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ECOSYSTEM CONSIDERATIONS

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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 that "*management measures should not only ensure the conservation 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 recognized ecosystem issues in many of its management decisions since 2003. This report provides a brief summary of what is known about the direct and indirect impacts of tuna

[1] The Code also provides that management measures should ensure that "biodiversity of aquatic habitats and eco-systems is conserved and endangered species are protected", and that "States should assess the impacts of envi-ronmental 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."

fisheries in the eastern Pacific Ocean (EPO) on the populations of species and ecological functional groups and the structure of the ecosystem, as controlled by the strength of predator-prey interactions.

This report does not suggest objectives for the incorporation of ecosystem considerations into the management of fisheries for tunas or billfishes, nor any new management measures. Rather, its main purpose is to quantify and evaluate the Commission's ecosystem approaches to fisheries (EAF)—through current tools available to assess the state of the ecosystem—and to demonstrate how ecosystem research can contribute to management advice and the decision-making process.

However, the view that we have of the ecosystem is based on the recent past; there is almost no information available 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 Southern Oscillation (ENSO) fluctuations and longer-term changes, such as the Pacific Decadal Oscillation (PDO) and other climate-related changes including *e.g.* ocean warming, anoxia and acidification.

In addition to reporting the catches of the principal species of tunas and billfishes, the staff estimates catches (retained and discarded) of non-target species. In this report, data on those species are presented in the context of the effect of the fishery on the ecosystem. While relatively good information is available for catches of tunas and billfishes across the entire fishery, this is not the case for bycatch species. The information is comprehensive for large[2] purse-seine vessels, which carry on-board observers under the Agreement on the International Dolphin Conservation Program (AIDCP). Detailed information on retained and discarded bycatch by the smaller purse-seine fleet and much of the longline fleet is limited, while virtually no information exists on bycatches and discards by fishing vessels that use other gear types (*e.g.* gillnet, harpoon, and recreational gear (SAC-07-INF-C(d); SAC-08-07b)).

Detailed information on past ecosystem studies can be found in documents for previous meetings of the Scientific Advisory Committee (*e.g.* SAC-08-07a), and current and planned ecosystem-related work by the IATTC staff is summarized in the proposed Strategic Science Plan (IATTC-93-06a) and the Staff Activities and Research report (SAC-10-01).

2. IMPACT OF CATCHES

2.1. Single-species assessments and description of available data

An ecosystem perspective requires a focus on how a fishery may have altered various components of an ecosystem. This report presents current information on the effects of the tuna fisheries on the stocks of individual species in the EPO. Sections 2.2 and 2.3 of this report refer to information on the current biomass of each stock. The influences of predator and prey abundances are not explicitly described. Sections 2.4-2.7 include catch data for vessels of the large purse-seine and large-scale tuna longline (herein 'longline fisheries') fisheries reported to the IATTC.

On-board observer data available to the IATTC staff as of March 2019 were used to provide estimates of total catches (retained and discards) by large purse-seine vessels in the EPO on floating objects (OBJ), unassociated schools (NOA), and dolphins (DEL). Data for 2017 and 2018 should be considered preliminary.

Complete data are not available for small purse-seine, longline, and other types of vessels. For example, there has been considerable variability in reporting formats of longline data by individual CPCs[3] through time, thereby limiting application of catch and effort data to scientific analyses (SAC-08-07b, SAC-08-07d, SAC-08-07e). Some catches of non-tuna species by the longline fisheries in the EPO are reported to the IATTC, but often in a highly summarized form (*e.g.* monthly aggregation of catch by broad taxonomic

[2] Carrying capacity greater than 363 t

[3] Members and Cooperating Non-Members of the IATTC

group (*e.g.* "Elasmobranchii"), often without verification of whether the reported catch has been raised to total catch (SAC-08-07b). Such non-tuna catch data for longline fisheries were obtained using "Task I Catch Statistics" of gross annual removals reported to IATTC in accordance with the specifications for the provision of these data described in Annex A of Memorandum ref. 0144-410, dated 27 March 2019 pursuant to Resolution C-03-05 on data provision. Because of data limitations described above, herein these data are considered "sample data" and therefore, such estimates should be regarded as minimum estimates. Preliminary sample data was available for 2017 as of March 2019.

Due to these limitations of catch data for the longline fishery, a report on establishing minimum data standards and reporting requirements for longline observer programs was discussed at SAC-08 (SAC-08-07e). Pursuant to paragraph 7 of Resolution C-11-08, the SAC adopted a requirement for CPCs to supply operational-level observer data. Some progress in longline data reporting has been made and a few CPCs have provided IATTC with operational-level, set-by-set observer data. For example, a summary of longline observer reporting by CPCs was presented at SAC-09, and IATTC staff noted only two CPCs had submitted observer data for 2013—the year in which Resolution C-11-08 entered into force—through 2017 (SAC-09 INF A, Table 3). IATTC staff also noted inconsistencies with reporting units for fishing effort and recommended the use of number of hooks fished, as opposed to the currently reported "effective days fished", which would allow the observer-reported catch data to be extrapolated to the longline fleet, thereby allowing estimates of total catch to be made. As data reporting continues to improve, better estimations of catches by longline vessels are expected to be available in future iterations of the *Ecosystem Considerations* report.

2.2. Tunas

Status reports are provided by IATTC staff for bigeye (SAC-10-06), yellowfin (SAC-10-07; SAC-10-08), and skipjack (SAC-10-09) tunas. The Pacific Bluefin Tuna Working Group of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) completed its stock assessment in 2018, and the ISC Northern Albacore Working Group completed its stock assessment in 2017. Updates from these ISC working groups are expected at SAC-10.

Preliminary estimates of the catches of tunas and bonitos in the EPO during 2018 are found in Table A-2a of Document SAC-10-03.

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 16. Stock assessments for swordfish (south EPO 2011, north EPO 2014), striped marlin (2010), eastern Pacific sailfish (2013) and blue marlin (2013, 2016) were completed by the IATTC staff. Stock assessments of striped marlin (2015), Pacific blue marlin (2016), and north Pacific swordfish (2018) have been completed by the ISC Billfish Working Group, with a 2019 assessment of western and central Pacific striped marlin currently in progress.

No stock assessments have been conducted for black marlin and shortbill spearfish, although historical data published pre-2008 in the IATTC Bulletin series showed trends in catches, effort, and catches per unit of effort (CPUEs).

Preliminary estimates of the catches of billfishes in the EPO during 2018 are found in Table A-2b of Document SAC-10-03.

2.4. 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 EPO. Purse-seine fishers commonly set their nets around herds of dolphins and the associated schools of yellowfin tuna, and then release the dolphins while retaining the tunas. The incidental mortality of dolphins was high during the early years of the fishery, but has been minimal since the early 1980s.

Preliminary estimates of the incidental mortality of marine mammals in the purse-seine fishery in 2018 are shown in Table 1. Estimated dolphin mortalities (numbers) for 1993–2018 are shown in Figure J-1. Decreasing mortalities were observed for northeastern spotted dolphins, western-southern spotted dolphins, whitebelly spinner dolphins, central common dolphins, and other Delphinidae. Numbers of mortalities were variable for northern common dolphins and eastern spinner dolphins, and those of southern common dolphins were generally less than 60 individuals, with the exception of peaks to 225 in 2004, 154 in 2005 and 137 in 2008.

TABLE 1. Incidental mortality of dolphins and other marine mammals caused by the purse-seine fishery in the EPO, 2018.

	Incidental mortality	
Species and stock	Numbers	t
Offshore spotted dolphin		
Northeastern	99	6.5
Western-southern	197	12.9
Spinner dolphin		
Eastern	252	11.2
Whitebelly	205	12.4
Common dolphin		
Northern	41	2.9
Central	1	0.1
Southern	18	1.3
Other mammals*	6	0.4
Total	**819**	**47.5**

*"Other mammals" includes the following species and stocks, whose observed mortalities were as follows: Central American spinner dolphin 3 (0.1 t), bottlenose dolphin (*Tursiops truncatus*) 2 (0.2 t) unidentified dolphins 1 (0.1 t).

2.5. 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. The mortality rates in the EPO industrial longline fishery are likely to be lowest in "deep" sets (around 200-300 m) targeting bigeye tuna, and highest in "shallow" sets (<150 m) for albacore and swordfish. In addition, there is a sizeable fleet of artisanal longline vessels from coastal nations that also impact sea turtles.

Sea turtles are occasionally caught in purse seines in the EPO tuna fishery, generally when the turtles associate with floating objects, and are captured when the object is encircled. Also, sets on unassociated tunas or tunas associated with dolphins may capture sea turtles that happen to be at those locations. Sea turtles sometimes become entangled in the webbing under fish-aggregating devices (FADs) and drown, although Resolution C-07-03 was adopted in 2007 to mitigate the impact of fishing on sea turtles. In some cases, they are entangled by the fishing gear and may be injured or killed.

The olive Ridley turtle (*Lepidochelys olivacea*) is, by far, the species of sea turtle taken most often by purse seiners. It is followed by green sea turtles (*Chelonia mydas*) and, very occasionally, by loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) turtles (Figure J-2). Since 1990, when IATTC observers began recording this information, 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.

Preliminary numbers of sea turtle mortalities and interactions in sets by large purse-seine vessels on floating objects (OBJ), unassociated tunas (NOA), and dolphins (DEL) during 2018 are shown in Table 2, and for 1993–2018 in Figure J-2. Data on sea turtle interactions or mortality was deficient in the IATTC longline sample data (SAC-08-07b), although with improvements in data reporting, estimations are expected to be available in future (see section 2.1).

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

2.6. Sharks and rays

Sharks are caught as bycatch or targeted catch in EPO tuna longline and purse-seine fisheries as well as multi-species and multi-gear fisheries of the coastal nations.

TABLE 2. Interactions and mortalities of sea turtles with purse-seine vessels in the EPO, 2018.

	Interactions				Mortalities			
	Set type			Total	Set type			Total
Species	OBJ	NOA	DEL		OBJ	NOA	DEL	
Olive Ridley	141	2	39	182	3	-	-	3
Eastern Pacific green	49	12	2	63	1	-	-	1
Loggerhead	11	4	3	18	-	-	-	-
Hawksbill	5	2	-	7	-	-	-	-
Leatherback	3	1	1	5	-	-	-	-
Unidentified	128	21	164	313	-	-	-	-
Total	**337**	**42**	**209**	**588**	**4**	**-**	**-**	**4**

Stock assessments or stock status indicators (SSIs) are available for only four shark species in the EPO: silky (*Carcharhinus falciformis*) (Lennert-Cody et al. 2018[4]; SAC-10-17), blue (*Prionace glauca*) (ISC Shark Working Group), shortfin mako (*Isurus oxyrinchus*) (ISC Shark Working Group), and common thresher (*Alopias vulpinus*) (NMFS). As part of the FAO Common Oceans Tuna Project, Pacific-wide assessments of the porbeagle shark[5] (*Lamna nasus*) in the southern hemisphere , and the bigeye thresher shark[6] (*Alopias superciliosus*) were completed in 2017, while that for silky shark[7] and a risk assessment for the Indo-Pacific whale shark population[8] were completed in 2018. Whale shark interactions with the tuna purse-seine fishery in the EPO are summarized in Document BYC-08 INF-A. The impacts of tuna fisheries on the stocks of other shark species in the EPO are unknown.

A quantitative ecological risk assessment on the impacts of the EPO tuna fishery on the spinetail devil ray (*Mobula mobular*)—using IATTC's newly developed Ecological Assessment for the Sustainable Impacts of

[4] Lennert-Cody, C.E.; Clarke, S.C.; Aires-da-Silva, A.; Maunder, M.N.; Franks, P.J.S.; Román, M.H.; Miller, A.J.; Minami, M. 2018. The importance of environment and life stage on interpretation of silky shark relative abundance indices for the equatorial Pacific Ocean Fish Oceanogr:1-11

[5] Clarke, S. 2017. Southern Hemisphere porbeagle shark (*Lamna nasus*) stock status assessment. WCPFC-SC13-2017/SA-WP-12 (rev. 2). Western and Central Pacific Fisheries Commission Scientific Committee Thirteenth Regular Session. Rarotonga, Cook Islands

[6] Fu, D.; Roux, M.-J.; Clarke, S.; Francis, M.; Dunn, A.; Hoyle, S.; Edwards, C. 2018. Pacific-wide sustainability risk assessment of bigeye thresher shark (*Alopias superciliosus*). WCPFC-SC13-2017/SA-WP-11. Rev 3 (11 April 2018). Western and Central Pacific Fisheries Commission Scientific Committee Thirteenth Regular Session. Rarotonga, Cook Islands

[7] Clarke, S. 2018. Pacific-wide silky shark (*Carcharhinus falciformis*) Stock Status Assessment. WCPFC-SC14-2018/SA-WP-08. Western and Central Pacific Fisheries Commission. Busan, Korea

[8] Clarke, S. 2018. Risk to the Indo-Pacific Ocean whale shark population from interactions with Pacific Ocean purse-seine fisheries. WCPFC-SC14-2018/SA-WP-12 (rev. 2). Western and Central Pacific Fisheries Commission, Scientific Committee Fourteenth Regular Session. Busan, Korea

Fisheries (EASI-Fish) approach—was undertaken by IATTC staff to explore the species' vulnerability status under 18 hypothetical conservation and management measures and will be presented at the 9th Meeting of the Working Group on Bycatch (BYC-09-01).

TABLE 3. Preliminary catches, in tons, of sharks and rays in the EPO by large purse-seine vessels, by set type, 2018, and by longline vessels, 2017. ***Longline sample data should be considered minimum catch estimates due to incomplete data reporting (see section 2.1)

	Purse seine				**Long-line***
Species	**OBJ**	**NOA**	**DEL**	**Total**	
Silky shark (*Carcharhinus falciformis)*	400	11	20	431	2,626
Oceanic whitetip shark (*C. longimanus)*	3	-	<1	3	202
Hammerhead sharks (*Sphyrna* spp.)	24	<1	<1	26	186
Thresher sharks (*Alopias* spp.)	<1	4	2	7	724
Mako sharks (*Isurus* spp.)	1	<1	<1	2	1,606
Other sharks	31	4	1	36	1,430
Blue sharks (*Prionace glauca*)	-	-	-	-	6,908
Manta rays (Mobulidae)	16	20	13	49	-
Pelagic sting rays (Dasyatidae)	<1	<1	<1	1	-

Preliminary estimates of the catches of sharks and rays reported by observers on large purse-seine vessels in the EPO during 2018 and minimum estimates of catches by longline vessels using sample data (see section 2.1) in 2017 are shown in Table 3. Here, it is important to note Resolution C-11-10 which entered into force in January 2012 prohibits the retention of oceanic whitetip sharks (*Carcharhinus longimanus*), and therefore discarded catch—reported under "Task II Catch and Effort Statistics", a subset of "Task I Catch Statistics", pursuant to Resolution C-03-05 and detailed in Annex A of Memorandum ref. 0144-410—was included to provide a better estimate of catch.

