11a. Updated SSIs, based on standardized catch-per-unit effort (CPUE) in purse-seine sets on floating objects (CPUE-OBJ), for silky sharks from 1994-2014 are presented in Document SAC-06-08b. Results therein indicate an apparent reduction in bycatch rates for all size classes north of the equator. For the southern stock, there is a major decline in bycatch rates. No stock status target and limit reference points have been developed for silky sharks based on these indicators. No harvest control rules have been developed and tested. At this point, the indicators cannot be used directly for determining the status of the stock or for establishing catch limits.

A stock assessment for blue sharks in the North Pacific Ocean was conducted by scientists of the ISC Shark Working Group in 2014. The report states, "Results of the reference case model showed that the stock biomass was near a time-series high in 1971, fell to its lowest level between the late 1980s and early 1990s, and subsequently increased gradually and has leveled off at a biomass similar to that at the beginning of the time-series."

The ISC Shark Working Group conducted a new stock assessment of mako sharks in 2015. The report acknowledged the limited data available for this species and the lack of information on important fisheries. Thus, the stock status (overfishing and overfished) of mako sharks in the North Pacific Ocean is undetermined.

Scientists at the NMFS conducted a stock assessment for common thresher sharks along the west coast of North America. Their results indicate, "this stock of common thresher sharks is unlikely to be in an overfished condition nor experiencing overfishing. The stock experienced a relatively large and quick decline in the late 1970s and early 1980s, soon after the onset of the USA swordfish/shark drift gillnet fishery, with spawning depletion dropping to 0.4 in 1985. The population appeared to have stabilized in the mid-1980s after substantial regulations were imposed. Over the past 15 years, the stock began recovering relatively quickly and is currently close to an unexploited level."

Preliminary estimates of the catches (including purse-seine discards), in metric tons, of sharks and other large fishes in the EPO during 2015, 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. In general, the bycatch rates of manta rays (Mobulidae), and stingrays (Dasyatidae) are greatest in unassociated sets, followed by dolphin sets, and lowest in floating-object sets, although in 2015 the bycatch rate was

TABLE 3. Catches, in tons, of sharks and other large fishes by large purse-seine vessels with observers aboard in the EPO, 2015

	Set type			**Total**
	OBJ	**NOA**	**DEL**	
Silky shark (*Carcharhinus falciformis)*	541	133	48	722
Oceanic whitetip shark (*C. longimanus)*	3	<1	<1	4
Hammerhead sharks (*Sphyrna* spp.)	54	4	1	59
Thresher sharks (*Alopias* spp.)	1	4	3	9
Other sharks	46	10	105	160
Manta rays (Mobulidae)	6	20	45	71
Pelagic sting rays (Dasyatidae)	<1	<1	<1	<1
Dorado (*Coryphaena* spp.)	1206	8	<1	1215
Wahoo (*Acanthocybium solandri)*	366	1	<1	368
Rainbow runner (*Elagatis bipinnulata*) and yellowtail (*Seriola lalandi*)	33	9	<1	42
Other large fishes	367	12	1	379

greater in dolphin sets than unassociated 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 data. The estimated numbers of purse-seine sets of each type in the EPO during 1999-2015 are shown in Table A-7 of Document SAC-07-03a.

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.

A recent review of bycatch in the tropical tuna purse-seine fisheries of the world addressed available actions and concepts to reduce shark bycatch. These included spatial and seasonal closures, effort controls, prohibition of shark landings, shark size limits, shark bycatch quotas per vessel, a mandate to release immediately any shark brought onboard, setting best procedures for shark handling during release, and training of crews in these procedures.

Dorado (*Coryphaena hippurus*) is one of the most important species caught in the artisanal fisheries of the coastal nations in the EPO. Dorado are also caught incidentally in the purse-seine tuna fishery in the EPO. Under the Antigua Convention and its ecosystem approach to fisheries, it is therefore appropriate that the IATTC staff study the species, with a view to determining the impact of fishing, and to recommend appropriate conservation measures of this important resource if required. In this context, some Members of the IATTC with coastlines in the region have requested that collaborative research on dorado be carried out with the IATTC staff so that solid scientific information is available for this purpose.

The IATTC held its first technical meeting on dorado in 2014. That meeting had three objectives: 1) to promote synergy among the Members of the IATTC for a regional investigation of dorado in the EPO; 2) to review the current state of knowledge of dorado and identify available data sets across fisheries/regions in the EPO); and 3) to plan a future collaborative research plan. This collaborative effort thus far includes: analysis of available catch statistics and trade records, improvement of field data collection programs, investigation of seasonal trends, and identification of fishery units. In addition, available fishery data on dorado from IATTC Members and other nations are being analyzed to develop stock status indicators (SSIs) which could potentially provide a basis for advice for managing the species in the EPO (see SAC-05-11b). The work was continued in 2015 and a second technical meeting was held with the aim to address two important questions: 1) What are reasonable stock structure assumptions to consider for regional management of dorado in the EPO? and 2) Which indicators of stock status should be monitored to provide scientific advice for regional management?

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.

Recent research by a scientist at NMFS focused on assessing the habitat use of several mesopelagic fish families throughout various life stages in the EPO to aid in understanding their role in the ecosystem. The work also included describing ontogenetic changes in abundance and horizontal distribution of common species of mesopelagic fish larvae impacted by the El Niño event in 1997-1998 followed by the La Niña in the California Cooperative Oceanic Fisheries Investigations (CalCOFI) study area. Within the CalCOFI sampling region, mesopelagic fishes (2 species of Myctophidae and 1 species of Phosichthyidae) with an affinity for warm water conditions had a higher larval abundance, were closer to shore during the El Niño, and were less abundant and farther offshore during the La Niña. The opposite pattern was generally observed for mesopelagic fishes (3 species of Bathylagidae and 4 species of Myctophidae) with an affinity for cold water conditions.

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 Humboldt 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 species or groups. 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 2015 are shown in Table 4

TABLE 4. Catches of small fishes, in tons, by large purse-seine vessels with observers aboard in the EPO, 2015

	Set type			Total
	OBJ	NOA	DEL	
Triggerfishes (Balistidae) and filefishes (Monacanthidae)	141	4	<1	145
Other small fishes	16	<1	<1	16
Frigate and bullet tunas (*Auxis* spp.)	177	65	0	242

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 Nino 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.

Historical studies of tuna diets in the EPO were based on qualitative data from few samples, with little or no indication of relative prey importance. Contemporary studies, however, have used diet indices, typically volume or weight importance, numeric importance, and frequency of occurrence of prey items to quantify diet composition, often in conjunction with chemical indicators, such as stable-isotope and fatty-acid analyses. A chapter entitled “Bioenergetics, trophic ecology, and niche separation of tunas” will be published in 2016 in the serial *Advances in Marine Biology*. It reviews current understanding of the bioenergetics and feeding dynamics of tunas on a global scale, with emphasis on yellowfin, bigeye, skipjack, albacore, and Atlantic bluefin tunas in seven oceans or ocean regions. Food consumption balances bioenergetics expenditures for respiration, growth (including gonad production), specific dynamic action, egestion, and excretion. Each species of tuna appears to have a generalized feeding strategy, in the sense that their diets were characterized by high prey diversity and overall low abundance of individual prey types. Ontogenetic and spatial diet differences are substantial, and significant inter-decadal changes in prey composition have been observed. Diet shifts from larger to smaller prey taxa highlight ecosystem-wide changes in prey availability and diversity, and provide implications for changing bioenergetics requirements into the future. The lack of long-term data limits the ability to predict the impacts of climate change on tuna feeding behavior, and thus there is a need for systematic collection of feeding data as part of routine monitoring of these species.

New statistical methods for analyzing complex, multivariate stomach-contents data have been developed through an international collaboration, Climate Impacts on Oceanic Top Predators-Integrated Marine Biogeochemistry and Ecosystem Research (CLIOTOP-IMBER), Working Group 3 (WG3: Trophic pathways in open-ocean ecosystems), to assess the trophodynamics of marine top predators. This methodology shows promise for analyzing broad-scale spatial, temporal, environmental, and biological relationships in a classification-tree modeling framework that predicts the prey compositions of predators. Two recent studies of yellowfin tuna and silky sharks in the EPO, discussed below, used the approach to infer changes in prey populations over space (yellowfin and silky sharks) and time (yellowfin) based on stomach contents data. In 2015, progress was made by WG3 on a global analysis of the diets of yellowfin, bigeye and albacore tunas, using the classification tree approach to assess whether spatial analyses can be used to hypothesize predation changes in a warming ocean. Diet data of yellowfin and bigeye tuna caught in the purse-seine fishery in the EPO was included in this global analysis.

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, mentioned above, 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).