Catches of sharks and rays in the purse-seine and minimum estimates by longline fisheries during 1993–2018 are shown in Figure J-3. Silky sharks are the most commonly-caught species of shark in the purse-seine fishery. Shark catches were generally greatest in sets on floating objects (mainly silky, oceanic whitetip, hammerhead (*Sphyrna* spp.) and mako (*Isurus* spp.) sharks), followed by unassociated sets and, at a much lower level, dolphin sets. Until about 2007, thresher sharks (*Alopias* spp.) occurred mostly in unassociated sets. Historically, oceanic whitetip sharks were commonly caught in sets on floating objects, but they became much less common after 2005. In general, the bycatch rates of manta rays (Mobulidae) and stingrays (Dasyatidae) have been greatest in unassociated sets, followed by dolphin sets, and lowest in floating-object sets, although catches by set type can be variable. The numbers of purse-seine sets of each type in the EPO during 2003–2018 are shown in Table A-7 of Document SAC-10-03.

The sample data reported to IATTC of minimum estimates of sharks caught by the longline fishery increased for most species after 2005 (Figure J-3). Mako and blue sharks were reported as early as 1993 and catches increased sharply after 2008. Catches of blue shark exceeded 10,000 mt in 2011 and 2013 while those of thresher sharks exceeded 8,000 mt in 2010 and 2011 and declined rapidly thereafter. Silky shark catches peaked at about 4,200 mt in 2013 and those of mako sharks at about 2,500 mt in 2014. Catches of oceanic whitetip shark reached nearly 300 mt in 2009 and, as previously mentioned, retention has been prohibited since 2012 under Resolution C-11-10; therefore, reported data since 2012 corresponds to discards (Figure J-3). However, it is important these sample data are interpreted with caution because they can only be considered as 'reported minimum estimates' due to limitations in data-reporting requirements for non-target species caught in the longline fishery resulting from Resolutions C-03-05 and C-11-08 and documented in SAC-08-07b—also see section 2.1.

The small-scale artisanal longline fisheries of the coastal CPCs target sharks, tunas, billfishes and dorado (*Coryphaena hippurus*), and some of these vessels are similar to industrial longline fisheries in that they operate in areas beyond coastal waters and national jurisdictions[9]. However, essential shark data from longline fisheries is lacking, and therefore conventional stock assessments and/or stock status indicators cannot be produced (see data challenges outlined in SAC-07-06b(iii)). A project is ongoing to improve data collection on sharks, particularly for Central America, for the longline fleet through funding from the Food and Agriculture Organization of the United Nations (FAO) and the Global Environmental Facility (GEF) under the framework of the ABNJ Common Oceans program (SAC-07-06b(ii)**,** SAC-07-06b(iii)). A pilot study was initiated in April 2018 to collect additional shark-fishery data and develop and test sampling designs for a long-term sampling program for the shark fishery in Central America (Phase 2 of the project). A progress report on the FAO-GEF ABNJ project will be presented at this meeting (SAC-10-16). Data obtained from this project may be included in future iterations of the *Ecosystem Considerations* report to provide better estimates of sharks caught by the various longline fleets

2.7. Other large fishes

Preliminary estimates of the catches of dorado (*Coryphaena* spp.) and other large fishes in the EPO by large purse-seine vessels during 2018 are shown in Table 4, along with minimum estimates from longline sample data in 2017. A time series of catches for these most commonly-caught species during 1993–2018, by set type and fishery, are shown in Figure J-4.

TABLE 4. Preliminary catches, in tons, of large fish species commonly caught in the EPO by large purse-seine vessels, by set type, 2018, and by longline vessels, 2017. *Longline sample data should be considered minimum catch estimates due to incomplete data reporting (see section 2.1)

	Purse-seine				Long-line*
	OBJ	NOA	DEL	Total	
Dorado (*Coryphaena* spp.)	1,493	4	6	1,503	1814
Wahoo (*Acanthocybium solandri*)	255	<1	-	227	308
Rainbow runner (*Elagatis bipinnulata*) & yellowtail (*Seriola lalandi*)	74	1	-	75	-
Opahs (*Lampris* spp.)	-	-	-	-	825
Snake mackerels (Gempylidae)	-	-	-	-	395
Pomfrets (Bramidae)	-	-	-	-	126

Dorado is the most commonly reported fish species caught incidentally in the EPO purse-seine and longline fisheries. It is also one of the most important species caught in the artisanal fisheries of the coastal nations of the EPO, which led to an exploratory stock assessment (SAC-07-06a(i)) and management strategy evaluation (MSE) in the south EPO (SAC-07-06a(ii)). An identification of potential reference points and the harvest control rule for dorado in the EPO will be presented at this meeting (SAC-10-11).

Purse-seine catches of dorado, wahoo, rainbow runner, and yellowtail were variable, and occurred primarily in sets on floating objects, while opahs, snake mackerels and pomfrets were included solely in catch reports of longline sample data and increasing catches were observed. Longline estimates of wahoo increased after 2002.

[9] Martínez-Ortiz, J., Aires-da-Silva, A.M., Lennert-Cody, C.E., Maunder, M.N. 2015. The Ecuadorian artisanal fishery for large pelagics: species composition and spatio-temporal dynamics. PLoS ONE 10(8): e0135136.

3. OTHER FAUNA

3.1. Seabirds

There are approximately 100 species of seabirds in the tropical EPO. Some of them associate with epipelagic predators, such as fishes (especially tunas) and marine mammals, near the ocean surface. Feeding opportunities for some seabird species are dependent on the presence of tuna schools feeding near the surface. Most species of seabirds take prey, mainly squid (primarily Ommastrephidae), within half a meter of the surface, or in the air (flyingfishes, Exocoetidae). Subsurface predators, such as tunas, often drive prey to the surface to trap it against the air-water interface, where it becomes available to the birds, which also feed on injured or disoriented prey, and on scraps of large prey.

Some seabirds, especially albatrosses (waved (*Phoebastria irrorata*), black-footed (*P. nigripes*), Laysan (*P. immutabilis*), and black-browed (*Thalassarche melanophrys*)) and petrels, are susceptible to being caught on baited hooks in pelagic longline fisheries. 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 have reported no interactions with waved albatross during those vessels' fishing operations. Data from the US pelagic longline fishery in the north EPO indicate that bycatches of black-footed and Laysan albatrosses occur.

The IATTC has adopted two measures on seabirds (Recommendation C-10-02 and Resolution C-11-02); also, the Agreement on the Conservation of Albatrosses and Petrels (ACAP) and BirdLife International have updated their maps of seabird distribution in the EPO, and have recommended guidelines for seabird identification, reporting, handling, and mitigation measures (SAC-05 INF-E, SAC-07-INF-C(d), SAC-08-INF-D(a), SAC-08-INF-D(b), BYC-08 INF J(b)). Additionally, ACAP has reported on the conservation status for albatrosses and large petrels (SAC-08-INF-D(c); BYC-08 INF J(a)).

Data pertaining to interactions with seabirds was deficient in the IATTC longline sample data (SAC-08-07b), although with improvements in data reporting, estimations are expected to be available in future (see section 2.1).

3.2. Forage species

A large number of taxa occupying the middle trophic levels in the EPO ecosystem—generically referred to as "forage" species—play a key role in providing a trophic link between primary producers at the base of the food web and the upper-trophic-level predators, such as tunas and billfishes. Cephalopods, especially squids, play a central role in many marine pelagic food webs by linking the massive biomasses of micronekton, particularly myctophid fishes, to many oceanic predators. For example, the Humboldt squid (*Dosidicus gigas*) is a common prey for yellowfin and bigeye tunas and other predatory fishes but is also a voracious predator of small fishes and cephalopods. Changes in the abundance and geographic range of Humboldt squid could affect the foraging behavior of the tunas and other predators, perhaps affecting their vulnerability to capture and the trophic structure of pelagic ecosystems. Given the high trophic flux passing through the squid community, concerted research on squids is important for understanding their role as key prey and predators.

Some small forage fishes are incidentally caught in the EPO by purse-seine vessels on the high seas, mostly in sets on floating objects, and by coastal artisanal fisheries, but are generally discarded at sea. Frigate and bullet tunas (*Auxis* spp.), for example, are a common prey of many high trophic level predators and can comprise 10% or more of their diet biomass. Preliminary estimates of the catches of small forage fishes by observers onboard large purse-seine vessels in the EPO during 2018 are shown in Table 5, and catches during 1993–2018 are shown in Figure J-5. Declines in catches of bullet and frigate tunas and small teleost fishes over the 26-year period were observed while catches of triggerfish were variable.

TABLE 5. Catches of small fishes, in tons, by large purse-seine vessels in the EPO, 2018 (preliminary data).				
	Set type			Total
	OBJ	NOA	DEL	
Triggerfishes (Balistidae) and filefishes (Monacanthidae)	56	<1	-	56
Other small fishes	18	<1	-	18
Frigate and bullet tunas (*Auxis* spp.)	315	268	-	583

3.3. Larval fishes and plankton

Larval fishes have been collected in surface net tows in the EPO for many years by personnel of the Southwest Fisheries Science Center of the US National Marine Fisheries Service (NMFS). Of the 314 taxonomic categories identified, 17 were found to be most likely to show the effects of environmental change; however, the occurrence, abundance, and distribution of these key taxa revealed no consistent temporal trends. Research[10] 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[11] and abundance of zooplankton predators. The same was true for the El Niño event in 1997 and the La Niña in mid-1998[12].

The species and size composition of zooplankton is often more variable than the zooplankton biomass. When the water temperatures increase, warm-water species often replace cold-water species at particular locations. The relative abundance of small copepods off northern Chile, for example, increased during the 1997–1998 El Niño event, while the zooplankton biomass did not change[13].

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, but are required to develop models to assess fishery and climate impacts on the ecosystem. Knowledge of the trophic ecology of predatory fishes in the EPO has been derived from stomach contents analysis, and more recently from chemical indicators. Each species of tuna appears to have a generalized feeding strategy (high prey diversity and low abundance of individual prey types) that varies spatially and ontogenetically.

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[12] Wang, X.; Christian, J.R.; Murtugudde, R.; Busalacchi, A.J. 2005. Ecosystem dynamics and export production in the central and eastern equatorial Pacific: A modeling study of impact of ENSO. Geophysical Research Letters. 32, L02608

[13] Fiedler, P.C. 2002. Environmental change in the eastern tropical Pacific Ocean: review of ENSO and decadal variability. Administrative Report LJ-02-16. Southwest Fisheries Science Center. La Jolla, CA: National Marine Fisheries Service, NOAA. 38 p

Stable isotope analysis can complement dietary data for delineating the trophic flows of marine food webs. While stomach contents represent a sample of the most-recent feeding events, stable carbon and nitrogen isotopes integrate all components of the entire diet into the animal's tissues, providing a history of recent trophic interactions. Finer-resolution information is provided by compound-specific isotope analysis of amino acids (AA-CSIA). For example, the trophic position of a predator in the food web can be determined from its tissues by relating "source" amino acids (*e.g.* phenylalanine) to "trophic" amino acids (*e.g.* glutamic acid), which describe the isotopic values for primary producers and the predator, respectively.

Trophic studies have revealed many of the key trophic connections in the tropical pelagic EPO, and have formed the basis for representing food-web interactions in an ecosystem model (IATTC Bulletin, Vol. 22, No. 3) to explore the ecological impacts of fishing and climate change. The staff aim to continue and improve trophic data collection for many components of the EPO ecosystem, such as small and large mesopelagic fishes, which will allow the ecosystem dynamics to be better understood, but also enable the development of an improved ecosystem model that represents the entire EPO.

In the meantime, IATTC staff will continue to analyze diet data from several predator species collected during two stomach sampling projects in the EPO—1992–1994 and 2003–2005—to further develop diet matrices to be used in ecosystem models for the EPO, such as Project O.2.b (SAC-10-15).

For example, a new project (SAC-10-01a, Project O.1b) is underway, to improve our understanding of the interplay between space and ontogeny in the trophic ecology of skipjack tuna in the EPO. Early accounts of skipjack stomach contents in the EPO have been limited to measurements of prey volume by size class with sampling strata determined *a priori* based on presumed areas of high skipjack densities[14]. Other studies have been focused on calculations of prey weight, number and frequency of occurrence of skipjack sampled opportunistically throughout the EPO[15]. Little attention has been placed on quantitatively assessing the potential relationships between oceanography, ontogeny and skipjack food habits. Such information is essential for developing spatially-explicit ecosystem models, including the aforementioned model of the EPO that is planned for development by the IATTC staff. Quantifying trophic linkages using such an approach provide descriptions of the magnitude of biomass transfer through the ecosystem and can assist in more reliably assigning proportions of both predator and prey biomass in spatial strata in spatially-explicit ecosystem models, such as Ecospace.

A separate project (SAC-10-INF-E, Project O.1.c) commenced in 2018 in an attempt to incrementally improve ecosystem model parameter inputs for the EPO. Specifically, a review of methods for estimating prey consumption rates, gastric evacuation, and daily ration, which can be used to estimate the consumption/biomass ratio (Q/B) (SAC-10 INF-E). This is one of the most influential parameters in mass-balance ecosystem models (*e.g*., Ecopath with Ecosim) as it determines the extent of trophic biomass flows between predators and prey species, and the standing biomass that is required for these species, after taking into account biomass losses due to mortality and fishing. The review will recommend the most appropriate and feasible method(s) for estimating Q/B in order to develop a collaborative project proposal to experimentally estimate Q/B.

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[14] Alverson, F.G. 1963. The food of yellowfin and skipjack tunas in the eastern tropical Pacific Ocean. Inter-American Tropical Tuna Commission, Bulletin. 7:293-396

[15] Olson, R.J.; Young, J.W.; Ménard, F.; Potier, M.; Allain, V.; Goñi, N.; Logan, J.M.; Galván-Magaña, F. 2016. Bioenergetics, trophic ecology, and niche separation of tunas. in: Curry B.E., ed. Adv Mar Biol. UK: Academic Press. Table 1. p 223

5. PHYSICAL ENVIRONMENT[16]

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. While a brief description of the physical environment is provided here, the reader is referred to SAC-04-08 section "Physical Environment" and SAC-06 INF-C for a more comprehensive description of the effects of the physical and biological oceanography on tunas, prey communities, and fisheries in the EPO.