The food-web representations that form the basis of ecosystem models are usually highly generalized, and do not account for variability in space and time. To gain insight into the role of the silky shark in the ecosystem, in 2014 an analysis of spatial variability was carried out, based on the stomach contents of 289 silky sharks captured as bycatch in sets on floating objects, primarily drifting fish-aggregating devices (FADs), by the tuna purse-seine fishery of the EPO. The dataset is novel because biological data for open-ocean carcharhinid sharks are difficult to collect, and it includes data for silky sharks caught over a broad region of the tropical EPO. Results from classification tree and quantile regression methodologies suggest that the silky shark is an opportunistic predator that forages on a variety of prey. Broad-scale spatial and shark size covariates explained the feeding habits of the silky sharks. A strong spatial shift in diet was revealed, with different foraging patterns in the eastern (inshore) and western (offshore) regions. Greater proportions of FAD-associated prey than non-FAD-associated prey were observed in the diet throughout the EPO, but especially in the offshore region. Yellowfin tuna and silky sharks shared some of the same prey resources during these same two 2-year periods separated by a decade, e.g., Humboldt squid, flyingfishes, jacks and pompanos, and Tetraodontiformes. As was the case for yellowfin tuna, spatial and temporal factors likely both have a role in determining silky shark predation habits, but the samples were inadequate to test whether the diet of the sharks had changed over time. The analysis provided a comprehensive description of silky shark predation in the EPO, while demonstrating the need for increased sampling coverage over space and time, and presents important information on the dynamic component of trophic interactions of silky sharks. This information can be used to improve future ecosystem models.

Predator-prey interactions for yellowfin, bigeye and albacore tunas, collected over a 40-year period from the Pacific, Indian and Atlantic Oceans, were used to quantitatively assess broad, macro-scale trophic patterns in pelagic ecosystems. Collation of these data, representing more than 10,000 predators, in a global database, was a critical first step, and underpinned analyses. A modified classification tree approach showed significant spatial differences and partitioning in the principal prey items consumed by all three tuna species, reflecting regional distributions of micronekton. Ommastrephid squids were one of the most important prey groups in all oceans across tuna species. Generalized additive models revealed that diet diversity was mainly driven by regional-scale processes and tuna length (59-81% Deviance Explained). In regions of low primary productivity the diet diversity of yellowfin tuna was more than double the diversity values in regions of high productivity. Ontogenetic and spatial patterns in diet diversity were found for bigeye tuna, with diet diversity of larger fish less related to primary production levels. Diet diversity of albacore tuna was globally higher than that of the other tunas and was uniformly high in all oceans except in the oligotrophic Mediterranean Sea. These results suggest that the current expansion of warmer, less productive waters in the world's oceans may alter foraging opportunities of yellowfin tuna due to changes in the regional abundance of prey resources. Due to the larger depth range across which bigeye and albacore tunas forage, these species are less likely to be affected by changes in temperature and other environmental processes at the surface and within the mixed layer. Well-planned, long-term diet studies for large pelagic ecosystems are needed to test these preliminary hypotheses.

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 ^{15}N by about 7.6‰ 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 more productive eastern waters.

CSIA was recently utilized in the EPO and other regions through a research grant from the Comparative Analysis of Marine Ecosystem Organization (CAMEO) program, which is implemented as a partnership between the NMFS and the U.S. National Science Foundation, Division of Ocean Sciences. The research collaboration among the IATTC, the University of Hawaii, Scripps Institution of Oceanography, and the Oceanic Institute, Hawaii, seeks to develop amino acid compound-specific isotopic analysis as a tool that can provide an unbiased evaluation of trophic position for a wide variety of marine organisms and to use this information to validate output from trophic mass-balance ecosystem models. To accomplish this goal, the research combines laboratory experiments and field collections in contrasting ecosystems that have important fisheries. The field component was undertaken in varying biogeochemical environments, including the equatorial EPO, to examine trophic position of a range of individual species, from macrozooplankton to large fishes, and to compare trophic position estimates derived from AA-CSIA for these species with ecosystem model output. The project began in 2010 and was extended into 2014.

Most of the samples for the EPO portion of the study were collected and stored frozen by personnel of the NMFS, Protected Resources Division, Southwest Fisheries Science Center (SWFSC), aboard the research vessels *David Starr Jordan* and *McArthur II* during the *Stenella* Abundance Research Project (STAR) in 2006. The samples for the study nearly span the food web in the EPO, and all were taken along an east-to-southwest transect that appeared to span a productivity gradient. The components include macroplankton (two euphausiid crustaceans, *Euphausia distinguenda* and *E. tenera*), mesopelagic-micronekton (two myctophid fishes, *Myctophum nitidulum* and *Symbolophorus reversus*), cephalopods (two species of pelagic squids, *Dosidicus gigas* and *Sthenoteuthis oualaniensis*), and small and large micronektonivores and nektonivores (skipjack, yellowfin, and bigeye tunas collected aboard commercial purse-seine vessels fishing in the EPO during 2003-2005).

Stable isotope analyses of bulk tissues and amino acids were conducted on several specimens each of the species listed above. Bulk δ^{15}N values varied markedly across the longitude and latitude gradients. There were no distinct longitudinal trends, but the δ^{15}N values increased consistently with increasing latitude. Trophic position estimates based on the amino-acid δ^{15}N values, however, varied little intra-specifically across the sample transect. These two results suggest that the isotopic variability in the food web was likely due to biogeochemical variability at the base of the food web rather than differences in diets within the food web. Increasing δ^{15}N values with latitude correspond to high rates of denitrification associated with the large oxygen minimum zone in the ETP. Among-species comparisons of absolute trophic positions based on AA-CSIA estimates with estimates based on diet from the EPO ecosystem model (IATTC Bulletin, Vol. 22, No. 3) showed underestimates for the predators occupying higher trophic levels, *i.e*. the three tunas and two squids. These underestimates are likely because the previously-accepted trophic enrichment factor of 7.6 ‰ for phenylalanine and glutamic acid, which was derived from laboratory experiments with primary producers and invertebrate consumers, is inadequate for higher-level predators. A Master of Science thesis was developed from this work, and a manuscript has been provisionally accepted for publication in 2016[2].

Previous studies suggest that differences in δ^{15}N values of source and trophic amino acids can be used to examine historical changes in the trophic positions of archived samples, to investigate, for example, the potential effects of fisheries removals on system trophic dynamics. Where historical diet data are lacking or absent, AA-CSIA of archived specimens may be the only way to determine the past trophic status of key predator and prey species. Given the importance of retrospective ecosystem analyses, capabilities are being developed for conducting these analyses by thoroughly examining the possible artifacts of sample preservation methods on subsamples of key species. In this two-year study, muscle samples from 3 yellowfin tuna and 3 Humboldt squid were collected, fixed in formalin, and stored long-term in ethanol. Paired samples were frozen for two years to compare with the preserved samples. The duration of preservation and freezing ranged from 1 week to 2 years, and all preserved samples showed a uniform increase in bulk δ^{15}N values. δ^{15}N values of several amino acids (threonine, phenylalanine, and valine) were significantly different between preserved and frozen samples. A follow-up experiment is underway to evaluate whether alteration of δ^{15}N values was caused by formalin fixation or ethanol preservation. These data suggest that caution and further investigation be used for future studies that aim to conduct AA-CSIA on formalin-ethanol preserved tissues.

In early 2016, a proposal by a task team of CLIOTOP WG3 members was accepted by the CLIOTOP Scientific Steering Committee. This work will be a companion paper to the global tuna diet analysis

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[2] Hetherington, E.D., R.J. Olson, J.C. Drazen, C.E. Lennert-Cody, L.T. Ballance, R.S. Kaufmann, and B.N. Popp. In revision. Spatial variability in food web structure in the eastern tropical Pacific Ocean using compound-specific nitrogen isotope analysis of amino acids. Limnology and Oceanography.

described above. The task team represents an international collaborative effort to move from regional trophic studies of top marine predators to a global comparative study of oceanic food webs using stable isotope compositions of the same three tuna species featured in the diet paper: yellowfin, bigeye, and albacore tunas. The team will assess isotopic differences among oceans, regions, and tuna species. Predictive models will be used to undertake an inter-ocean comparison of a proxy for trophic position based on stable isotope values. The proxy is based on $\delta^{15}N$ values of the tunas minus known regional differences in baseline $\delta^{15}N$ values derived from a coupled ocean circulation-biogeochemical-isotope model. A similar approach will be taken with lipid-corrected $\delta^{13}C$ values to examine regional differences in carbon-based primary production origins. Environmental variables (SST, Chl-*a*, net primary productivity, and mixed layer depth) will be included to explore the influence of global oceanographic processes on the isotopic compositions of the tuna species and food-chain length.

5. PHYSICAL ENVIRONMENT[3]

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, 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 staff issues quarterly reports of the monthly average oceanographic and meteorological data

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[3] 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.

for the EPO, including a summary of current ENSO conditions. The SSTs had been mostly below normal from October 2013 through March 2014, but during April 2014 through September 2015 they were virtually all above normal. By January 2015 the area of warm water off Mexico had expanded to the southwest, combining with an area of warm water along the equator that persisted through June. During the third quarter, the areas of warm water off Baja California and along the equator grew larger and warmer. During the fourth quarter, the SSTs were above normal over much of the area north of 10°S, and off Peru, but nearly normal over most of the rest of the area south of the equator. According to the Climate Diagnostics Bulletin of the U.S. National Weather Service for December 2015, "Most models indicate that a strong El Niño will weaken with a transition to…neutral [conditions] during the late spring or early summer…The forecasters are in agreement with the model consensus, though the exact timing of the transition is difficult to predict."

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 (2002-2012) recruitment. The recruitments for 2013 and 2014 have been estimated to be above average, but there is high uncertainty in the estimated values.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 (<~10 µmol 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.

Ecological Metrics. 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.

A variety of ecological metrics were employed in a study published in 2012[4] to evaluate the ecological effects of purse-seine fishing in the EPO during 1993-2008. Comparisons of the catch of target and non-target (bycatch) species, both retained and discarded, by types of purse-seine sets (on dolphins, floating objects, and unassociated tunas) were made on the basis of replacement time, diversity, biomass (weight), number of individuals, and trophic level. Previous comparisons considered only numbers of individuals and only discarded animals, without regard to body size, life-history characteristics, or

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[4] Gerrodette, T., R. Olson, S. Reilly, G. Watters, and W. Perrin. 2012. Ecological metrics of biomass removed by three methods of purse-seine fishing for tunas in the eastern tropical Pacific Ocean. Conservation Biology. 26 (2): 248-256

position in the food web. During 1993-2008, the mean biomass removed was 17.0, 41.1 and 12.8 t/set for dolphin sets, floating-object sets, and unassociated sets, respectively. Of these amounts, bycatch was 0.3% for dolphin sets, 3.8% for floating-object sets, 1.4% for unassociated sets, and 2.1% for all methods combined. The discard rate was 0.7% for dolphin sets, 10.5% for floating-object sets, 2.2% for unassociated sets, and 5.4% for all methods combined. With the addition of 0.7% estimated for smaller vessels, the overall discard rate was 4.8%. This rate is low compared with global estimates of 7.5% for tuna longlines, 30.0% for tuna mid-water trawls, and 8.0% for all fisheries combined.

Replacement time is a measure of the length of time required for replacement of biomass removed by the fishery. Unsustainable levels of harvest may lead to greater decreases in probabilities of persistence of long-lived animals with low fecundity and late age of maturity than of fast-growing, highly fecund species. In contrast to trophic-level metrics, replacement-time metrics were sensitive to categories of animals with relatively high biomass to production-of-biomass (B/P) ratios, such as bigeye tunas, sharks, and cetaceans. Mean replacement time for total removals averaged over years was lowest for dolphin sets (mean 0.48 years), intermediate for unassociated sets (0.57 years), and highest for floating-object sets (0.74 years). There were no temporal trends in mean replacement time for landings, and mean replacement times for discards were more variable than those for landings. Mean replacement times for dolphin-set discards were approximately 7 times the mean replacement times for floating-object or unassociated-set discards because dolphins have a low reproductive rate.

Diversity. Fishing alters diversity by selectively removing target species. The relationship between diversity of species removed and effects on the diversity and stability of the ecosystem from which they were removed may be complex. Higher diversity of catch may be associated with fewer undesirable effects on the ecosystem, although the complexity of competitive and trophic interactions among species makes the relationship between diversity of catch and diversity and stability of the ecosystem difficult to determine. The Shannon diversity index for total removals was lowest for dolphin sets (mean 0.62), intermediate for unassociated sets (1.22), and highest for floating-object sets (1.38). The diversity of dolphin-set landings increased by 0.023/year, on average, from 0.45 to 0.79, due primarily to an increase of the percentage of skipjack tuna in the catch from <1% to >7% and a concurrent decrease in the percentage of yellowfin tuna. The diversity of unassociated-set landings and discards both decreased, and diversity of total removals decreased by a mean of 0.024/year, from 1.40 to 1.04.

Biomass. The relative amounts and characteristics of the biomass removed by each of the fishing methods varied as a function of how removal was measured. Landings from floating-object sets were greatest by all four measures of removal, but were particularly high when removal was measured on the basis of number of individuals or replacement time. The amount and composition of discards varied among the fishing methods. Discards of the target tuna species were the greatest proportion of removed animals whether measured in biomass, number of individuals, or trophic-level units. Discards of cetaceans in dolphin sets and sharks in floating-object and unassociated sets were greater when measured in replacement-time units than when measured in other units because of the low reproductive rates of these animals.

Trophic structure and trophic levels of catches. 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 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 2014 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 based on diet data for all species groups and mass balance among groups. The weighted mean TLs of the summed catches of all purse-seine and pole-and-line fisheries were similar and fairly constant from year to year (Figure J-2: Average PS+LP). A slight downward trend for the unassociated sets, amounting to 0.05 TL over the 21-year period, resulted from increasing proportions of skipjack and decreasing proportions of yellowfin tuna 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 2014 (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 21-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. In 2014, the mean TLs of dolphin-set discards increased by about 0.2 TLs from those in 2013 primarily due to an increase in the proportions of discarded mesopelagic (TL 4.65) and spotted (TL 5.03) dolphins and a decrease in the proportions of discarded rays. 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 4.93-5.23), and an increase in prey fishes such as *Auxis* spp. (TL 3.86) in the bycatch. In 2014, the mean TLs of unassociated-set discards also increased by about 0.2 TLs from those in 2013, mostly due to an incease in the proportion of skipjack and a decrease in the proportion of discarded bullet and frigate tunas. For floating-object sets, the discards of bigeye were related to higher mean TLs of the discarded catches.

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 has applied a version of productivity and susceptibility analysis (PSA[5]), used to evaluate fisheries in other ocean regions in recent years, to estimate the vulnerability of data-poor, non-target species caught by the purse-seine fishery in the EPO. PSA 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. The scale of the x-axis on the scatter plot 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. When scoring the attributes, the data quality associated with each attribute score is assessed, and the attributes are weighted by the data-quality score. Stocks that receive a low productivity score (*p*) and high susceptibility score (*s*) are considered to be at a high risk of becoming depleted, while stocks with a high productivity score and low susceptibility score are considered to be at low risk. Vulnerability scores (*v*) are 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 for assessing the 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 in 2010, using 26 species that comprise the majority of the biomass removed by Class-6 purse-seine vessels (carrying capacity greater than 363 metric tons) during 2005-2009. Nine productivity and eight susceptibility attributes, based on established PSA methodology[4], were used in the preliminary PSA, and some were modified for greater consistency with data from the tuna fisheries in the EPO. Information corresponding to the productivity attributes for each species was compiled from a variety of published and unpublished 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 were derived by dividing the compiled data into equal thirds. Scoring criteria for the susceptibility attributes were taken from the example PSA[4] and modified where appropriate to better fit the EPO fisheries. However, problems arose when trying to compare susceptibility estimates for species across

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[5] 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.

the different fisheries (Fishery Status Report 8). In 2012, the PSA was revised to include seven additional species, based on data from 2005-2011 (Fishery Status Report 10).

The staff of the Biology and Ecosystem Program had planned to finalize and publish the PSA analysis during 2014, but the retirement of one staff member and budget constraints have prevented the work from being finished. In 2015 a vacancy announcement for an Ecosystem Specialist was posted. The selected appointee, a senior scientist and recognized expert in developing ERAs, will join the IATTC staff in August of 2016. He will lead the ERA effort for the EPO. Substantial progress on this work will be made during the latter half of 2016 and a report on the advancement will be available at the 2017 SAC meeting. Meanwhile, in response to requests made by SAC participants at the 2015 meeting, an effort was made by the IATTC staff to describe available catch data for the purposes of including gear types in addition to large purse seiners, in an ERA (described in SAC-07-INF C(d)). This effort will assist the new appointee in choosing the appropriate type of ERA for the EPO fisheries. Here we review the modifications made to the PSA presented at the 2015 SAC meeting.

Three modifications of the analysis were made to the PSA for the SAC meeting in May 2015: 1) the procedures for determining which species to include in the analysis were modified; 2) the susceptibility values for each fishery were combined to produce one overall susceptibility value for each species; and 3) the use of bycatch and catch information in the formulation of s was modified. The list of productivity attributes remains unchanged (Table J-1) while the list of susceptibility attributes has been revised due to this 3rd modification (Table J-2). These three modifications are described briefly below. For the remainder of this section, the term “catch” will be used to refer to bycatch for non-tuna species and catch for tuna species.

The first modification was to establish a two-step procedure to identify and exclude rare species, based on the biomass caught per fishery. However, as a precautionary measure, rare species classified as “vulnerable,” “endangered,” or “near threatened” on the IUCN Red List were retained, or are now included, in the analysis. Currently, the PSA includes 32 species (Table J-3a); an additional eight sensitive species, two rays and six sharks, will be included in the future.

The second modification was to combine the susceptibility values for each species across fisheries to produce one overall species-specific purse-seine susceptibility. A preliminary combined susceptibility score for a species, s_j^1, was calculated as the weighted sum of the individual fishery susceptibility values for that species (Table J-3a), with weights equal to the proportion of sets in each fishery:

$$s_j^1 = \sum_k s_{jk} p_k$$

where

s_j^1 is the combined susceptibility for species *j*

s_{jk} is the susceptibility for species *j* in set type *k,* computed using only the attributes in Table J-2. s_{jk} ranges from 1 (lowest) to 3 (highest). For a species with catches < 5% in set type *k*, $s_{jk} \equiv 1$, unless a s_{jk} was computed for one of the previous PSAs (Fishery Status Reports 8 and 10), in which case this s_{jk} was used; otherwise it was assumed that if catches were less than 5% in a fishery, the species was only minimally susceptible to that fishery. A previous PSA (Fishery Status Report 10) used catch trend information as an additional attribute to calculate the s_{jk}, however, the catch trend information was removed from the s_{jk} here because, following the established PSA[4] methodology, the other susceptibility attributes are time-invariant (but see below).