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), an irregular fluctuation involving the entire tropical Pacific Ocean and global atmosphere. El Niño events occur at 2- to 7-year intervals, and are characterized by weaker trade winds, deeper thermoclines, and abnormally high sea-surface temperatures (SSTs) in the equatorial EPO. El Niño's opposite phase, commonly called La Niña, is characterized by stronger trade winds, shallower thermoclines, and lower SSTs. The changes in the physical and chemical environment due to ENSO have a subsequent impact on the biological productivity, feeding, and reproduction of fishes, birds, and marine mammals.

With respect to commercially important tunas and billfishes, ENSO is thought to cause considerable variability in their availability for capture as well as recruitment. For example, a shallow thermocline in the EPO during La Niña events can contribute to increased success of purse-seine fishing for tunas, by compressing the preferred thermal habitat of small tunas near the sea surface. In contrast, during an El Niño event, when the thermocline is deeper, tunas are likely to be less vulnerable to capture, and catch rates can be expected to decline. Furthermore, warmer- or cooler-than-average SSTs can also cause these mobile fishes to move to more favorable habitats, which may also affect catch rates as fishers potentially expend more effort in locating the fish.

Recruitment of tropical tunas in the EPO is also thought to be affected by ENSO events. For example, strong La Niña events in 2007–2008 may be partly responsible for lower recruitment of bigeye tuna in the EPO while highest recruitment has corresponded to the strongest El Niño events in 1982–1983 and 1998 (SAC-09-05). Similarly, yellowfin tuna recruitment was low in 2007 while higher recruitment was observed during 2015–2016 which corresponded to the extreme El Niño event in 2014–2016 (SAC-09-06).

Indices of variability in oceanographic and atmospheric conditions are commonly used to monitor the strength and magnitude of ENSO events in the Pacific Ocean. Several indicators are available to measure ENSO, including air pressure indices (*e.g*., the Southern Oscillation Index, or SOI, which measures the difference between atmospheric pressure at sea level in Tahiti and Darwin, Australia), sea surface temperature indices (*e.g.* the Oceanic Niño Index, or ONI, which measures SST anomalies), outgoing longwave radiation indices related to thunderstorm activity, and wind indices[17]. Here, the ONI is presented to characterize inter-annual variability in SSTs, because it is used by the US National Oceanic and Atmospheric Administration (NOAA) as the primary indicator of warm El Niño (ONI $\geq$+0.5) and cool La Niña (ONI $\leq$-0.5)

[16] 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.

[17] Barnston, A. 2015. Why are there so many ENSO indexes, instead of just one? https://www.climate.gov/news-features/blogs/enso/why-are-there-so-many-enso-indexes-instead-just-one. Climategov science & information for a climate-smart nation. USA: National Oceanic and Atmospheric Administration

conditions within the Niño 3.4 region in the east-central tropical Pacific Ocean[18] (Figure J-6a). Categories of ENSO events represented by the ONI describe the magnitude of the event from "extreme" to "weak" (Figure J-6b). For example, an "extreme El Niño" event occurred in 1997–1998 followed by a "strong La Niña" event in 1998–2000. "Strong La Niña" events were also observed in 2007–2008 and 2010–2011. Values of the ONI were greatest (>2.5) in the recent 2015–2016 El Niño event.

Climate-induced variability on a decadal scale (*i.e.* 10 to 30 years) also affects the EPO and has often been described as "regimes" characterized by relatively stable means and patterns in the physical and biological variables. Decadal fluctuations in upwelling coincide with higher-frequency ENSO patterns, and have basin-wide effects on the SSTs and thermocline depth that are similar to those caused by ENSO, but on longer time scales. For example, analyses by the IATTC staff have indicated that yellowfin in the EPO have experienced regimes of lower (1975–1982 and 2003–2014) and higher (1983–2002) recruitment, thought to be due to a shift in the primary productivity regime in the Pacific Ocean (SAC-09-06).

One such index used to describe longer-term fluctuations in the Pacific Ocean is the Pacific Decadal Oscillation (PDO). The PDO—a long-lived El Niño-like pattern of Pacific climate variability—tracks large-scale interdecadal patterns of environmental and biotic changes, primarily in the North Pacific Ocean[19], with secondary signatures in the tropical Pacific[20]. Similar to ENSO, PDO phases have been classified as "warm" or "cool" phases. The PDO has been used to explain the influence of environmental drivers on the vulnerability of silky sharks impacted by fisheries in the EPO[21]. A time series of the PDO index is presented in Figure J-7 to show variability in warm and cool phases of the PDO from 1993–2018. PDO values peaked at 2.79 in August 1997, and at 2.62 in April 2016, both of which coincided with the extreme El Niño events as represented by the ONI.

Time-longitude Hovmöller diagrams are presented for SST (Figure J-8a) and chlorophyll-a (Figure J-8b) to aid in the visualization of variability in SSTs and chlorophyll-a concentrations over time. The SST time series show meanly monthly values for the period 1993–2018 averaged over the eastern tropical Pacific (ETP) from 5°N to 5°S—the same latitudinal band used in the ONI for the same time series. In contrast, monthly chlorophyll-a concentrations (mg m^{-3}) were averaged over the same spatial area as SST but for 2003–2018 due to data availability. The SST plot (Figure J-8a) clearly shows the extreme El Niño events of 1997–1998 and 2015–2016 with warmer waters and the strong La Niña events in 1999–2000, 2007–2008 and 2010–2011 with cooler waters extending across the ETP. The chlorophyll-a plot (Figure J-8b) shows an increase in chlorophyll-a concentrations following the strong La Niña events in 2007–2008 and 2010–2011 due to changes in nutrient availability and abundance of zooplankton predators (see section 3.3 Larval fishes and plankton).

Because this report is also focused on data solely from 2018, information on ENSO conditions—as reported by the Climate Diagnostics Bulletin of the U.S. National Weather Service for 2018—are provided. Anomalies in oceanic and atmospheric conditions were indicative of La Niña conditions for the beginning of 2018, ENSO neutral conditions from June through August, and developing El Niño conditions from Sep-

[18] Dahlman, L. 2016. Climate Variability: Oceanic Niño Index. https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index. National Oceanic and Atmospheric Administration

[19] Mantua, N.J.; Hare, S.R.; Zhang, Y.; Wallace, J.M.; Francis, R.C. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull Am Meteorol Soc. 78:1069-1079

[20] Hare, S.R.; Mantua, N.J. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Prog Oceanogr. 47:103-145

[21] Lennert-Cody, C.E.; Clarke, S.C.; Aires-da-Silva, A.; Maunder, M.N.; Franks, P.J.S.; Román, M.H.; Miller, A.J.; Minami, M. 2018. The importance of environment and life stage on interpretation of silky shark relative abundance indices for the equatorial Pacific Ocean Fish Oceanogr:1-11

tember to December. Although ENSO conditions are determined by various oceanic and atmospheric conditions, this report contains maps of quarterly mean SST data (Figure J-9a) to provide a general indication of seasonal variability in SST across the EPO during 2018. Warmer waters developed off Central America and extended westwards during quarters 2 (April–June) and 3 (July–September) while cooler waters occurred off South America, particularly south of 20°S in quarter 3.

As changes in biological productivity can impact prey and predator communities, and researchers have provided evidence of declines in primary productivity, here broad-scale variability in quarterly mean chlorophyll-a concentrations (mg m^{-3}) for 2018 is shown in Figure J-9b. An oligotrophic gyre is persistent in the EPO around 20°-40°S that appears to have slightly retracted in quarter 3 relative to the rest of the year while higher chlorophyll concentrations were observed along the coast of the Americas.

6. ECOLOGICAL INDICATORS

Over the past two decades, many fisheries worldwide have broadened the scope of management to consider fishery impacts on non-target species and the ecosystem more generally. This ecosystem approach to fisheries management is important for maintaining the integrity and productivity of ecosystems while maximizing the utilization of commercially important assets. However, demonstrating the ecological sustainability of EPO fisheries is a significant challenge, given the wide range of species with differing life histories with which those fisheries interact. While biological reference points have been used for single-species management of target species, alternative performance measures and reference points are required for the many non-target species for which reliable catch and/or biological data are lacking; for example, incidental mortality limits for dolphins have been set in the EPO purse-seine fishery under the AIDCP.

Another important aspect of assessing ecological sustainability is to ensure that the structure and function of the ecosystem is not negatively impacted by fishing activities. Several ecosystem metrics or indicators have been proposed to address this issue, such as 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.

Given the complexity of marine ecosystems, no single indicator can completely represent their structure and internal dynamics. In order to monitor changes in these multidimensional systems and detect the potential impacts of fishing and the environment, a variety of indicators is required. Therefore, a range of indicators that can be calculated with the ecosystem modelling software *Ecopath with Ecosim* (EwE) are used in this report to describe the long-term changes in the EPO ecosystem. The analysis covers the 1970–2017 period, and the indicators included are: mean trophic level of the catch (TL_c), the Marine Trophic Index (MTI), the Fishing in Balance index (FIB), Shannon's index, and three indicators that describe the mean trophic level of three ecosystem components, or 'communities' (TL 2.0–3.25, ≥3.25–4.0, and >4.0), after fisheries have extracted biomass as catches. These indicators, and the results derived from the ecosystem model of the pelagic eastern tropical Pacific Ocean (ETP)[22], are summarized below

Trophic structure of the EPO ecosystem. Ecologically-based approaches to fisheries management require accurate depictions of trophic links and biomass flows through the food web. Trophic levels (TLs) are used in food-web ecology to characterize the functional role of organisms and to estimate energy flows through communities. A simplified food-web diagram, with approximate TLs, from the ETP model is shown in Figure J-10. Toothed whales (Odontoceti, average TL 5.2), large squid predators (large bigeye tuna and

[22] Olson, R.J., and G.M. Watters. 2003. A model of the pelagic ecosystem in the eastern tropical Pacific Ocean. Inter-American Tropical Tuna Commission, Bulletin 22(3): 133-218.

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).

Ecological indicators. 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 trophic level of the catch (TL_c) by fisheries can be a useful metric of ecosystem change and sustainability, because it integrates an array of biological information about the components of the system. TL_c is also an indicator of whether fisheries are changing their fishing or targeting practices in response to changes in the abundance or catchability of traditional target species. For example, declines in the abundance of large predatory fish by overfishing has resulted in fisheries progressively targeting species at lower trophic levels in order to remain profitable. Studies that have documented this phenomenon, referred to as 'fishing down the food web', have shown that the TL_c decreased by around 0.1 of a trophic level per decade.

The Marine Trophic Index (MTI) is essentially the same as TL_c, but it includes only high trophic level species—generally TL>4.0—that are the first indicator of 'fishing down the food web'. Some ecosystems, however, have changed in the other direction, from lower to higher TL communities, sometimes as a result of improved technologies to allow exploitation of larger species—referred to as 'fishing up the food web'—but it can also result from improved catch reporting, as previously unreported catches of discarded predatory species, such as sharks, are recorded.

The Fishing in Balance (FIB) index indicates whether fisheries are balanced in ecological terms and not disrupting the functionality of the ecosystem (FIB = 0). A negative FIB indicates overexploitation, when catches do not increase as expected given the available productivity in the system, or if the effects of fishing are sufficient to compromise the functionality of the ecosystem, while a positive FIB indicates expansion of a fishery, either spatially, or through increased species richness of the catch.

Shannon' index measures the diversity and evenness in the ecosystem. Because the number of functional groups defined by an ecosystem model is fixed, a decrease in the index indicates that the relative contribution of each group to the overall biomass has changed relative to a reference year.

In contrast to TL_c, the mean trophic level of the modelled community (TL_{MC}) essentially describes the expected trophic level of components of the ecosystem after fishing has extracted biomass as catches. There are three components—referred to as "communities"—that aggregate the biomass of functional groups in the model by trophic level: 2.0–3.25 ($TL_{2.0}$), ≥3.25–4.0 ($TL_{3.5}$), and >4.0 ($TL_{4.0}$). These indicators can be used in unison to detect trophic cascades, whereby a decline in biomass of $TL_{4.0}$ due to fishing would reduce predation pressure on $TL_{3.5}$ and thus increase its biomass, which would in turn increase predation pressure on $TL_{2.0}$ and reduce its biomass.

Monitoring the EPO ecosystem using ecological indicators. Given the potential utility of combining ecological indicators for describing the various structures and internal dynamics of the EPO ecosystem, annual indicator values were estimated from a 1970–2017 time series of annual catches and discards, by species, for three purse-seine fishing modes, the pole-and-line fishery, and the longline fishery in the EPO. The estimates were made by assigning the annual catch of each species from the IATTC tuna, bycatch, and discard databases to a relevant functional group defined in the ETP ecosystem model, and refitting the Ecosim model to the time series of catches to estimate the aforementioned ecological indicators.

Values for TL_c and MTI increased from 4.65 and 4.67 in 1970 to 4.69 and 4.70 in 1991, respectively, as the purse-seine fishing effort on FADs increased significantly (Figure J-11). TL_c continued to decrease to a low of 4.65 in 1997, due to the rapid expansion of the fishery from 1993 where there was increasing catches in the intervening period of high trophic level bycatch species that also aggregate around floating objects (*e.g.* sharks, billfish, wahoo and dorado). This expansion is seen in the FIB index that exceeds zero during the same period, and also a change in the evenness of biomass of the community indicated by Shannon's index. By the early 2000s, TL_c, MTI, and Shannon's index all show a gradual decline, while the FIB gradually increased further from zero to its peak in 2017 at 0.66 (Figure J-11). Both TL_c and MTI reached their lowest historic levels of 4.64 and 4.65 in 2017, respectively. Since its peak in 1991, TL_c declined by 0.05 of a trophic level in the subsequent 27 years, or 0.02 trophic levels per decade.

The above indicators generally describe the change in the exploited components of the ecosystem, whereas community biomass indicators describe changes in the structure of the ecosystem once biomass has been removed due to fishing. The biomass of the $TL_{MC4.0}$ community was at one of its highest values (4.449) in 1993, but has continued to decline to 4.443 in 2017 (Figure J-11). As a result of changes in predation pressure on lower trophic levels, between 1993 and 2017 the biomass of the $TL_{MC3.25}$ community increased from 3.800 to 3.803, while interestingly, the biomass of the $TL_{MC2.0}$ community also increased from 3.306 to 3.308.