$p_k = \left(\frac{N_k}{\sum_k N_k}\right)$ and N_k is the total number of sets (class-6) of set type *k* in 2013

s_j^1 takes into account fishing effort by set type, even for set types with little or no catch of a species. A preliminary PSA plot using s_j^1 is shown in Figure J-4a, and the values of s_{jk}, s_j^1 and v_1 are shown in Table J-3a. A concern with regard to s_j^1 for some species is that the variation in the s_{jk} computed from the attributes in Table J-2 does not correlate well with differences observed among catch rates by set type, suggesting the attributes in Table J-2 do not capture the full susceptibility of species *j*; in general it is assumed that higher catch rates should reflect higher overall susceptibility. In addition, the s_{jk} do not account for long-term trends.

The third modification, the use of catch information in the formulation of *s*, was made to try to account for differences in observed catch rates among set types, by species, and to account for long-term trends in abundance. Two preliminary alternate susceptibility formulations were computed as "proof of concept" for these ideas. The first, s_j^2, modifies s_j^1 to take into consideration current catch rates, which are assumed to be an alternate proxy for susceptibility and to reflect the actual integrated effects of the susceptibility attributes in Table J-2:

$$s_j^2 = \sum_k s_{jk}^* p_k$$

where

s_j^2 is the combined susceptibility for species *j*, adjusted for recent catch rates

s_{jk}^* is the average of s_{jk} and of the catch rate susceptibility: $s_{jk}^* = \frac{1}{2}\left(s_{jk} + s_{cps\_jk}\right)$

s_{jk} is as defined for s_j^1

s_{cps_jk} is the catch rate susceptibility and takes a value of 1, 2 or 3, assigned as follows. If the species is not a target tuna species, catch-per set, in number of animals per set, is used to assign a value to s_{cps_jk}:

$$\begin{cases} 1 & \text{for} \quad \text{cps}_{jk} = 0 \\ 2 & \text{for } 0 < \text{cps}_{jk} < 1.0 \\ 3 & \text{for } \text{cps}_{jk} \geq 1.0 \end{cases}$$

If the species is a target tuna species, then the following values are assigned to s_{cps_jk}:

	Dolphin sets	Unassociated sets	Floating-object sets
Bigeye	1	2	3
Yellowfin	3	3	3
Skipjack	2	3	3

$cps_{\_jk}$ is the catch-per-set for species *j* in set type *k* (= class-6 catch (in numbers of animals) divided by number of class-6 sets), for the most recent year (2013). Catch-per-set was used instead of total catch in order to control for differences in effort among set types.

p_k is as defined for s_j^1

A preliminary PSA plot using s_j^2 is shown in Figure J-4b and the values of s_{jk}^*, s_j^2 and v_2 are shown in Table J-3b. s_j^2 could be affected by differences in abundance among species because catch-per-set is affected by abundance. Ranking cps_{jk} may help to minimize this problem. The present rules for ranking cps_{jk} for non-target tuna species were based on the idea that no catch equates to minimal susceptibility, catch that increases at a rate of less than one animal per set equates to moderate susceptibility, and catch that increases at an effort rate of one or more animals per set equates to high susceptibility.

However, these rules are a "proof of concept" and could be modified.

The second alternate susceptibility formulation, computed for species other than target tunas and dolphins, s_j^3, adjusts for long-term trends:

$$s_j^3 = \sum_k s_{jk}^{**} p_k$$

where

s_j^3 is the combined susceptibility for species *j*, adjusted for long-term trends

s_{jk}^{**} is the average of s_{jk} and the trend susceptibility: $s_{jk}^{**} = \frac{1}{2}\left(s_{jk} + s_{trend\_jk}\right)$;

s_{jk} is as defined for s_j^1

S_{trend_jk} is the trend susceptibility for species *j* in set type *k*, obtained as follows:

$$\begin{cases} 1.0 & \text{if species } j \text{ does not occur in set type } k \\ 1.5 & \text{if } trend_{jk} \text{ is not significant or is significant but increasing} \\ 3.0 & \text{if } trend_{jk} \text{ is significant and decreasing} \end{cases}$$

$trend_{jk}$ is the slope of the regression of $cps_{jk,y}$ and year *y*, from the start of the data collection (which may vary by species). $trend_{jk}$ was computed for species for which full assessments (or management indicators) do not exist and for which the fishery data have not been determined to be unsuitable for trend estimation; *i.e.*, for species other than the three target tuna species and the dolphin species (but see below) . A significant trend was any slope with a p-value < 0.05.

$cps_{,jk,y}$ is the catch-per-set of species *j* of set type *k* in year *y*

A preliminary PSA plot using s_j^3 for species other than the three target tuna species and dolphin species is shown in Figure J-4c, and the values of s_{jk}^{**} , s_j^3 and v_3 are shown in Table J-3c. For the future, s_j^3 could be expanded to include the three target tuna species by estimating trends from spawning biomass, and could be expanded to dolphin species by using trends estimated from historical line-transect abundance estimates. A concern with regards to s_j^3 is that trends estimated from catch-per-set may not reliably track changes in abundance (as was shown for dolphins in Document SAC-05-11d).

The three susceptibility measures, s_j^1, s_j^2, and s_j^3, are considered preliminary and represent "proof of concept" ideas to illustrate several options for computing susceptibility tailored to the EPO purse-seine fishery. These measures along with the available catch data for non-target species by gear type will be reviewed with the new Ecosystem Specialist in August 2016. This work will help to facilitate future improvements to the existing PSA in the EPO and/or assist in the development of a new ERA.

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, transhipping, 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.

d. Resolution C-15-04, adopted by the IATTC in July 2015, prohibits retaining onboard, transhipping, landing, storing, selling, or offering for sale any part or whole carcass of manta rays (Mobulidae) (which includes *Manta birostris* and *Mobula* spp.) and requires vessels to release all mobulid rays alive wherever possible. The requirements set forth in the resolution do not apply to small-scale and artisanal fisheries exclusively for domestic consumption. The number of discards and releases of mobulid rays and the status (dead or alive) will be reported to the IATTC via the observer programs.

9.5. Fish-aggregating devices (FADs)

a. Resolution C-15-03, adopted by the IATTC in July 2015, requires all purse-seine vessels, when fishing on FADs in the IATTC Convention Area, 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. In addition to this information, for each FAD activity, the position, date, hour, type of activity, and results of any set in terms of catch and by-catch must be reported. Data may be collected through a dedicated logbook, modifications to regional logsheets, or other domestic reporting procedures. 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. Recommendations shall include methods for limiting the capture of small bigeye and yellowfin tuna associated with fishing on FADs. CPCs shall require owners and operators of their applicable flagged purse-seine fishing vessels to identify all FADs deployed or modified by such vessels in accordance with a Commission identification scheme. 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. A working group on FADs is established and its objectives are to collect and compile information on FADs, review data collection requirements, compile information regarding developments in other tuna-RFMOs on FADs, compile information regarding developments on the latest scientific information on FADs, including information on non-entangling FADs, and prepare a preliminary report for the SAC.

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.

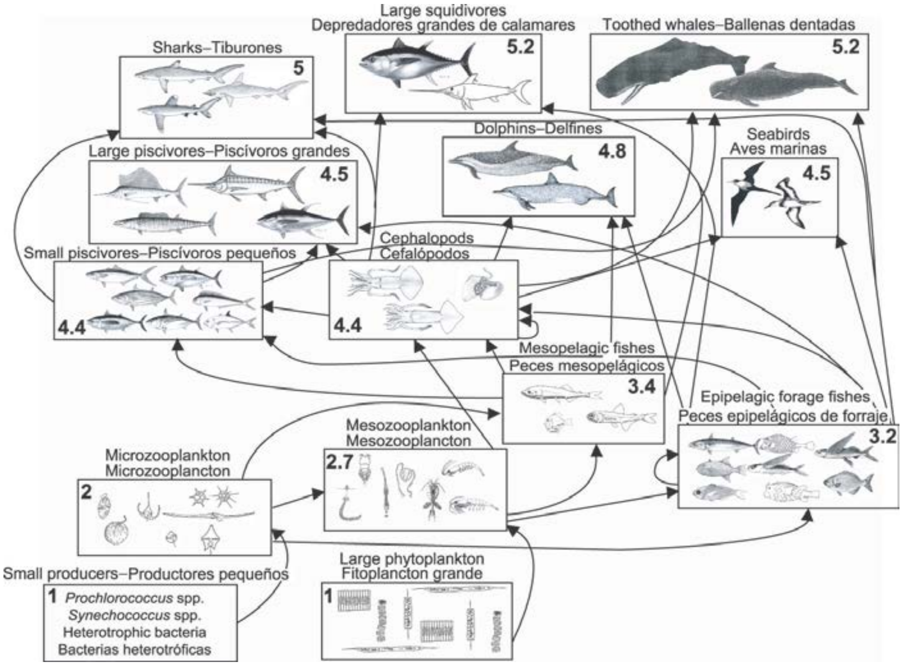

FIGURE J-1. Simplified food-web diagram of the pelagic ecosystem in the tropical EPO. The numbers inside the boxes indicate the approximate trophic level of each group.

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.

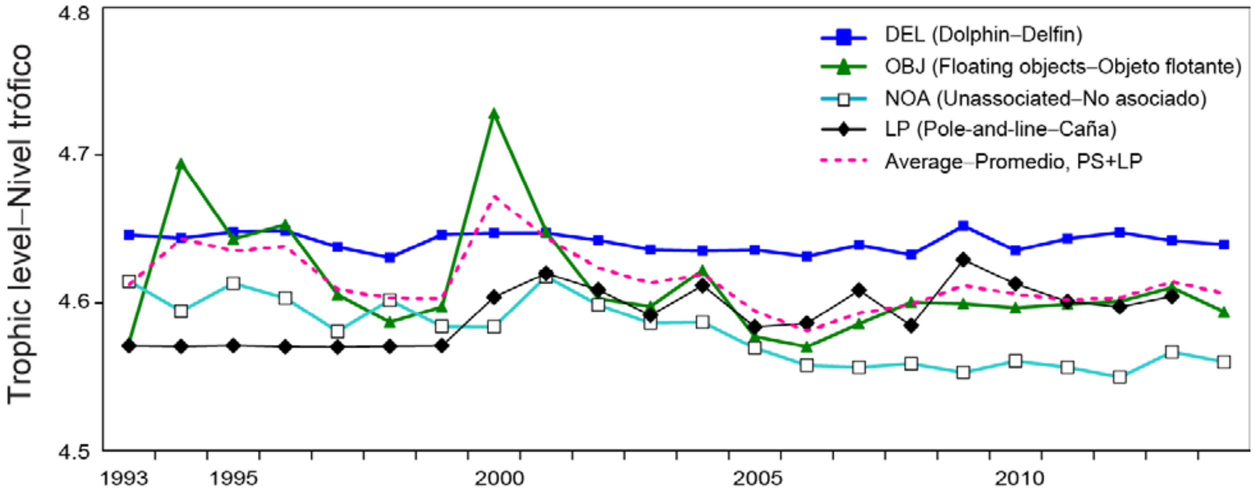

FIGURE J-2. Yearly mean trophic level estimates of the catches (retained and discarded) by the purse-seine and pole-and-line fisheries in the tropical EPO, 1993-2014. Pole-and-line catches were not reported separately in 2014, instead they were combined with other gears.

FIGURA J-2. Estimaciones anuales del nivel trófico de las capturas (retenidas y descartadas) de las pesquerías cerquera y cañera en el OPO tropical, 1993-2014. Las capturas cañeras no fueron reportadas por separado en 2014, sino que fueron combinadas con otras artes.

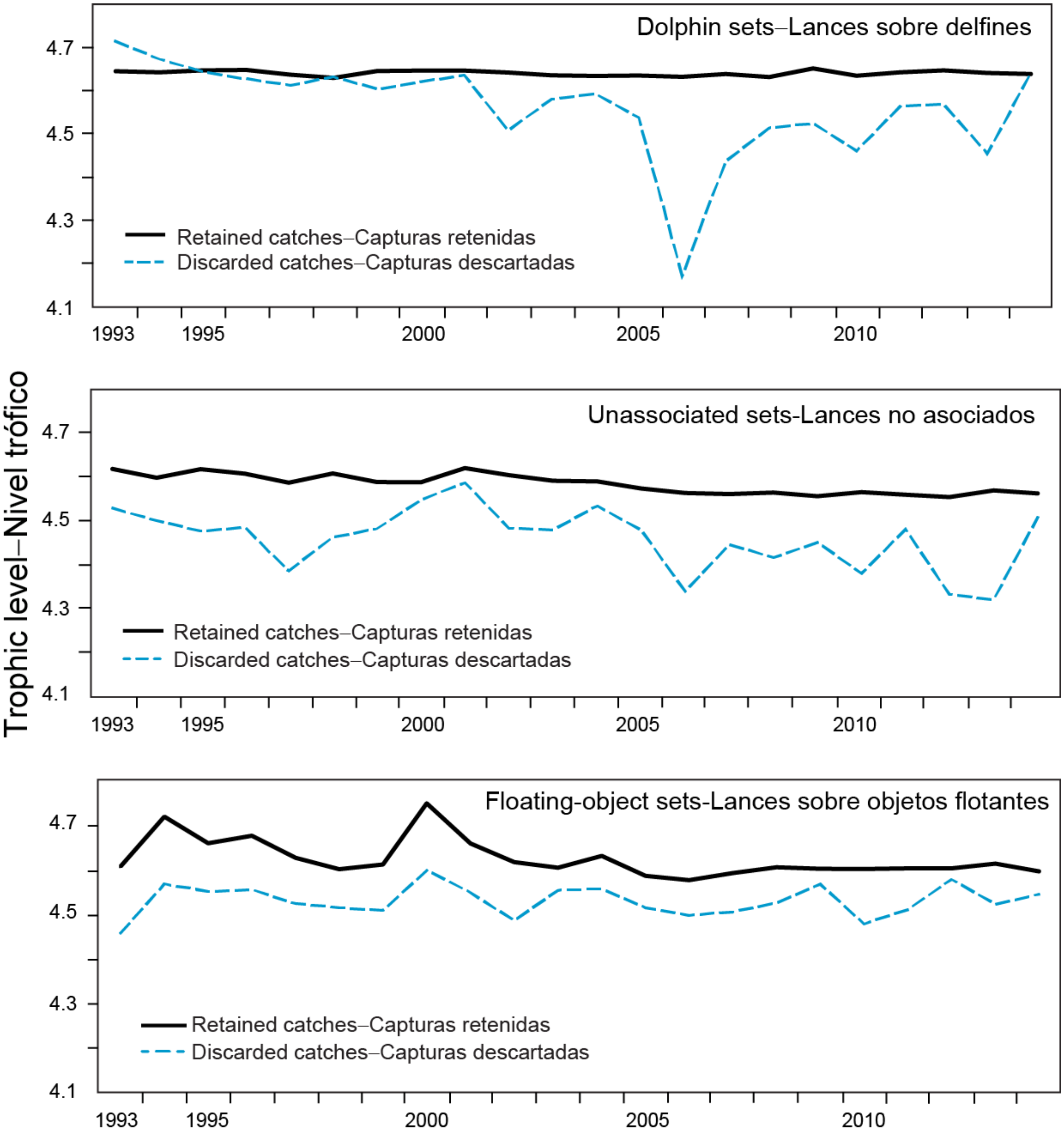

FIGURE J-3. Trophic level estimates of the retained catches and discarded catches by purse-seine fisheries in the tropical EPO, 1993-2014.

FIGURA J-3. Estimaciones del nivel trófico de las capturas retenidas y descartadas por las pesquerías cerqueras en el OPO tropical, 1993-2014.