Together, these indicators show that the ecosystem structure has likely changed over the 48-year analysis period. However, these changes, even if they are a direct result of fishing, are not considered ecologically detrimental, but the patterns of changes, particularly in the mean trophic level of the communities, certainly warrant the continuation, and possible expansion, of monitoring programs for fisheries in the EPO.

7. ECOLOGICAL RISK ASSESSMENT

The primary goal of ecosystem-based fisheries management is to ensure the long-term sustainability of all species impacted—directly or indirectly—by fishing. However, this is a significant challenge for fisheries that interact with many non-target species with diverse life histories, for which sufficiently reliable catch and biological data for single-species assessments are lacking. An alternative approach for such data-limited situations is Ecological Risk Assessment (ERA), a tool for prioritizing management action or further data collection and research for potentially vulnerable species.

'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 an ERA approach called 'productivity-susceptibility analysis' (PSA) to estimate the vulnerability of data-poor, non-target species caught in the EPO purse-seine fishery by large (Class-6) vessels and in the longline fishery. PSA considers a stock's vulnerability as a combination of its susceptibility to being captured by, and incur mortality from, a fishery and its capacity to recover, given its biological productivity.

Purse-seine fishery. A manuscript describing the evaluation of three purse-seine "fisheries" in the EPO is in review, using 27 species (3 target tunas, 4 billfishes, 3 dolphins, 7 large fishes, 3 rays, 5 sharks, and 2 small fishes) that comprised the majority of the biomass removed by the purse-seine fleet during 2005-2013 (Table J-1). The overall productivity (*p*) and susceptibility (*s*) values that contributed to the overall vulnerability score (*v*) are shown in Table J-1. Vulnerability was highest for elasmobranchs, namely the giant manta ray (*Manta birostris*), bigeye and pelagic thresher shark (*Alopias superciliosus* and *A. pelagicus*), smooth and scalloped hammerhead sharks (*Sphyrna mokarran* and *S. lewini*), and silky shark (*Carcharhinus falciformis*). Billfishes, dolphins, other rays, ocean sunfish, and yellowfin and bigeye tunas were classified as moderately vulnerable, while the remaining species, all teleosts had the lowest vulnerability scores (Table J-1; Figure J-12a).

Large-scale tuna longline fishery. A preliminary assessment of the longline fishery in the EPO was undertaken in 2016 for 68 species that had some level of interaction (captured, discarded, or impacted) with the fishery (SAC-08-07d). There were 12, 38, and 18 species classified as having low, moderate, and high vulnerability, respectively (Figure J-12b; Table J-2). Of the 18 highly vulnerable species, 13 were elasmobranchs—with the bigeye thresher, tiger, porbeagle and blue sharks identified as most vulnerable—, and 5 were commercially important tunas and billfishes (albacore, Pacific bluefin, and yellowfin tunas, swordfish, and striped marlin). Other tuna-like and mesopelagic species were classified as either having moderate or low vulnerability in the fishery, although four species—wahoo, snake mackerel, and the two species of dorado—had *v* scores close to 2.0, in close vicinity to being highly vulnerable (Figure J-12b; Table J-2).

Cumulative impacts of 'industrial' fisheries on EPO species. Because a limitation of PSA is the inability to estimate the cumulative effects of multiple fisheries on data-poor bycatch species, a new flexible spatially-explicit approach—Ecological Assessment of Sustainable Impacts of Fisheries (EASI-Fish)—was developed by the IATTC staff in 2018 (SAC-09-12) to overcome this issue. EASI-Fish uses a reduced set of parameters that are present in the PSA, and first produces a proxy of the instantaneous fishing mortality rate (*F*) of each species based on the 'volumetric overlap' of each fishery with the stock's distribution. *F* is then used in length-structured per-recruit models to assess the vulnerability of each species using conventional biological reference points (*e.g.* F_{MSY}, $F_{0.1}$ and $SSB_{40\%}$). EASI-Fish has major advantages over PSA including: (i) the capability of quantitatively estimating species-specific vulnerability for the purposes of prioritizing species for data collection, further detailed analysis, research and management, (ii) transferability between species with different life histories (*e.g*., teleosts to marine mammals), and (iii) the ability to rapidly and cost-effectively explore hypothetical spatial and/or temporal conservation and management measures that may reduce or mitigate the risk posed by a fishery to a species. EASI-Fish was successfully applied to 14 species representing a range of life histories, including tunas, billfish, tuna-like species and elasmobranchs caught in EPO tuna fisheries as a 'proof of concept' in 2018 (SAC-09-12). Therefore, EASI-Fish will continue to be refined and is planned to supersede the PSA in future ERAs for fisheries operating in the EPO. Given EPO tuna fisheries interact with at least 117 taxa (SAC-07-INF C(d)), the IATTC staff will continue in the coming years to incrementally include more species to the analysis until all impacted species are assessed, as stipulated in the proposed 5-year SSP. This year, the spinetail devil ray was assessed and results will be presented at the Ninth Meeting of the Working Group on Bycatch (BYC-09-01).

8. ECOSYSTEM MODELING

Although ERA approaches can be useful for assessing the ecological impacts of fishing, they generally do not consider changes in the structure and internal dynamics of an ecosystem. As data collection programs improve and ecological studies (*e.g.* on diet) are conducted on components of the ecosystem, more data-rich ecosystem models can be employed that quantitatively represent ecological interactions among species or ecological 'functional groups'. These models are most useful as descriptive devices for exploring the potential impacts of fishing and/or environmental perturbations on components of the system, or the ecosystem structure as a whole.

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 species of conservation importance (*e.g.* sea turtles). Fisheries landings and discards are included as 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 included.

The model has been calibrated to time series of biomass and catch data for a number of target and non-target species for 1961–1998. There have been significant improvements in data collection programs in the EPO since 1998, and these new data has allowed the model include catch data to 2017. Additionally, simulations using this new data were conducted to assess potential impacts of the FAD fishery on the structure of the ecosystem (SAC-10-15).

One shortcoming of the model, in its current form, is that its underlying diet matrix—the component of the model that defines the trophic linkages between species in the ecosystem—that is based on stomach content data from fish collected over two decades ago (1992–1994). Furthermore, these data were supplemented with diet data from other regions of the Pacific Ocean and beyond where no local data were available for a particular species or functional group. Given the significant environmental changes that have been observed in the EPO over the past decade, in the form of some of the strongest El Nino events on record, it stands to reason that there is a critical need to collect trophic information from not only species of economic (*e.g.* tunas) or conservation (*e.g.* sharks) importance, but also their prey, and the base of the food web (*i.e.* phytoplankton).

A second limitation of the model is that it describes only the tropical component of the EPO ecosystem, and results cannot be reliably extrapolated to other regions of the EPO. Therefore, future work may aim to update the model to a spatially-explicit model that covers the entire EPO. This is a significant undertaking, but it would allow for an improved representation of the ecosystem and the potential fishery and climate impact scenarios that may be modelled to guide ecosystem-based fisheries management.

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

Both the IATTC's Antigua Convention and the AIDCP have objectives that involve the incorporation of ecosystem considerations into the management of the tuna fisheries in the EPO. Actions taken in the past can be found in adopted Resolutions by the IATTC and AIDCP.

10. FUTURE DEVELOPMENTS

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

An ecosystem-based approach to fisheries management may be best facilitated through a multi-faceted approach involving the monitoring of biologically and ecologically meaningful indicators for key indicator species and ecosystem integrity. Ecological indicators may be aggregate indices describing the structure of the entire ecosystem (*e.g.* diversity), or specific components (*e.g.* trophic level of the catch), as presented in Section 6 "Ecological Indicators". Biological indicators may generally relate to single species—perhaps those of key ecological importance or 'keystone' species—and be in the form of commonly-used fishery reference points (*e.g.* F_{MSY}), CPUE, or other simple measures such as changes in size spectra. However, the indicator(s) used depend heavily on the reliability of the information available at the species to ecosystem level.

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 the 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.

Future ecosystem work is described in the proposed IATTC Strategic Science Plan (IATTC-93-06a) and staff activities report (SAC-10-01). Briefly, this work will include improving ERAs—using EASI-Fish to identify species at risk and prioritize species-specific research—and developing and maintaining databases of key biological and ecological parameters (*e.g.* growth parameters), continuation of diet studies to update diet matrices in ecosystem models, developing research proposals for biological sampling, ecosystem monitoring and field-based research on consumption and evacuation experiments, development of a spatially-explicit ecosystem model of the EPO and ecological indicators, and continued reporting of bycatch estimates. A review of ecosystem-related research was undertaken to improve IATTC's reporting of ecological research with suggested improvements outlined in SAC-10 INF-B.

ACKNOWLEDGMENTS

We would like to thank Nick Vogel, Joydelee Marrow, and Joanne Boster for their assistance with data preparation, Alexandre Aires-da-Silva, Nick Webb and Paulina Llano for their reviews of this document, and Christine Patnode for improving the figures. We also thank Ricardo Oliveros-Ramos and Jon Lopez for help with the Hovmöller diagrams and Haikun Xu and Cara Wilson for assisting with code for the quarterly SST and chlorophyll figures. We gratefully acknowledge the early ecosystem research by Robert Olson that contributed to this report. His initiation of the *Ecosystem Considerations* report was first presented at the 8th Meeting of the Working Group to Review Stock Assessments in 2007 (SAR-8-17 J) and has since been updated annually.

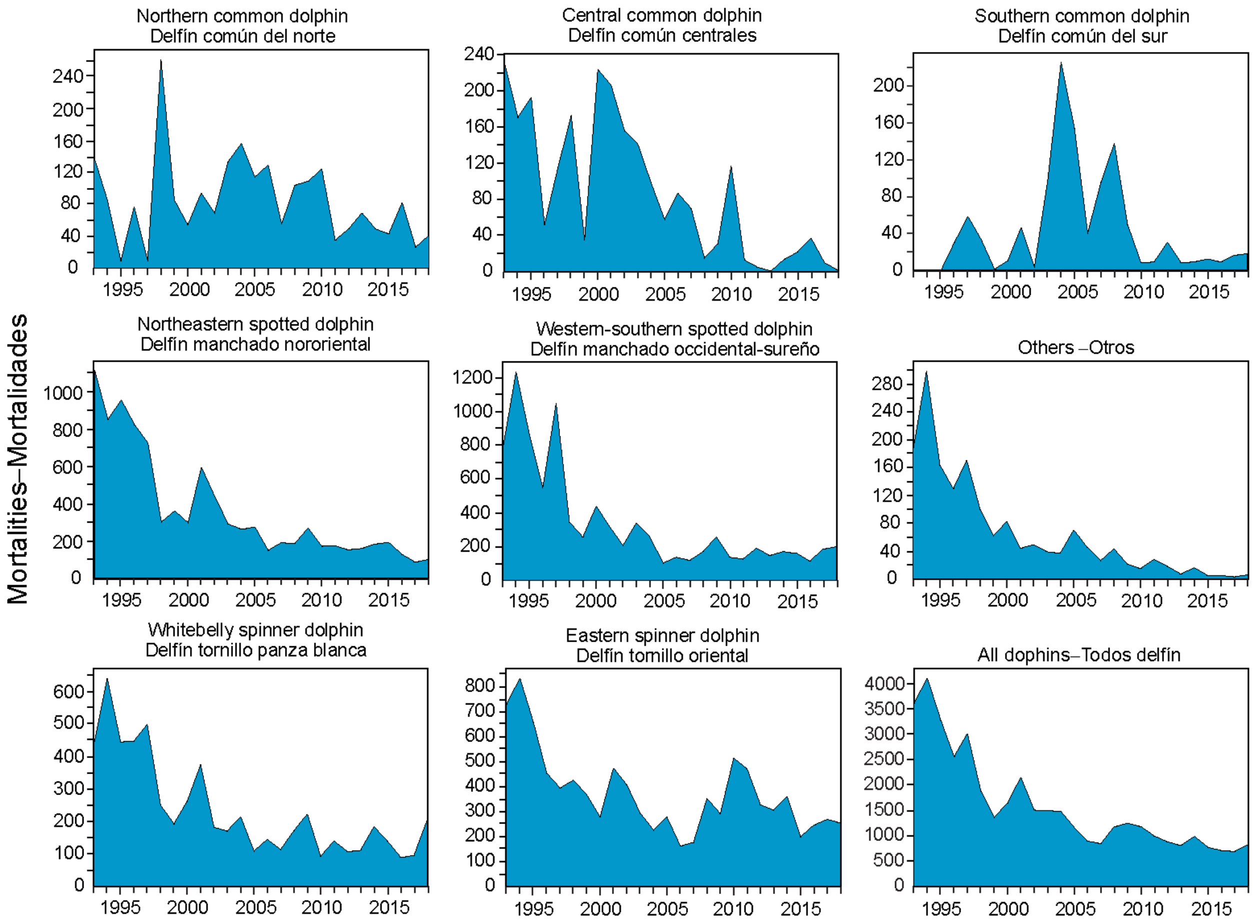


FIGURE J-1. Incidental dolphin mortalities, in numbers of animals by purse-seine vessels, 1993–2018.
FIGURA J-1. Mortalidades incidentales de delfines, en número de animales, 1993–2018.