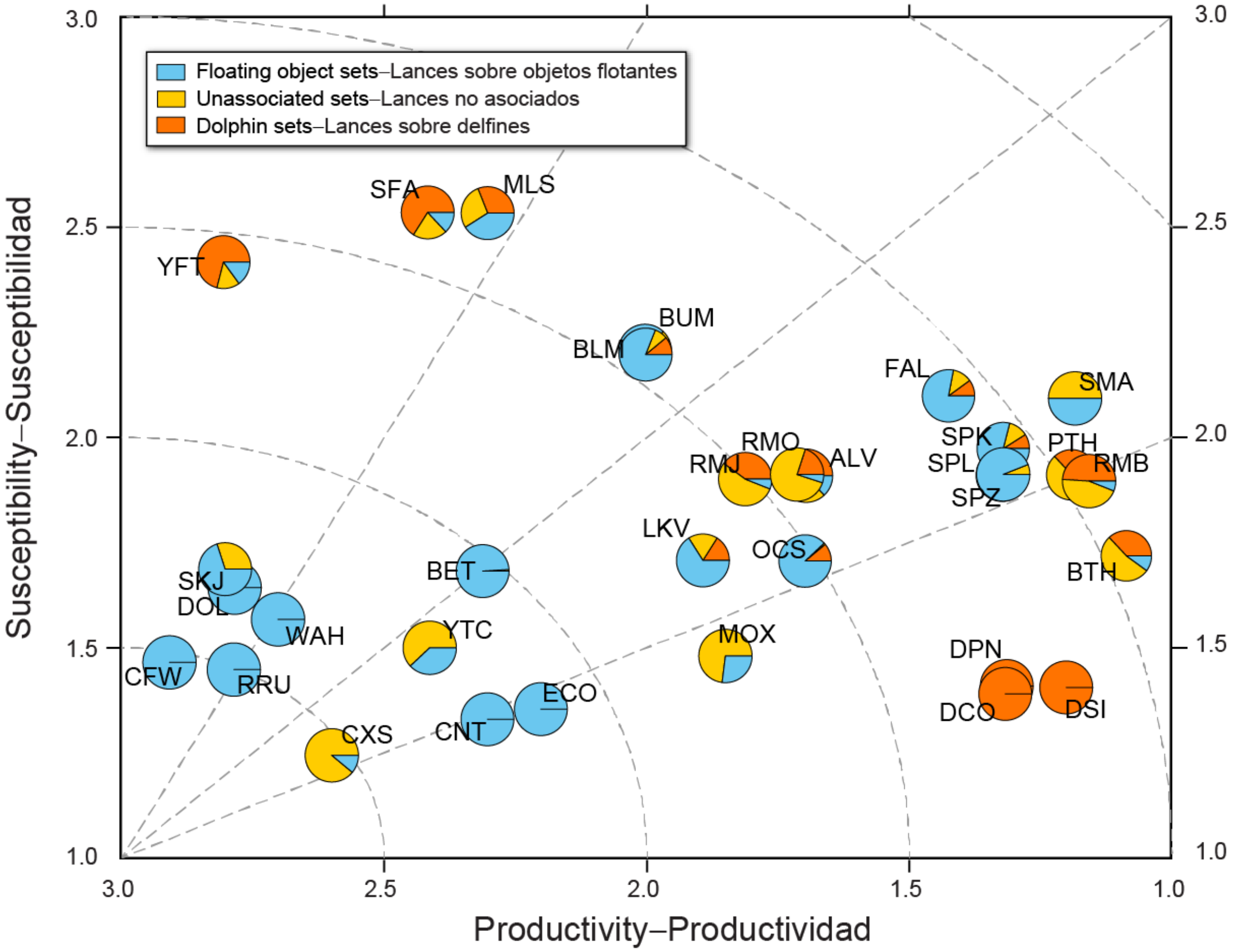

FIGURE J-4a. Productivity and susceptibility x-y plot for target and bycatch species caught by the purse-seine fishery of the EPO during 2005-2013, based on s_j^1. The pie charts show the proportion of bycatch (non-tuna species) or proportion of catch (tuna species), by set type, for those set types with bycatch or catch ≥ 5% for the species. The 3-alpha species codes next to each pie chart are defined in Table J-3a.

FIGURA J-4a. Gráfica x-y de productividad y susceptibilidad de especies objetivo y de captura incidental capturadas por la pesquería de cerco del OPO durante 2005-2013, basada en s_j^1. Las gráficas de sectores ilustran la proporción de captura incidental (especies aparte de los atunes) o proporción de la captura (especies de atunes), por tipo de lance, en aquellos tipos de lance con captura incidental o captura ≥ 5% de esa especie. En la Tabla J-3a se definen los códigos de tres letras al lado de cada gráfica de sectores.

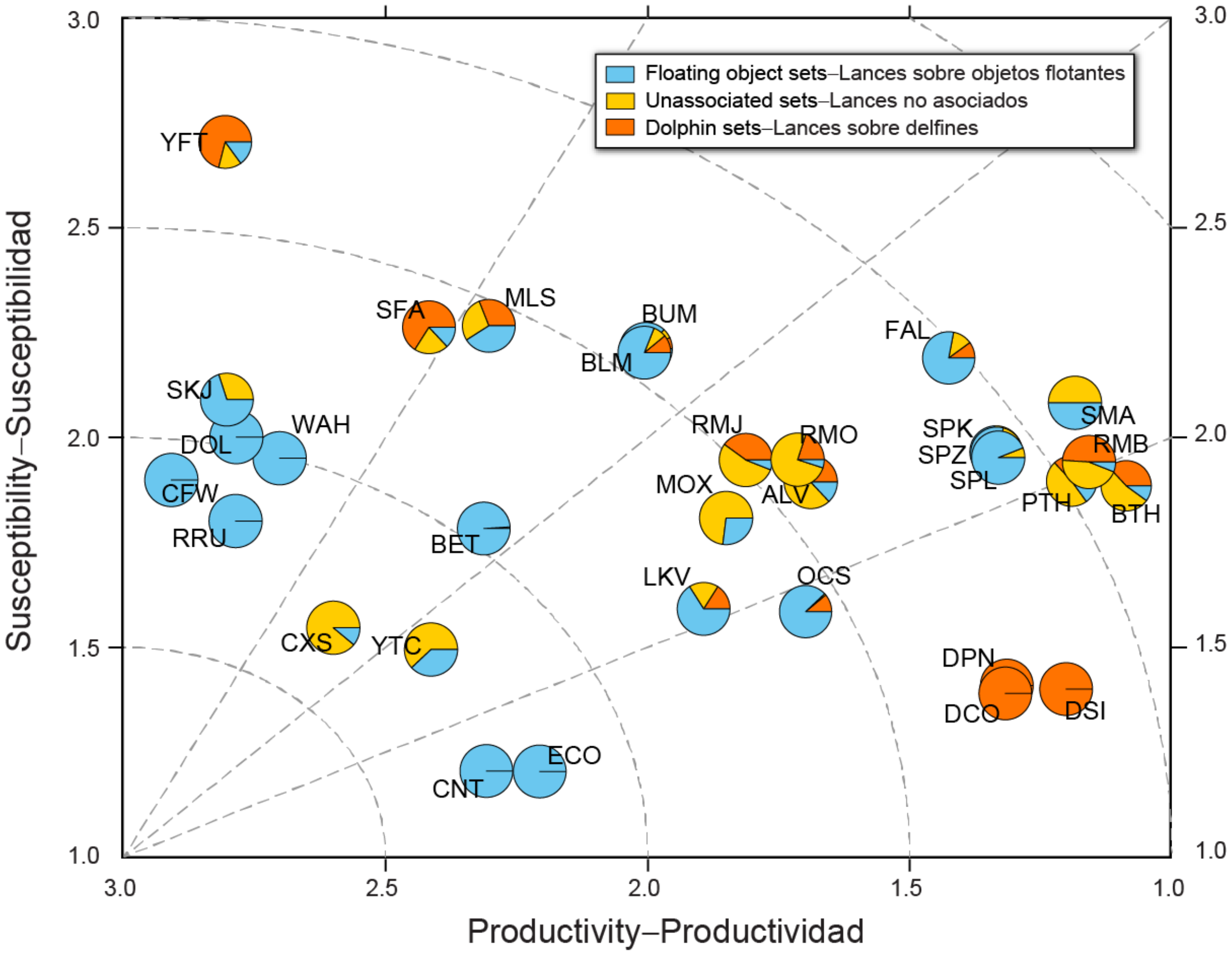

FIGURE J-4b. Productivity and susceptibility x-y plot for target and bycatch species caught by the purse-seine fishery of the EPO during 2005-2013, based on s_j^2. The pie charts show the proportion of bycatch (non-tuna species) or proportion of catch (tuna species), by set type, for those set types with bycatch or catch ≥ 5% for the species. The 3-alpha species codes next to each pie chart are defined in Table J-3b.

FIGURA J-4b. Gráfica x-y de productividad y susceptibilidad de especies objetivo y de captura incidental capturadas por la pesquería de cerco del OPO durante 2005-2013, basada en s_j^2. Las gráficas de sectores ilustran la proporción de captura incidental (especies aparte de los atunes) o proporción de la captura (especies de atunes), por tipo de lance, en aquellos tipos de lance con captura incidental o captura ≥ 5% de esa especie. En la Tabla J-3b se definen los códigos de tres letras al lado de cada gráfica de sectores.

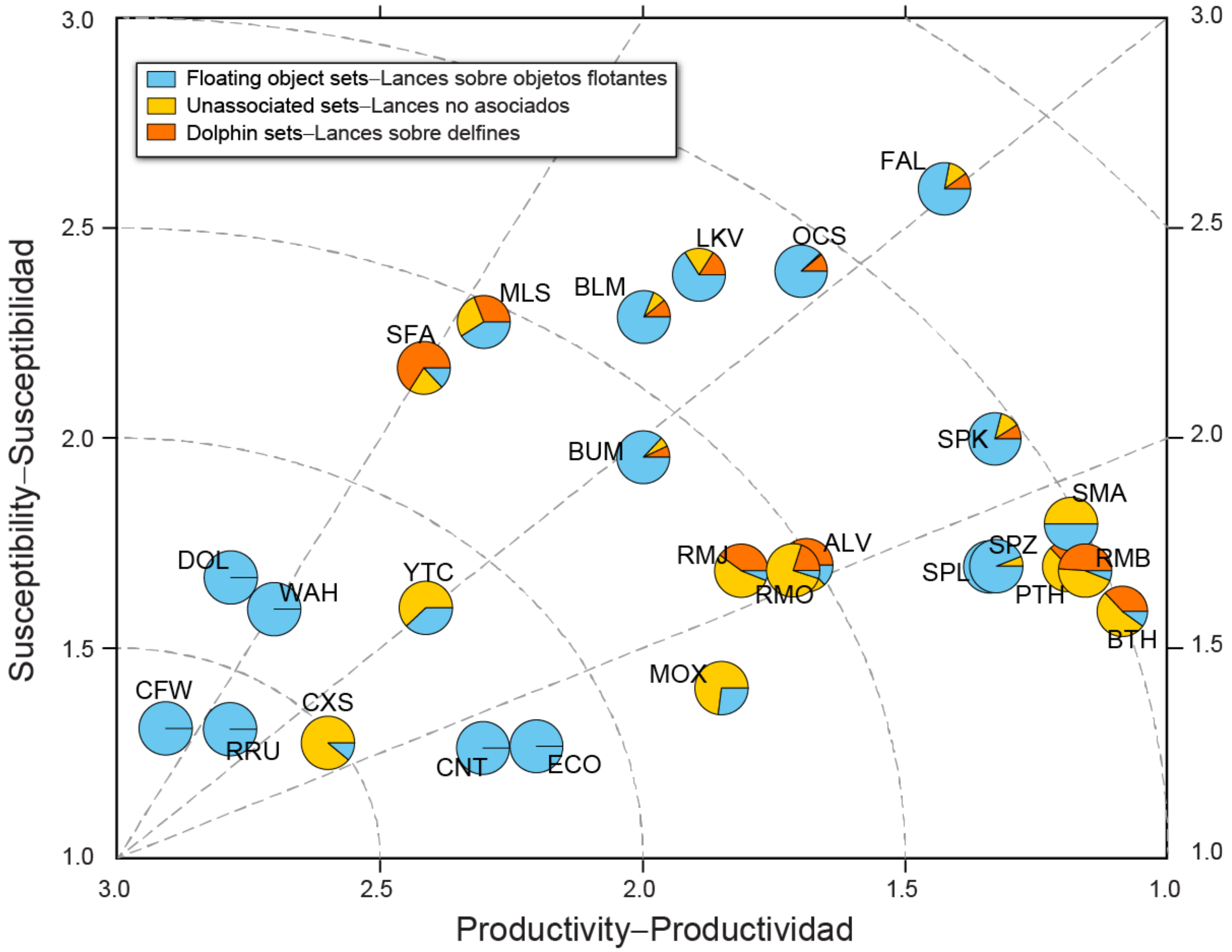

FIGURE J-4c. Productivity and susceptibility x-y plot for bycatch species caught by the purse-seine fishery of the EPO during 2005-2013, based on s_j^3. s_j^3 was not computed for species for which full assessments (or management indicators) exist or for which the fishery data have been determined to be unsuitable for trend estimation; *i.e.*, for the three target tuna species and the dolphin species. The pie charts show the proportion of bycatch (non-tuna species), by set type, for those set types with bycatch ≥ 5% for the species. The 3-alpha species codes next to each pie chart are defined in Table J-3c.

FIGURA J-4c. Gráfica x-y de productividad y susceptibilidad de especies objetivo y de captura incidental capturadas por la pesquería de cerco del OPO durante 2005-2013, basada en s_j^3. No se computó s_j^3 para especies para las cuales existen evaluaciones completas (o indicadores de ordenación), o para las cuales se determinó que los datos de pesca no son adecuados para la estimación de tendencias; es decir, para las tres especies de atunes objetivo y las especies de delfines. Las gráficas de sectores ilustran la proporción de captura incidental (especies aparte de los atunes), por tipo de lance, en aquellos tipos de lance con captura incidental ≥ 5% de esa especie. En la Tabla J-3c se definen los códigos de tres letras al lado de cada gráfica de sectores.

TABLE J-1. Productivity attributes and scoring thresholds used in the IATTC PSA.
TABLA J-1. Atributos de productividad y umbrales de puntuación usados en el APS de la CIAT.

	Ranking – Clasificación		
Productivity attribute Atributo de productividad	**Low – Bajo (1)**	**Moderate – Moderado (2)**	**High – Alto (3)**
Intrinsic rate of population growth (*r*) Tasa intrínseca de crecimiento de la población (*r*)	≤ 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 (*k*) Coeficiente de crecimiento de von Bertalanffy (*k*)	< 0.095	0.095 – 0.21	> 0.21
Natural mortality (*M*) Mortalidad natural (*M*)	< 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-2. 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)

TABLE J-3a. Preliminary productivity and susceptibility scores used to compute the overall vulnerability measure v_1. Dolphin=DEL, unassociated=NOA, and floating-object sets=OBJ. Individual susceptibility scores, s_{jk}, are shown for each fishery and as a weighted combination of the individual fishery values, s_j^1; see text for details. Productivity, p, and vulnerability, v_1, scores are provided. These values are preliminary as this year's PSA is considered a proof of concept.

*IUCN listings are defined as: EN=endangered, NT=near threatened, VU=vulnerable, LC=least concern, DD=data deficient, NA=not assessed

					s_{jk} scores by fishery					
GROUP	**Scientific name**	**Common name**	**3-alpha species code**	**IUCN***	**DEL**	**NOA**	**OBJ**	p	s_j^1	v_1
Tunas	*Thunnus albacares*	Yellowfin tuna	YFT	NT	2.38	2.38	2.38	2.78	2.38	1.40
	Thunnus obesus	Bigeye tuna	BET	VU	1.00	2.23	2.38	2.33	1.70	0.97
	Katsuwonus pelamis	Skipjack tuna	SKJ	LC	1.00	2.38	2.38	2.78	1.73	0.76
Billfishes	*Makaira nigricans*	Blue marlin	BUM	VU	2.23	2.23	2.69	2.00	2.39	1.71
	Istiompax indica	Black marlin	BLM	DD	2.23	2.23	2.69	2.00	2.39	1.71
	Kajikia audax	Striped marlin	MLS	NT	2.54	2.54	2.54	2.33	2.54	1.68
	Istiophorus platypterus	Indo-Pacific sailfish	SFA	LC	2.54	2.54	2.54	2.44	2.54	1.64
Dolphins	*Stenella longirostris*	Unidentified spinner dolphin	DSI	DD	1.77	1.00	1.00	1.22	1.36	1.82
	Stenella attenuata	Unidentified spotted dolphin	DPN	LC	1.77	1.00	1.00	1.33	1.36	1.71
	Delphinus delphis	Common dolphin	DCO	LC	1.62	1.00	1.00	1.33	1.29	1.70
Large fishes	*Coryphaena hippurus*	Common dolphinfish	DOL	LC	1.00	2.00	2.31	2.78	1.64	0.68
	Coryphaena equiselis	Pompano dolphinfish	CFW	LC	1.00	1.00	2.38	2.89	1.48	0.50
	Acanthocybium solandri	Wahoo	WAH	LC	1.00	1.00	2.62	2.67	1.57	0.66
	Elagatis bipinnulata	Rainbow runner	RRU	NA	1.00	1.00	2.31	2.78	1.46	0.51
	Mola mola	Ocean sunfish, Mola	MOX	NA	1.00	1.92	1.92	1.78	1.49	1.31
	Caranx sexfasciatus	Bigeye trevally	CXS	LC	1.00	2.38	1.00	2.56	1.25	0.51
	Seriola lalandi	Yellowtail amberjack	YTC	NA	1.00	2.08	1.85	2.44	1.49	0.75
Rays	*Manta birostris*	Giant manta	RMB	VU	1.92	2.08	1.77	1.22	1.90	1.99
	Mobula japanica	Spinetail manta	RMJ	NT	1.92	2.08	1.77	1.78	1.90	1.51
	Mobula thurstoni	Smoothtail manta	RMO	NT	1.92	2.08	1.77	1.67	1.90	1.60
Sharks	*Carcharhinus falciformis*	Silky shark	FAL	NT	2.08	2.08	2.15	1.44	2.10	1.91
	Carcharhinus longimanus	Oceanic whitetip shark	OCS	VU	1.69	1.00	2.08	1.67	1.70	1.50
	Sphyrna zygaena	Smooth hammerhead shark	SPZ	VU	1.77	1.92	2.08	1.33	1.91	1.90
	Sphyrna lewini	Scalloped hammerhead shark	SPL	EN	1.77	1.92	2.08	1.33	1.91	1.90
	Sphyrna mokarran	Great hammerhead shark	SPK	EN	2.08	1.77	1.92	1.33	1.97	1.93
	Alopias pelagicus	Pelagic thresher shark	PTH	VU	1.92	1.92	1.77	1.22	1.87	1.98
	Alopias superciliosus	Bigeye thresher shark	BTH	VU	1.77	2.08	1.46	1.11	1.72	2.02
	Alopias vulpinus	Common thresher shark	ALV	VU	1.92	1.92	1.77	1.67	1.87	1.59
	Isurus oxyrinchus	Short fin mako shark	SMA	VU	2.23	2.23	1.92	1.22	2.12	2.10
Small fishes	*Canthidermis maculatus*	Ocean triggerfish	CNT	NA	1.00	1.00	2.00	2.33	1.35	0.76
	Sectator ocyurus	Bluestriped chub	ECO	NA	1.00	1.00	2.08	2.22	1.38	0.87
Turtles	*Lepidochelys olivacea*	Olive ridley turtle	LKV	VU	1.62	2.23	1.62	1.89	1.73	1.33

TABLE J-3b. Preliminary productivity and susceptibility scores used to compute the overall vulnerability measure v_2. Dolphin=DEL, unassociated=NOA, and floating-object sets=OBJ. Individual susceptibility scores, $s^*_{jk,}$ are shown for each fishery and as a weighted combination of the individual fishery values, s^2_j; see text for details. Productivity, p, and vulnerability, v_2, scores are provided. These values are preliminary as this year's PSA is considered a proof of concept.