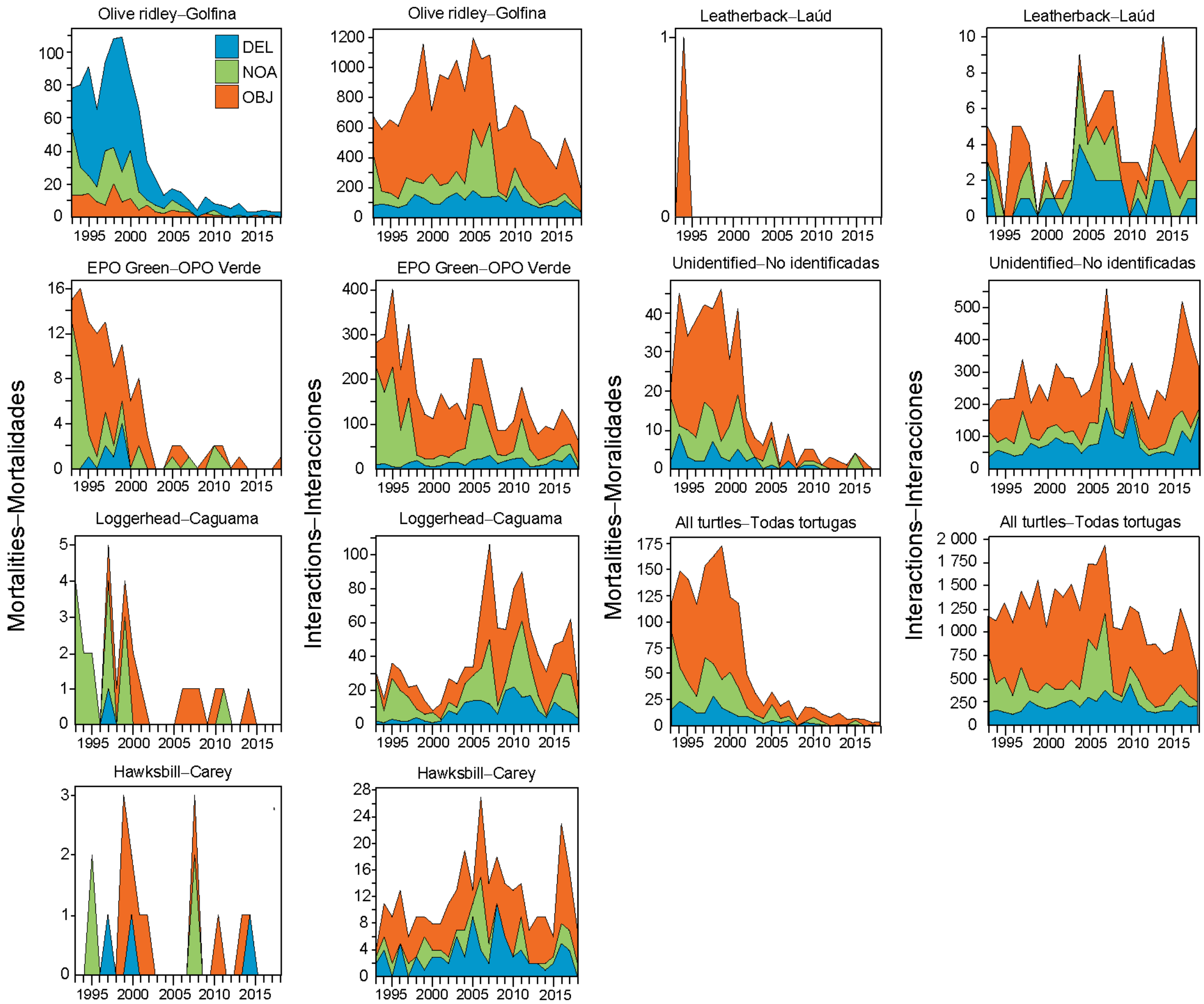


FIGURE J-2. Sea turtle interactions and mortalities, in numbers of animals, for large purse-seine vessels, 1993–2018, by set type (dolphin (DEL), unassociated (NOA), floating object (OBJ)).
FIGURA J-2. Interacciones y mortalidades de tortugas marinas, en número de animales, para buques cerqueros grandes, 1993-2018, por tipo de lance (delfín (DEL), no asociado (NOA), objeto flotante (OBJ)).

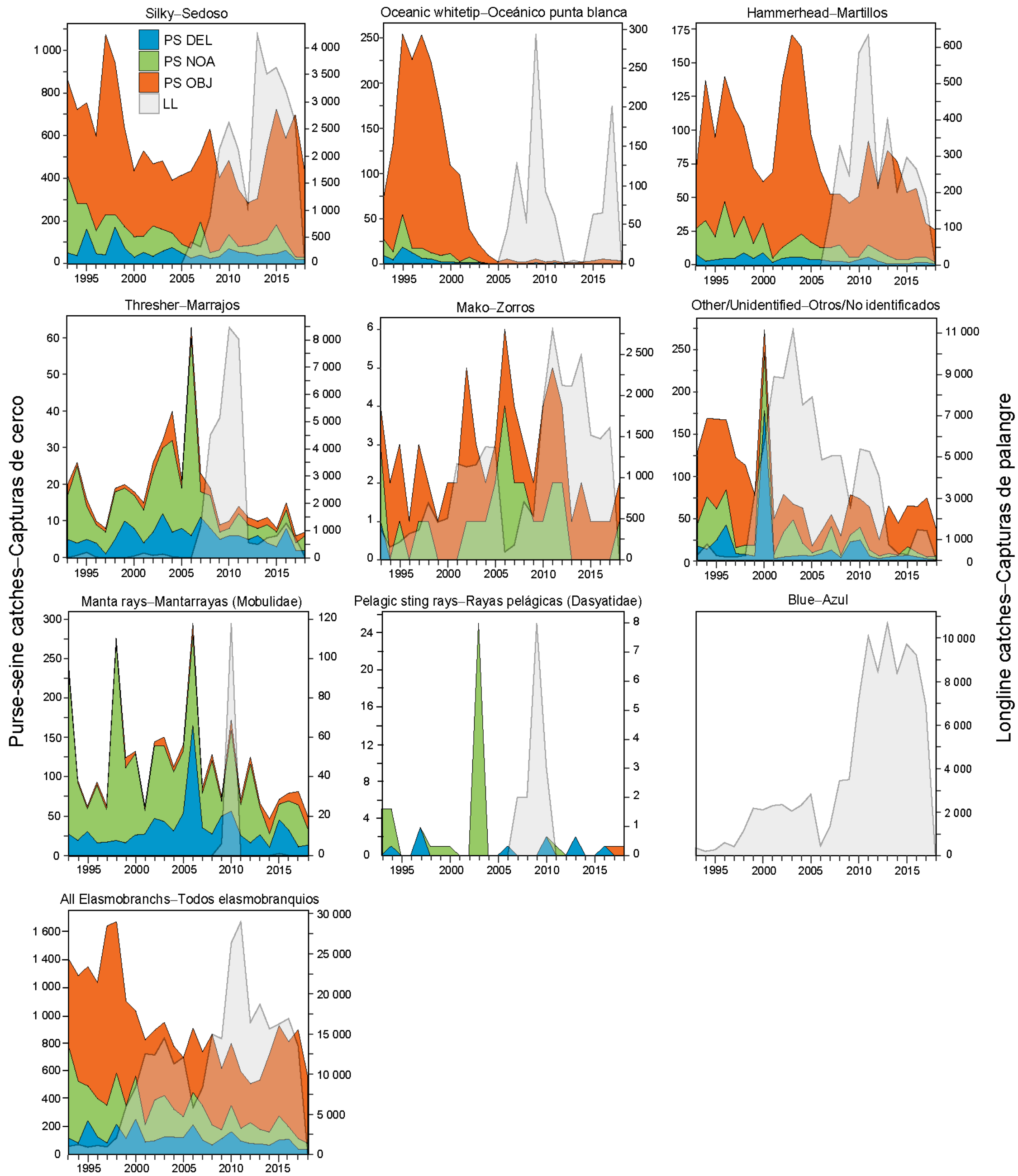


FIGURE J-3. Retained and discarded catches of sharks and rays, in tons, reported by observers aboard large purse-seine vessels, 1993–2018, by set type (dolphin (DEL), unassociated (NOA), floating object (OBJ)) (left y-axis). Longline data (right y-axis) are considered to be minimum catch estimates. Data for the past two years should be considered preliminary; longline data for 2018 not currently available.

FIGURA J-3. Capturas retenidas y descartadas de tiburones y rayas, en toneladas, notificadas por observadores a bordo de buques cerqueros grandes, 1993–2018, por tipo de lance (delfín (DEL), no asociado (NOA), objeto flotante (OBJ)). Los datos de palangre (eje *y* derecho) se consideran estimaciones mínimas de captura. Los datos de los dos últimos años deben considerarse preliminares; los datos de palangre para 2018 no están disponibles.

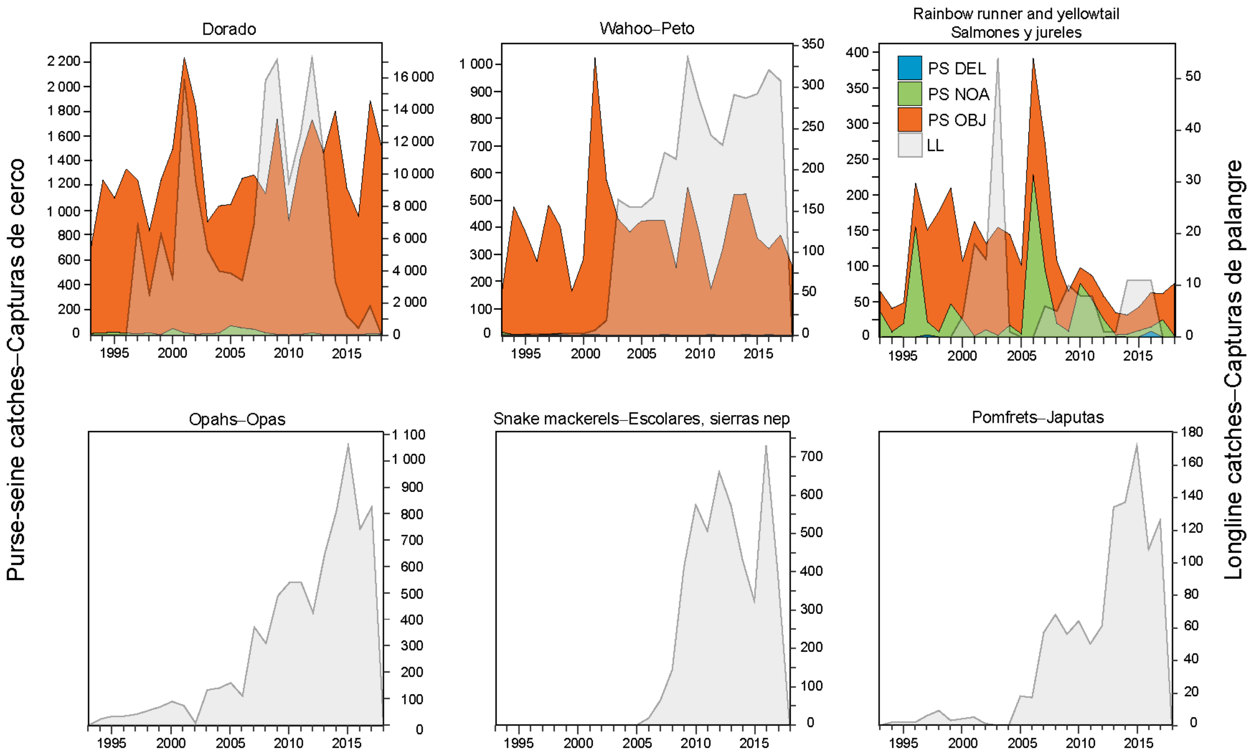


FIGURE J-4. Catches, in tons, of commonly-caught fishes by large purse-seine vessels, 1993–2018, by set type (dolphin (DEL), unassociated (NOA), floating object (OBJ)) (left y-axis). Longline data (right y-axis) are considered to be minimum catch estimates. Data for the past two years should be considered preliminary; longline data for 2018 not currently available.

FIGURA J-4. Capturas, en toneladas, de peces capturados comúnmente por buques cerqueros grandes, 1993-2018, por tipo de lance (delfín (DEL), no asociado (NOA), objeto flotante (OBJ)) (eje *y* izquierdo). Los datos de palangre (eje *y* derecho) se consideran estimaciones mínimas de captura. Los datos de los dos últimos años deben considerarse preliminares; los datos de palangre para 2018 no están disponibles.

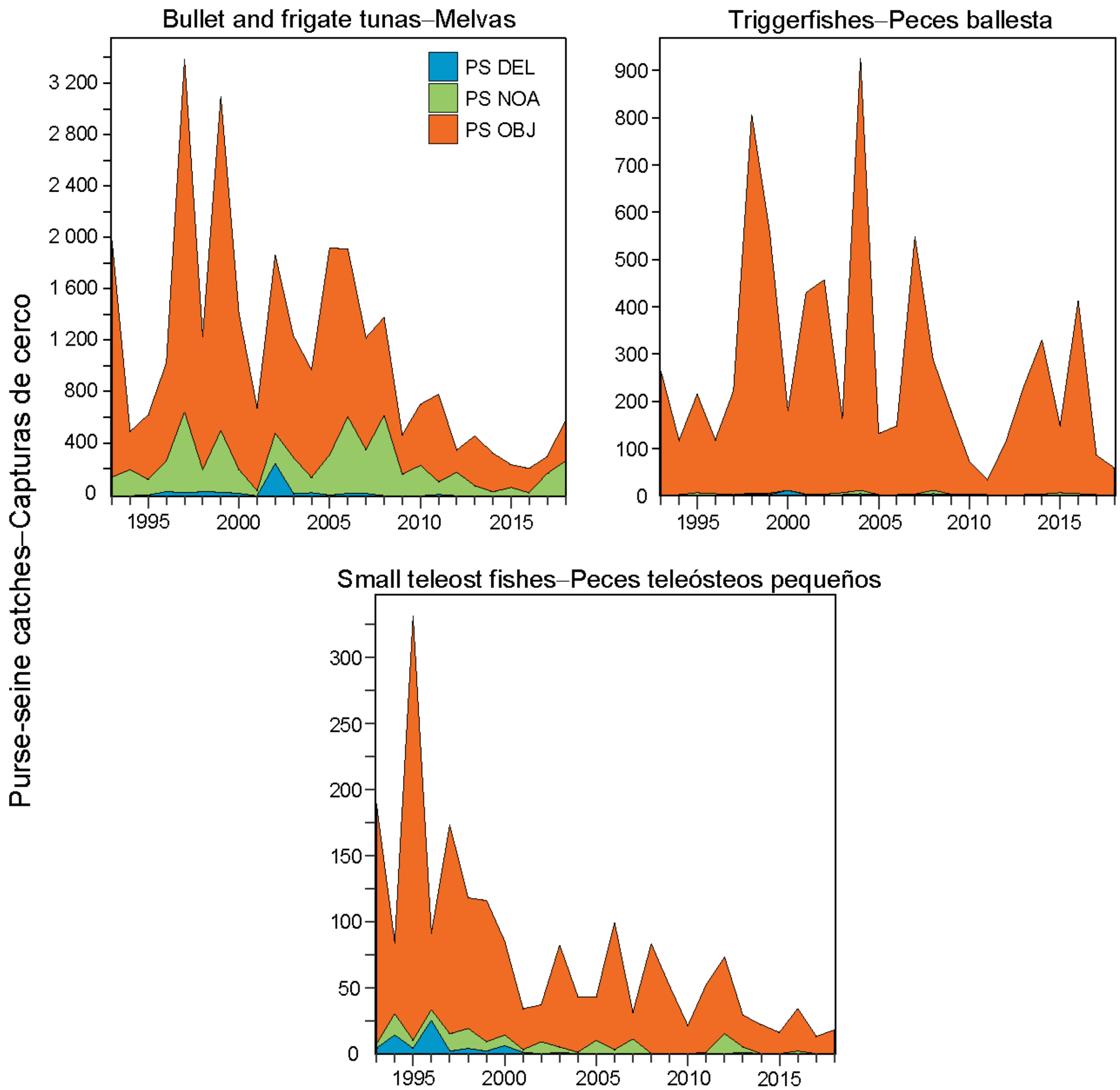
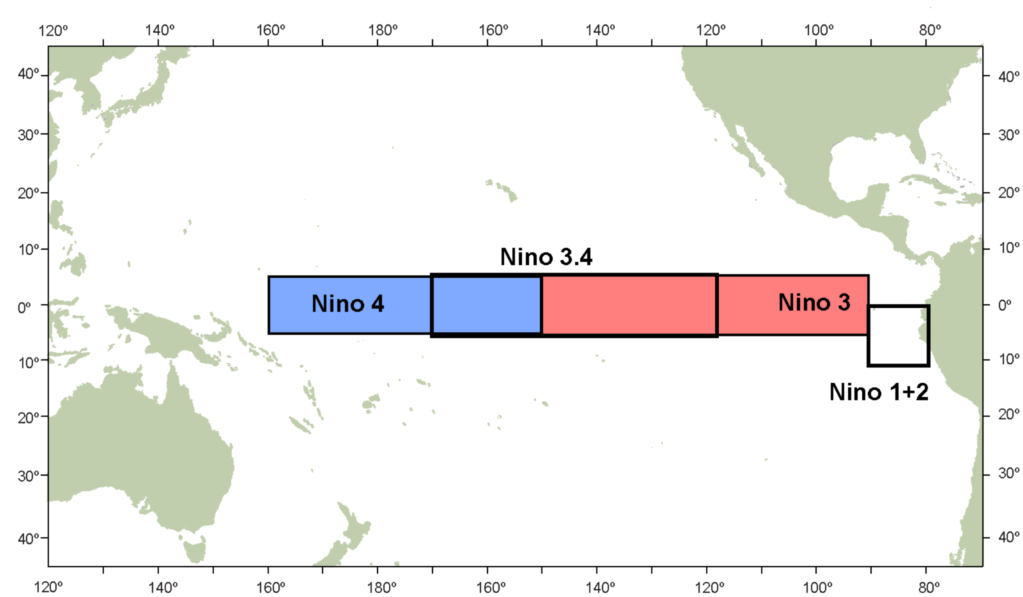


FIGURE J-5. Catches, in tons, of forage fishes by large purse-seine vessels, 1993–2018, by set type (dolphin (DEL), unassociated (NOA), floating object (OBJ)).
FIGURA J-5. Capturas, en toneladas, de peces de alimento por buques cerqueros grandes, 1993–2018, por tipo de lance (delfín (DEL), no asociado (NOA), objeto flotante (OBJ)).

a.



b.

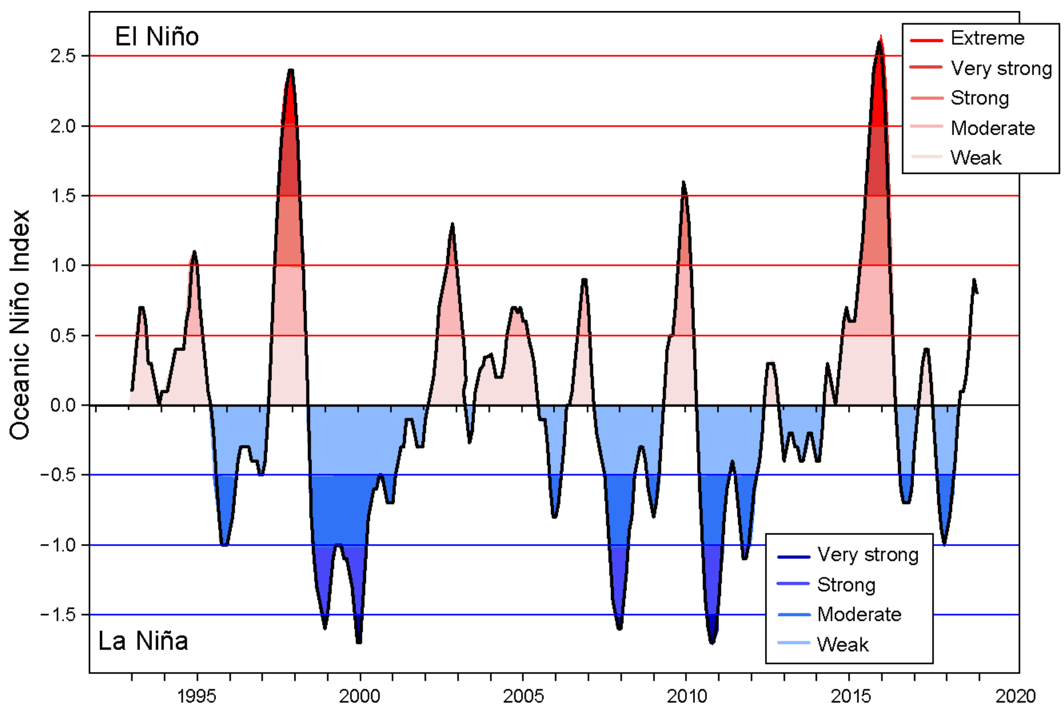


FIGURE J-6. a) El Niño regions used as indicators of El Niño Southern Oscillation (ENSO) events in the Pacific Ocean. The Oceanic Niño Index (ONI) used to monitor ENSO conditions in Niño region 3.4 from 5°N to 5°S and 120°W to 170°W. b) Time series from the start of the IATTC observer program through December 2018 showing the running 3-month mean values of the ONI. ONI data obtained from: http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

FIGURA J-6 a) Regiones de El Niño utilizadas como indicadores de los eventos de El Niño-Oscilación del Sur (ENOS) en el Océano Pacífico. El Índice de El Niño Oceánico (ONI) usado para dar seguimiento a las condiciones de ENOS en la región Niño 3.4 de 5°N a 5°S y de 120°O a 170°O. b) Series de tiempo desde el inicio del programa de observadores de la CIAT hasta finales de diciembre de 2018 mostrando los valores del promedio móvil de 3 meses del ONI. Datos del ONI obtenidos de: http://www.cpc.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

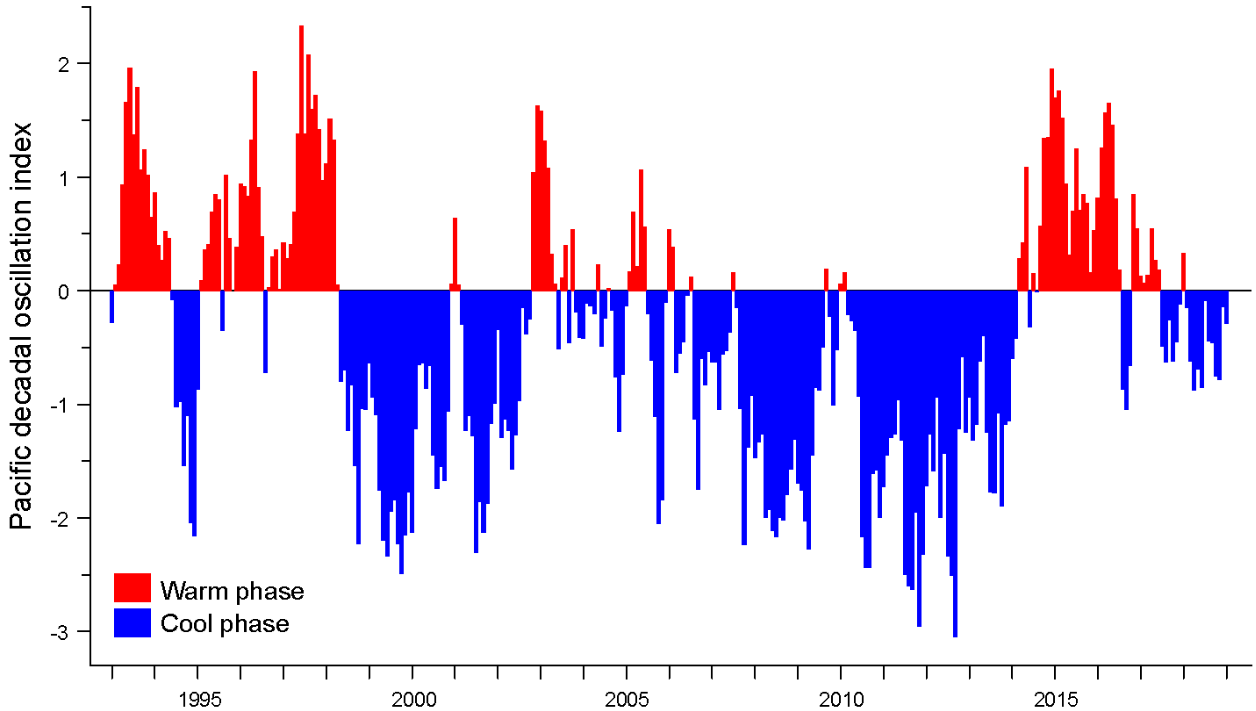


FIGURE J-7. Monthly values of the Pacific Decadal Oscillation (PDO) Index, January 1993–December 2018. PDO data obtained from: https://www.ncdc.noaa.gov/teleconnections/pdo/data.csv

FIGURA J-7 Valores mensuales del índice de Oscilación Decadal del Pacífico (PDO), enero de 1993–diciembre de 2018. Datos de la PDO obtenidos de: https://www.ncdc.noaa.gov/teleconnections/pdo/data.csv

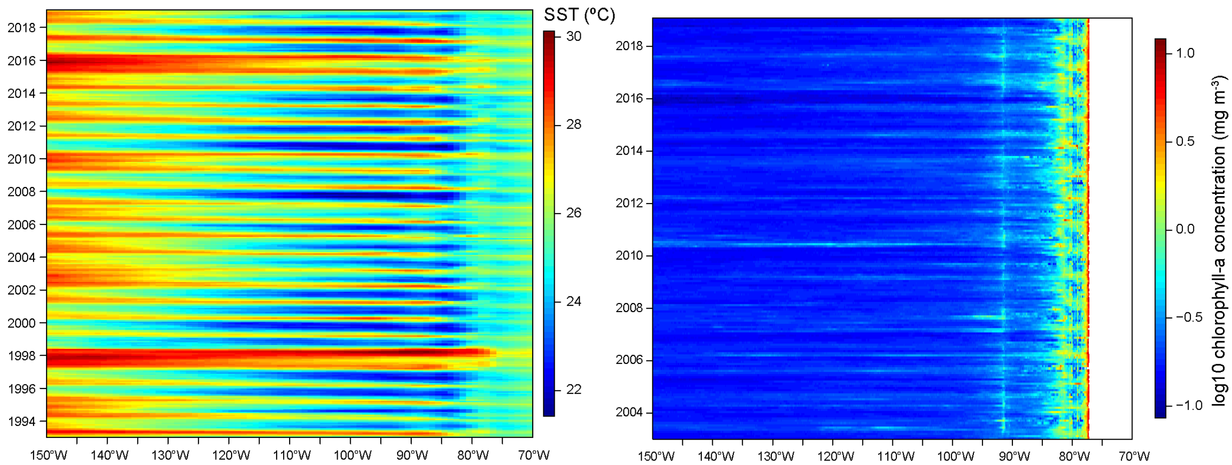


FIGURE J-8. Time-longitude Hovmöller diagram with data averaged across the tropical eastern Pacific Ocean from 5°N to 5°S for a) mean monthly SST for January 1993–January 2019. *NOAA_OI_SST_V2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at* https://www.esrl.noaa.gov/psd/ and b) mean monthly chlorophyll-a concentration for January 2003–January 2019. Chlorophyll-a concentration data obtained from ERDDAP, NASA/GSFC/OBPG, downloaded on 27 Mar 2019, Chlorophyll-a, Aqua MODIS, NPP, L3SMI, Global, 4km, Science Quality, 2003–present (Monthly Composite), NOAA, NMFS, SWFSC, ERD, https://coastwatch.pfeg.noaa.gov/erddap/info/erdMH1chlamday/index.html, DOI: 10.5067/AQUA/MODIS/L3M/CHL/2018.

FIGURA J-8 Diagrama de Hovmöller tiempo-longitud con datos promediados en el Océano Pacífico tropical oriental de 5°N a 5°S para a) la TSM promedio mensual de enero de 1993 a enero de 2019. Datos NOAA_OI_SST_V2 proporcionados por la NOAA/OAR/ESRL PSD, Boulder, Colorado, EE. UU., de su sitio web: https://www.esrl.noaa.gov/psd/ y b) concentración promedio mensual de clorofila-a de enero de 2003 a enero de 2019. Datos de concentración de clorofila-a obtenidos de ERDDAP, NASA/GSFC/OBPG, descargados el 27 de marzo de 2019, "Chlorophyll-a, Aqua MODIS, NPP, L3SMI, Global, 4km, Science Quality, 2003–present (Monthly Composite)", NOAA, NMFS, SWFSC, ERD, https://coastwatch.pfeg.noaa.gov/erddap/info/erdMH1chlamday/index.html DOI: 10.5067/AQUA/MODIS/L3M/CHL/2018.