*IUCN listings are defined as: EN=endangered, NT=near threatened, VU=vulnerable, LC=least concern, DD=data deficient, NA=not assessed

					s^*_{jk}, scores by fishery					
GROUP	**Scientific name**	**Common name**	**3-alpha species code**	**IUCN***	**DEL**	**NOA**	**OBJ**	p	s^2_j	v_2
Tunas	*Thunnus albacares*	Yellowfin tuna	YFT	NT	2.38	2.38	2.38	2.78	2.69	1.70
	Thunnus obesus	Bigeye tuna	BET	VU	1.00	2.23	2.38	2.33	1.79	1.04
	Katsuwonus pelamis	Skipjack tuna	SKJ	LC	1.00	2.38	2.38	2.78	2.13	1.15
Billfishes	*Makaira nigricans*	Blue marlin	BUM	VU	2.23	2.23	2.69	2.00	2.20	1.56
	Istiompax indica	Black marlin	BLM	DD	2.23	2.23	2.69	2.00	2.20	1.56
	Kajikia audax	Striped marlin	MLS	NT	2.54	2.54	2.54	2.33	2.27	1.44
	Istiophorus platypterus	Indo-Pacific sailfish	SFA	LC	2.54	2.54	2.54	2.44	2.27	1.39
Dolphins	*Stenella longirostris*	Unidentified spinner dolphin	DSI	DD	1.77	1.00	1.00	1.22	1.42	1.83
	Stenella attenuata	Unidentified spotted dolphin	DPN	LC	1.77	1.00	1.00	1.33	1.42	1.72
	Delphinus delphis	Common dolphin	DCO	LC	1.62	1.00	1.00	1.33	1.38	1.71
Large fishes	*Coryphaena hippurus*	Common dolphinfish	DOL	LC	1.00	2.00	2.31	2.78	1.99	1.02
	Coryphaena equiselis	Pompano dolphinfish	CFW	LC	1.00	1.00	2.38	2.89	1.92	0.92
	Acanthocybium solandri	Wahoo	WAH	LC	1.00	1.00	2.62	2.67	1.96	1.01
	Elagatis bipinnulata	Rainbow runner	RRU	NA	1.00	1.00	2.31	2.78	1.67	0.70
	Mola mola	Ocean sunfish, Mola	MOX	NA	1.00	1.92	1.92	1.78	1.74	1.43
	Caranx sexfasciatus	Bigeye trevally	CXS	LC	1.00	2.38	1.00	2.56	1.56	0.72
	Seriola lalandi	Yellowtail amberjack	YTC	NA	1.00	2.08	1.85	2.44	1.51	0.76
Rays	*Manta birostris*	Giant manta	RMB	VU	1.92	2.08	1.77	1.22	1.95	2.02
	Mobula japanica	Spinetail manta	RMJ	NT	1.92	2.08	1.77	1.78	1.95	1.55
	Mobula thurstoni	Smoothtail manta	RMO	NT	1.92	2.08	1.77	1.67	1.95	1.63
Sharks	*Carcharhinus falciformis*	Silky shark	FAL	NT	2.08	2.08	2.15	1.44	2.23	1.98
	Carcharhinus longimanus	Oceanic whitetip shark	OCS	VU	1.69	1.00	2.08	1.67	1.62	1.47
	Sphyrna zygaena	Smooth hammerhead shark	SPZ	VU	1.77	1.92	2.08	1.33	1.95	1.92
	Sphyrna lewini	Scalloped hammerhead shark	SPL	EN	1.77	1.92	2.08	1.33	1.95	1.92
	Sphyrna mokarran	Great hammerhead shark	SPK	EN	2.08	1.77	1.92	1.33	1.98	1.94
	Alopias pelagicus	Pelagic thresher shark	PTH	VU	1.92	1.92	1.77	1.22	1.93	2.01
	Alopias superciliosus	Bigeye thresher shark	BTH	VU	1.77	2.08	1.46	1.11	1.86	2.08
	Alopias vulpinus	Common thresher shark	ALV	VU	1.92	1.92	1.77	1.67	1.93	1.63
	Isurus oxyrinchus	Short fin mako shark	SMA	VU	2.23	2.23	1.92	1.22	2.06	2.07
Small fishes	*Canthidermis maculatus*	Ocean triggerfish	CNT	NA	1.00	1.00	2.00	2.33	1.18	0.69
	Sectator ocyurus	Bluestriped chub	ECO	NA	1.00	1.00	2.08	2.22	1.19	0.80
Turtles	*Lepidochelys olivacea*	Olive ridley turtle	LKV	VU	1.62	2.23	1.62	1.89	1.63	1.28

TABLE J-3c. Preliminary productivity and susceptibility scores used to compute the overall vulnerability measure v_3. Dolphin=DEL, unassociated=NOA, and floating-object sets=OBJ. Individual susceptibility scores, $s^{**}_{jk,}$ are shown for each fishery and as a weighted combination of the individual fishery values, s^3_j; see text for details. Productivity, p, and vulnerability, v_3, scores are provided. These values are preliminary as this year's PSA is considered a proof of concept.

*IUCN listings are defined as: EN=endangered, NT=near threatened, VU=vulnerable, LC=least concern, DD=data deficient, NA=not assessed

					s^{**}_{jk} scores by fishery					
GROUP	**Scientific name**	**Common name**	**3-alpha species code**	**IUCN***	**DEL**	**NOA**	**OBJ**	p	s^3_j	v_3
Tunas	*Thunnus albacares*	Yellowfin tuna	YFT	NT	2.38	2.38	2.38	2.78		
	Thunnus obesus	Bigeye tuna	BET	VU	1.00	2.23	2.38	2.33		
	Katsuwonus pelamis	Skipjack tuna	SKJ	LC	1.00	2.38	2.38	2.78		
Billfishes	*Makaira nigricans*	Blue marlin	BUM	VU	2.23	2.23	2.69	2.00	1.95	1.38
	Istiompax indica	Black marlin	BLM	DD	2.23	2.23	2.69	2.00	2.34	1.67
	Kajikia audax	Striped marlin	MLS	NT	2.54	2.54	2.54	2.33	2.28	1.45
	Istiophorus platypterus	Indo-Pacific sailfish	SFA	LC	2.54	2.54	2.54	2.44	2.16	1.28
Dolphins	*Stenella longirostris*	Unidentified spinner dolphin	DSI	DD	1.77	1.00	1.00	1.22		
	Stenella attenuata	Unidentified spotted dolphin	DPN	LC	1.77	1.00	1.00	1.33		
	Delphinus delphis	Common dolphin	DCO	LC	1.62	1.00	1.00	1.33		
Large fishes	*Coryphaena hippurus*	Common dolphinfish	DOL	LC	1.00	2.00	2.31	2.78	1.67	0.70
	Coryphaena equiselis	Pompano dolphinfish	CFW	LC	1.00	1.00	2.38	2.89	1.33	0.35
	Acanthocybium solandri	Wahoo	WAH	LC	1.00	1.00	2.62	2.67	1.63	0.71
	Elagatis bipinnulata	Rainbow runner	RRU	NA	1.00	1.00	2.31	2.78	1.32	0.39
	Mola mola	Ocean sunfish, Mola	MOX	NA	1.00	1.92	1.92	1.78	1.38	1.28
	Caranx sexfasciatus	Bigeye trevally	CXS	LC	1.00	2.38	1.00	2.56	1.26	0.51
	Seriola lalandi	Yellowtail amberjack	YTC	NA	1.00	2.08	1.85	2.44	1.64	0.85
Rays	*Manta birostris*	Giant manta	RMB	VU	1.92	2.08	1.77	1.22	1.70	1.91
	Mobula japanica	Spinetail manta	RMJ	NT	1.92	2.08	1.77	1.78	1.70	1.41
	Mobula thurstoni	Smoothtail manta	RMO	NT	1.92	2.08	1.77	1.67	1.70	1.50
Sharks	*Carcharhinus falciformis*	Silky shark	FAL	NT	2.08	2.08	2.15	1.44	2.55	2.20
	Carcharhinus longimanus	Oceanic whitetip shark	OCS	VU	1.69	1.00	2.08	1.67	2.35	1.90
	Sphyrna zygaena	Smooth hammerhead shark	SPZ	VU	1.77	1.92	2.08	1.33	1.70	1.81
	Sphyrna lewini	Scalloped hammerhead shark	SPL	EN	1.77	1.92	2.08	1.33	1.70	1.81
	Sphyrna mokarran	Great hammerhead shark	SPK	EN	2.08	1.77	1.92	1.33	2.00	1.94
	Alopias pelagicus	Pelagic thresher shark	PTH	VU	1.92	1.92	1.77	1.22	1.68	1.91
	Alopias superciliosus	Bigeye thresher shark	BTH	VU	1.77	2.08	1.46	1.11	1.61	1.99
	Alopias vulpinus	Common thresher shark	ALV	VU	1.92	1.92	1.77	1.67	1.68	1.50
	Isurus oxyrinchus	Short fin mako shark	SMA	VU	2.23	2.23	1.92	1.22	1.81	1.96
Small fishes	*Canthidermis maculatus*	Ocean triggerfish	CNT	NA	1.00	1.00	2.00	2.33	1.26	0.72
	Sectator ocyurus	Bluestriped chub	ECO	NA	1.00	1.00	2.08	2.22	1.28	0.83
Turtles	*Lepidochelys olivacea*	Olive ridley turtle	LKV	VU	1.62	2.23	1.62	1.89	2.36	1.76