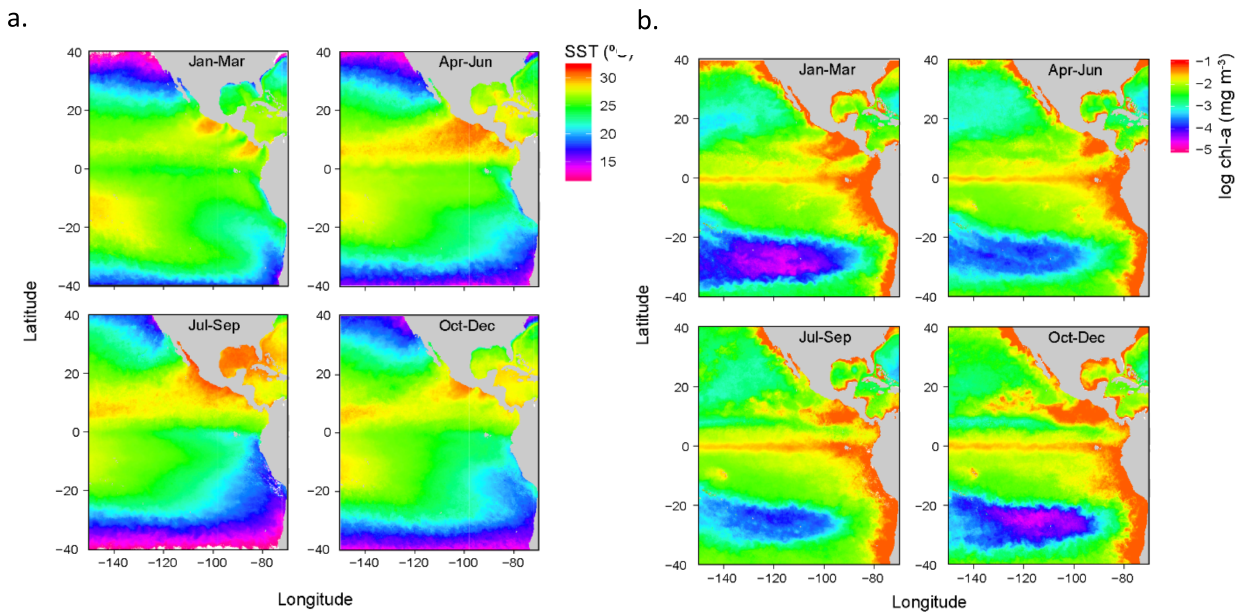


FIGURE J-9. a) Mean sea surface temperature (SST) b) Mean chlorophyll-a concentration mg m^3 for each quarter during 2018. SST data obtained from NOAA NMFS SWFSC ERD on February 11, 2019, "SST, Aqua MODIS, NPP, 4km, Daytime (11 microns), 2003–present (Monthly Composite)", https://coastwatch.pfeg.noaa.gov/erddap/info/erdMH1sstdmday/index.html. Chlorophyll data presented as log chl-a concentration, obtained from NOAA CoastWatch on February 1, 2019, "Chlorophyll, NOAA, VIIRS, Science Quality, Global, Level 3, 2012-present, Monthly", NOAA NMFS SWFSC ERD, https://coastwatch.pfeg.noaa.gov/erddap/info/nesdisVHNSQchlaMonthly/index.html

FIGURA J-9 a) Temperatura superficial del mar (TSM) promedio b) Concentración promedio de clorofila-a mg m^3 para cada trimestre de 2018. Datos de TSM obtenidos de NOAA NMFS SWFSC ERD el 11 de febrero de 2019, "SST, Aqua MODIS, NPP, 4km, Daytime (11 microns), 2003–present (Monthly Composite)", https://coastwatch.pfeg.noaa.gov/erddap/info/erdMH1sstdmday/index.html. Datos de clorofila presentados como concentración log chl-a, obtenidos de NOAA CoastWatch el 1 de febrero de, 2019, "Chlorophyll, NOAA, VIIRS, Science Quality, Global, Level 3, 2012-present, Monthly", NOAA NMFS SWFSC ERD, https://coastwatch.pfeg.noaa.gov/erddap/info/nesdisVHNSQchlaMonthly/index.html

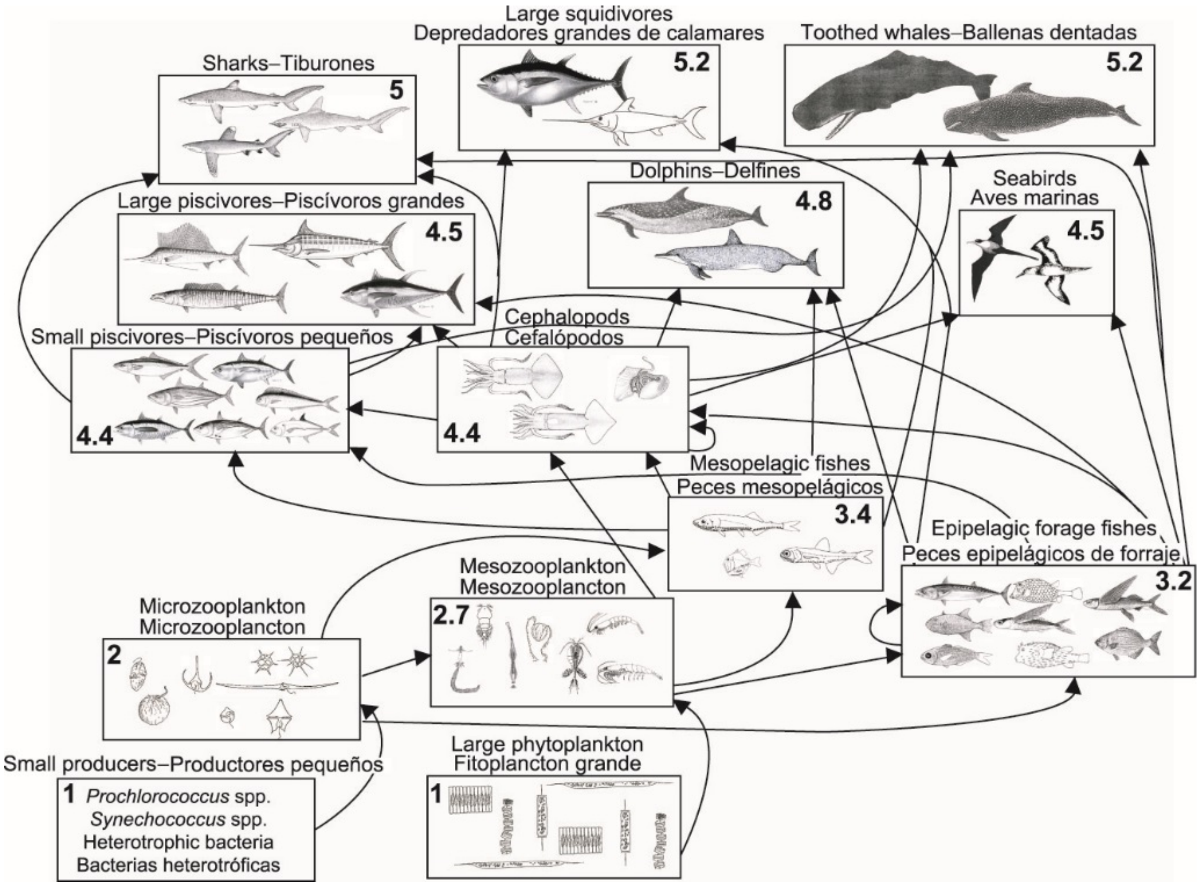


FIGURE J-10. Simplified food-web diagram of the pelagic ecosystem in the tropical EPO. The numbers inside the boxes indicate the approximate trophic level of each group.

FIGURA J-10. 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.

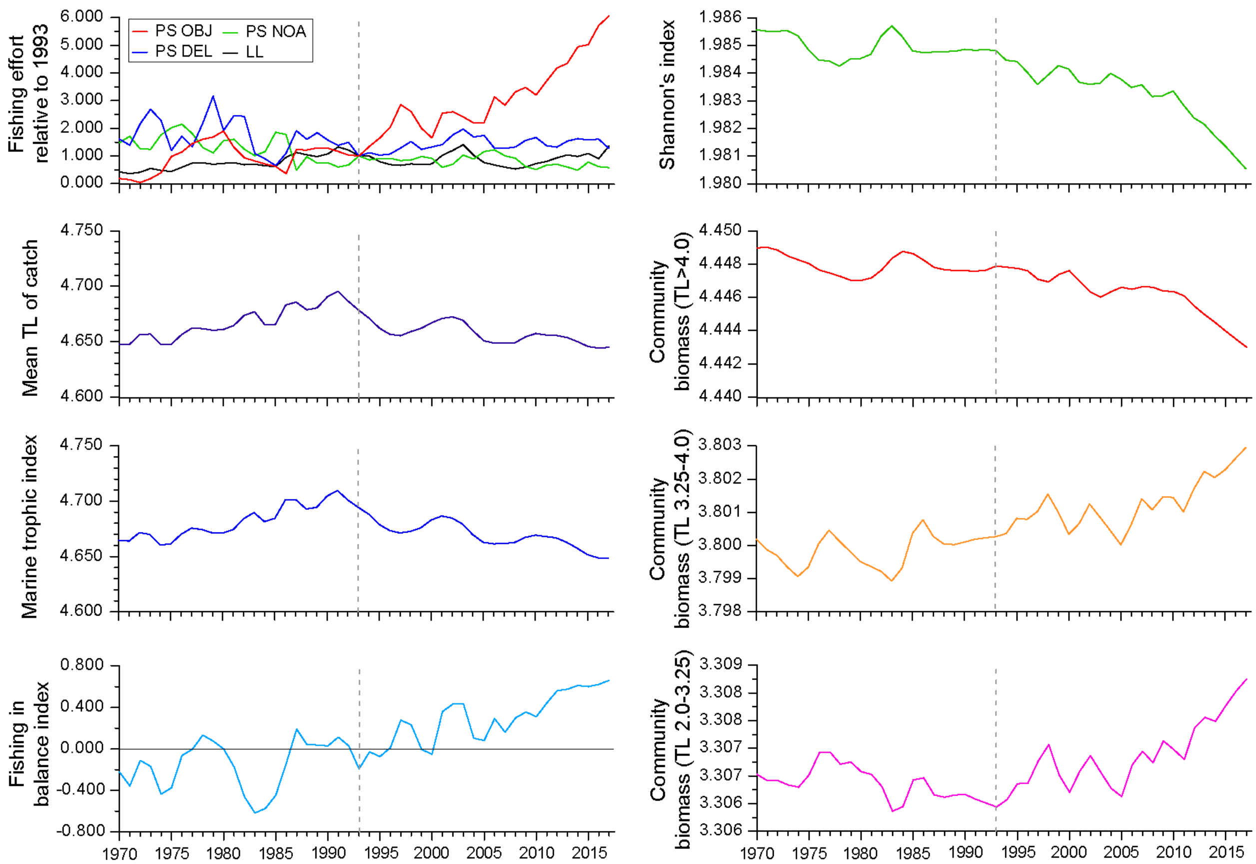


FIGURE J-11. Annual values for seven ecological indicators of changes in different components of the tropical EPO ecosystem, 1970–2017 (see Section 6 of text for details), and an index of longline (LL) and purse-seine (PS) fishing effort, by set type (dolphin (DEL), unassociated (NOA), floating object (OBJ)), relative to the model start year of 1993 (vertical dashed line), when the expansion of the purse-seine fishery on FADs began.

FIGURA J-11. Valores anuales de siete indicadores ecológicos de cambios en diferentes componentes del ecosistema tropical del OPO, 1970–2017 (ver detalles en la sección 6 del texto), y un índice de esfuerzo palangrero (LL) y cerquero (PS), por tipo de lance (delfín (DEL), no asociado (NOA), objeto flotante (OBJ)) relativo al año de inicio del modelo de 1993 (línea de trazos vertical), cuando comenzó la expansión de la pesquería cerquera sobre plantados.

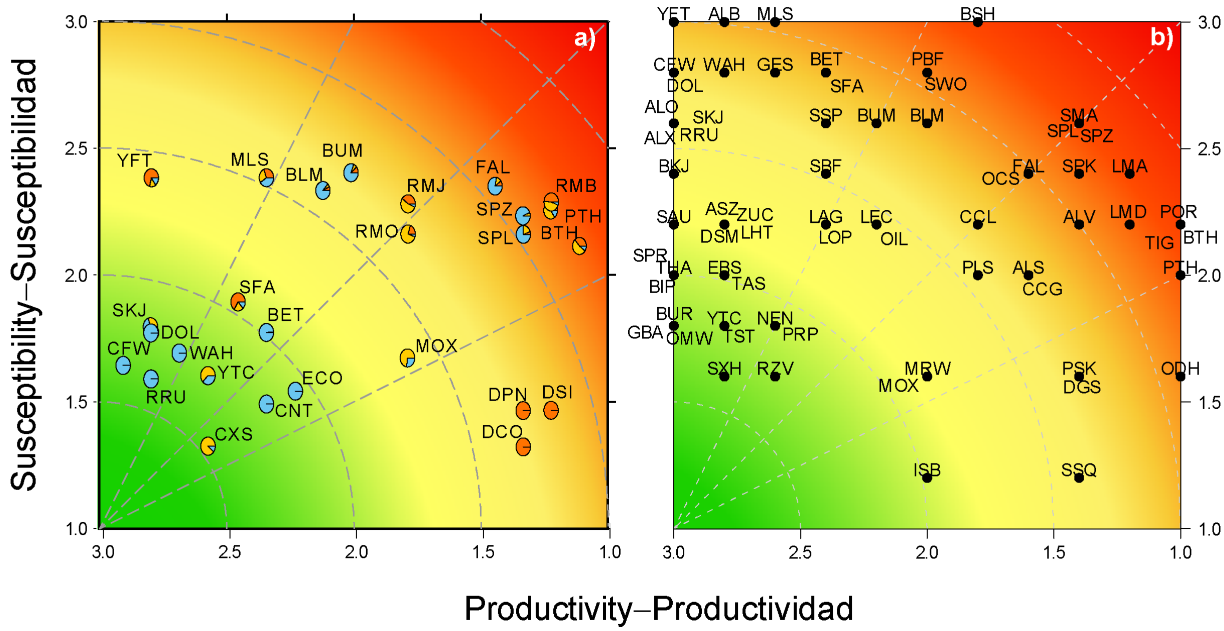


FIGURE J-12. Productivity and susceptibility x-y plot for target and bycatch species caught by the purse-seine fishery (a) with proportion of catch by set type shown in the pie charts, and the longline fishery (b) in the EPO during 2005–2013 and 2017, respectively. Dashed lines represent vulnerability (*v*) isopleths starting from the origin and have *v* values of 0.5, 1.0, 1.5, and 2.0 with categories defined as low (*v*≤ 1.0, green), moderate (1<*v*<2, yellow), and high (*v*≥2.0, red). See Tables J-1 and J-2 for species codes for each fishery.

FIGURA J-12. Gráfica x-y de productividad y susceptibilidad de especies objetivo y de captura incidental capturadas por la pesquería cerquera (a) con proporción de captura por tipo de lance indicada en los gráficos circulares, y la pesquería palangrera (b) en el OPO durante 2005–2013 y 2017, respectivamente. Las líneas de trazos representan isolíneas de vulnerabilidad (*v*) a partir del origen y tienen valores de *v* de 0.5, 1.0, 1.5 y 2.0 con categorías definidas como baja (*v*≤ 1.0, verde), moderada (1<*v*<2, amarilla) y alta (*v*≥2.0, roja). Ver Tablas J-1 y J-2 para los códigos de especies para cada pesquería.

TABLE J-1. Productivity (p) and susceptibility (s) scores used to compute the overall vulnerability measure (v). Susceptibility scores are shown for each fishery (dolphin (DEL), unassociated (NOA), floating object (OBJ)) and as a weighted combination of the individual fishery values. Vulnerability scores rated as low (green), medium (yellow), and high (red). Mean data quality (DQ) scores for susceptibility (s_k) by fishery and productivity DQ p are categorized as green (high: DQ<2), yellow (moderate: 3<DQ>2) and red (low: DQ≥3).

TABLA J-1. Puntuaciones de productividad (p) y susceptibilidad (s) usadas para computar la medida general de vulnerabilidad v. D. Se señalan las puntuaciones de susceptibilidad para cada pesquería (DEL: delfín; NOA: no asociada; OBJ: objeto flotante) y como combinación ponderada de los valores de las pesquerías individuales. Puntuaciones de vulnerabilidad clasificadas de baja (verde), mediana (amarillo), y alta (rojo). Las puntuaciones promedio de calidad de los datos (DQ) para la susceptibilidad (s_k) por pesquería y productividad DQ p se clasifican en verde (alta: DQ<2), amarillo (moderada: 3<DQ>2) y rojo (baja: DQ≥3).

				s_k scores by fishery						***DQ s_k scores by fishery***			
Group	**Scientific name**	**Common name**	**Species code**	**DEL**	**NOA**	**OBJ**	***p***	***s***	***v***	**DEL**	**NOA**	**OBJ**	***DQ p***
Tunas	*Thunnus albacares*	Yellowfin tuna	YFT	2.29	2.29	2.57	2.78	2.39	1.41	1.14	1.14	1.14	1.78
	Thunnus obesus	Bigeye tuna	BET	1	2.29	2.57	2.33	1.78	1.03		1.14	1.14	1.78
	Katsuwonus pelamis	Skipjack tuna	SKJ	1	2.29	2.57	2.78	1.78	0.81		1.14	1.14	2
Billfishes	*Makaira nigricans*	Blue marlin	BUM	2.29	2.14	2.71	2	2.41	1.73	2.14	2.14	2.14	2.33
	Istiompax indica	Black marlin	BLM	2.14	2.14	2.71	2.11	2.34	1.67	2.14	2.14	2.14	2.22
	Kajikia audax	Striped marlin	MLS	2.29	2.29	2.57	2.33	2.39	1.54	2	2	2	1.89
	Istiophorus platypterus	Indo-Pacific sailfish	SFA	2.43	2.29	1	2.44	1.90	1.06	2	2		2.11
Dolphins	*Stenella longirostris*	Unidentified spinner dolphin	DSI	2	1	1	1.22	1.47	1.84	1.29			2.44
	Stenella attenuata	Unidentified spotted dolphin	DPN	2	1	1	1.33	1.47	1.73	1.29			2.33
	Delphinus delphis	Common dolphin	DCO	1.71	1	1	1.33	1.33	1.70	1.71			2.56
Large fishes	*Coryphaena hippurus*	Common dolphinfish	DOL	1	2.14	2.71	2.78	1.80	0.83		2.29	2.29	1.89
	Coryphaena equiselis	Pompano dolphinfish	CFW	1	1	2.86	2.89	1.65	0.66			2.43	3.33
	Acanthocybium solandri	Wahoo	WAH	1	1	3	2.67	1.70	0.77			2.29	2.11
	Elagatis bipinnulata	Rainbow runner	RRU	1	1	2.71	2.78	1.60	0.64			2.29	3.33
	Mola mola	Ocean sunfish, Mola	MOX	1	2.29	2.29	1.78	1.68	1.40		2.43	2.43	3.56
	Caranx sexfasciatus	Bigeye trevally	CXS	1	2.86	1	2.56	1.33	0.55		2.71		3.56
	Seriola lalandi	Yellowtail amberjack	YTC	1	2.43	2	2.56	1.61	0.75		2.43	2.43	2.78
Rays	*Manta birostris*	Giant manta	RMB	2.43	2.57	2	1.22	2.30	2.21	2.57	2.57	2.57	3.11
	Mobula japanica	Spinetail manta	RMJ	2.29	2.57	2.14	1.78	2.29	1.77	2.43	2.43	2.43	3.33
	Mobula thurstoni	Smoothtail manta	RMO	2.14	2.57	2	1.78	2.17	1.77	2.57	2.57	2.57	3.44
Sharks	*Carcharhinus falciformis*	Silky shark	FAL	2.29	2.14	2.57	1.44	2.36	2.07	2.14	2.29	2.29	2.22
	Sphyrna zygaena	Smooth hammerhead shark	SPZ	2.14	2.14	2.43	1.33	2.24	2.08	2.14	2.29	2.29	3.33
	Sphyrna lewini	Scalloped hammerhead shark	SPL	2.14	2.29	2.14	1.33	2.17	2.04	2.14	2.29	2.29	2.33
	Alopias pelagicus	Pelagic thresher shark	PTH	2.29	2.14	2.29	1.22	2.26	2.18	2.14	2.29	2.29	2.11
	Alopias superciliosus	Bigeye thresher shark	BTH	2.14	2.29	2	1.11	2.12	2.20	2.14	2.29	2.29	2.22
Small fishes	*Canthidermis maculatus*	Ocean triggerfish	CNT	1	1	2.43	2.33	1.50	0.84			2.71	4
	Sectator ocyurus	Bluestriped chub	ECO	1	1	2.57	2.22	1.55	0.95			2.57	3.33

TABLE J-2. Species included in the productivity-susceptibility analysis for the large-scale tuna longline fishery in the eastern Pacific Ocean, showing average productivity (*p*) and susceptibility (*s*) scores used to compute the overall vulnerability score (*v*) for each species, rated as low (green), medium (yellow), and high (red).

TABLA J-2. Especies incluidas en el análisis de productividad-susceptibilidad de la pesquería atunera palangrera a gran escala en el Océano Pacífico oriental. indicado las puntuaciones promedio de productividad (*p*) y susceptibilidad (*s*) usadas para calcular la puntuación general de vulnerabilidad (*v*) para cada especie, clasificada como baja (verde), mediana (amarillo), y alta (rojo).

Group Grupo	Scientific name Nombre científico	Common name	Nombre común	Code Código	*p*	*s*	*v*
Billfishes	*Istiompax indica*	Black marlin	Marlín negro	BLM	2.00	2.60	1.89
Peces picudos	*Istiophorus platypterus*	Indo-Pacific sailfish	Pez vela indopacífico	SFA	2.40	2.80	1.90
	Kajikia audax	Striped marlin	Marlín rayado	MLS	2.60	3.00	2.04
	Makaira nigricans	Blue marlin	Marlín azul	BUM	2.20	2.60	1.79
	Tetrapturus angustirostris	Shortbill spearfish	Marlín trompa corta	SSP	2.40	2.60	1.71
	Xiphias gladius	Swordfish	Pez espada	SWO	2.00	2.80	2.06
Tunas	*Katsuwonus pelamis*	Skipjack	Barrilete	SKJ	3.00	2.60	1.60
Atunes	*Thunnus alalunga*	Albacore	Albacora	ALB	2.80	3.00	2.01
	Thunnus albacares	Yellowfin	Aleta amarilla	YFT	3.00	3.00	2.00
	Thunnus maccoyii	Southern bluefin	Aleta azul del sur	SBF	2.40	2.40	1.52
	Thunnus obesus	Bigeye	Patudo	BET	2.40	2.80	1.90
	Thunnus orientalis	Pacific bluefin	Aleta azul del Pacífico	PBF	2.00	2.80	2.06
Elasmobranchs	*Alopias pelagicus*	Pelagic thresher shark	Zorro pelágico	PTH	1.00	2.00	2.24
Elasmobranquios	*Alopias superciliosus*	Bigeye thresher shark	Zorro ojón	BTH	1.00	2.20	2.33
	Alopias vulpinus	Common thresher shark	Zorro	ALV	1.40	2.20	2.00
	Carcharhinus albimarginatus	Silvertip shark	Tiburón de puntas blancas	ALS	1.60	2.00	1.72
	Carcharhinus falciformis	Silky shark	Tiburón sedoso	FAL	1.60	2.40	1.98
	Carcharhinus galapagensis	Galapagos shark	Tiburón de Galápagos	CCG	1.60	2.00	1.72
	Carcharhinus limbatus	Blacktip shark	Tiburón macuira	CCL	1.80	2.20	1.70
	Carcharhinus longimanus	Oceanic whitetip shark	Tiburón oceánico punta blanca	OCS	1.60	2.40	1.98
	Galeocerdo cuvier	Tiger shark	Tintorera tigre	TIG	1.00	2.20	2.33
	Prionace glauca	Blue shark	Tiburón azul	BSH	1.80	3.00	2.33
	Pteroplatytrygon violacea	Pelagic stingray		PLS	1.80	2.00	1.56
	Isurus oxyrinchus	Shortfin mako shark	Marrajo dientuso	SMA	1.40	2.60	2.26
	Isurus paucus	Longfin mako shark	Marrajo carite	LMA	1.20	2.40	2.28
	Lamna ditropis	Salmon shark	Marrajo salmón	LMD	1.20	2.20	2.16
	Lamna nasus	Porbeagle shark	Marrajo sardinero	POR	1.00	2.20	2.33

Group Grupo	Scientific name Nombre científico	Common name	Nombre común	Code Código	*p*	*s*	*v*
	Odontaspis noronhai	Bigeye sand tiger shark	Solrayo ojigrande	ODH	1.00	1.60	2.09
	Pseudocarcharias kamoharai	Crocodile shark	Tiburón cocodrilo	PSK	1.40	1.60	1.71
	Sphyrna lewini	Scalloped hammerhead shark	Cornuda común	SPL	1.40	2.60	2.26
	Sphyrna mokarran	Great hammerhead	Cornuda gigante	SPK	1.40	2.40	2.13
	Sphyrna zygaena	Smooth hammerhead	Cornuda cruz	SPZ	1.40	2.60	2.26
	Isistius brasiliensis	Cookie cutter shark	Tollo cigarro	ISB	2.00	1.20	1.02
	Squalus acanthias	Picked dogfish, Spiny dogfish	Mielga	DGS	1.40	1.60	1.71
	Zameus squamulosus	Velvet dogfish		SSQ	1.40	1.20	1.61
Mesopelagic	*Alepisaurus brevirostris*	Short snouted lancetfish		ALO	3.00	2.60	1.60
fishes	*Alepisaurus ferox*	Long snouted lancetfish	Lanzón picudo	ALX	3.00	2.60	1.60
Peces	*Eumegistus illustris*	Brilliant pomfret		EBS	2.80	2.00	1.02
mesopelágicos	*Taractes asper*	Rough pomfret		TAS	2.80	2.00	1.02
	Taractichthys steindchneri	Sickle Pomfret	Tristón segador	TST	2.80	1.80	0.82
	Gempylus serpens	Snake mackerel	Escolar de canal	GES	2.60	2.80	1.84
	Lepidocybium flavobrunneum	Escolar	Escolar negro	LEC	2.20	2.20	1.44
	Nesiarchus nasutus	Black gemfish	Escolar narigudo	NEN	2.60	1.80	0.89
	Promethichthys prometheus	Roudi escolar	Escolar prometeo	PRP	2.60	1.80	0.89
	Ruvettus pretiosus	Oilfish	Escolar clavo	OIL	2.20	2.20	1.44
	Lampris guttatus	Opah	Opa	LAG	2.40	2.20	1.34
	Lophotus capellei	Crestfish		LOP	2.40	2.20	1.34
	Masturus lanceolatus	Sharptail mola		MRW	2.00	1.60	1.17
	Mola mola	Sunfish	Pez luna	MOX	2.00	1.60	1.17
	Ranzania laevis	Slender sunfish		RZV	2.60	1.60	0.72
	Omosudis lowii	Omosudid (Hammerjaw)		OMW	3.00	1.80	0.80
	Scombrolabrax heterolepis	Longfin escolar		SXH	2.80	1.60	0.63
	Desmodema polystictum	Polka-dot ribbonfish		DSM	2.80	2.20	1.22
	Zu cristatus	Scalloped ribbonfish		ZUC	2.80	2.20	1.22
	Assurger anzac	Razorback scabbardfish	Sable aserrado	ASZ	2.80	2.20	1.22
	Trachipterus fukuzakii	Tapertail ribbonfish		LHT	2.80	2.20	1.22
Tuna-like species	*Elagatis bipinnulata*	Rainbow runner	Salmón	RRU	3.00	2.60	1.60
Especies afines a	*Seriola lalandi*	Yellowtail amberjack	Medregal rabo amarillo	YTC	2.80	1.80	0.82
los atunes	*Opisthonema oglinum*	Atlantic thread herring	Machuelo hebra atlántico	THA	3.00	2.00	1.00
	Sprattus sprattus	European sprat	Espadín	SPR	3.00	2.00	1.00
	Coryphaena equiselis	Pompano dolphinfish	Dorado pompano	CFW	3.00	2.80	1.80

Group Grupo	Scientific name Nombre científico	Common name	Nombre común	Code Código	*p*	*s*	*v*
	Coryphaena hippurus	Common dolphinfish	Dorado	DOL	3.00	2.80	1.80
	Pomadasys jubelini	Sompat grunt	Ronco sompat	BUR	3.00	1.80	0.80
	Scomberesox saurus	Atlantic saury	Paparda del Atlántico	SAU	3.00	2.20	1.20
	Acanthocybium solandri	Wahoo	Peto	WAH	2.80	2.80	1.81
	Euthynnus lineatus	Black skipjack	Barrilete negro	BKJ	3.00	2.40	1.40
	Sarda orientalis	Striped bonito	Bonito mono	BIP	3.00	2.00	1.00
	Sphyraena barracuda	Great barracuda	Picuda barracuda	GBA	3.00	1.80	0.80