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STOCK STATUS INDICATORS FOR FISHERIES OF THE EASTERN PACIFIC OCEAN

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1. INTRODUCTION

The primary purpose of this document is to 1) provide background on existing data and sources that may be used to develop stock status (or stability) indicators (SSIs) for species taken in the fisheries for tuna and billfishes in the eastern Pacific Ocean (EPO), 2) describe candidate SSIs, and 3) provide a preliminary evaluation of the suitability of each SSI for stocks managed by the IATTC. Indicators are useful when full assessments are infeasible and/or an indication of stock status is needed during periods between full stock assessments, and can also be used in harvest-control rules developed for management. Indicators based on catch, catch rates, and size or size frequencies were identified for possible further investigation and validation before use by the Commission.

Generally, full stock assessments require at least data on total catch covering the full time period of the assessment and a reliable index of relative abundance. They also need biological (*e.g.* growth, natural mortality) and fishery (*e.g.* selectivity) information or, if a production model is used, an understanding of the production function. Modern integrated stock assessment models can use other types of information (*e.g.* age- and length-composition data, mark-recapture data) that aid in estimating the biological and fishery processes in addition to providing information on abundance and mortality (Maunder and Punt 2013), and there are general programs to conduct these analyses (*e.g.* Stock Synthesis; Methot and Wetzel 2013). Unfortunately, these data are not available for some stocks and species.

For over fifty years, the IATTC staff, national agencies, and other organizations have collected detailed data on all aspects of the principal species of tunas (albacore, bigeye, Pacific bluefin, skipjack, and yellowfin) and of the fisheries in the EPO, making full assessments of these species possible. It has also undertaken research on some species caught incidentally in longline and purse-seine fisheries, including billfishes, dolphins, and sharks, but the quantity and quality of the data available for such species are much more variable, and in most cases insufficient for conventional assessments. There are also a large number of data sets that are collected for specific purposes (*e.g.* to test circle- vs. J-hooks in longline fisheries) and which may be useful for integrated stock assessments, but unless they are collected on a continuing basis, they may not be useful for SSIs. They also need to be representative of the whole stock being managed, which may not be the case for studies with limited spatial or temporal coverage.

The IATTC staff has conducted full assessments of the principal species of tunas, as well as of blue marlin, sailfish, striped marlin, and swordfish, but not of any bycatch species other than dolphins. It has also conducted productivity and susceptibility analyses (PSAs) to gauge the vulnerability of bycatch species to overfishing (Anonymous 2011), and has identified several which may be adversely affected by fishing (Figure 1); for example, many species of sharks, and some turtles and rays, which share general life history characteristics such as low reproductive rates and long lives. The PSA measures productivity of a species by identifying attributes such as high intrinsic population growth rate and maximum age that contribute to resiliency; and it measures susceptibility to fisheries by identifying attributes that moderate vulnerability such as seasonal migration and value. The results of the PSA may provide an initial set of candidate species for which developing indicators is a priority.

Indicators fill the void when data are insufficient for an assessment. The demand for SSIs has increased with the increased emphasis on ecosystem management (Garcia and Staples 2000) and with efforts to manage the tradeoffs between conservation and economic benefits (Cheung and Sumaila 2008), but the resources necessary for obtaining the basic biological and life history data required for full assessments for the multitude of bycatch species taken in fisheries are not available (Zhou *et al.* 2011). A triage system is needed to determine which species to focus on, particularly if new data need to be collected. The data available on bycatches is fishery-dependent, and quite varied in nature, scope and detail, and the development of indicators will require identifying what data are available and suitable for the purpose.

Evaluating sustainability using a SSI is possible only if the indicator can be evaluated against a sustainability-based reference point (Garcia and Staples 2000). Although no standard for stability or sustainability has been established, maximum sustainable yield (MSY) is the reference point for management by the Commission under the Antigua Convention. However, MSY is not the only possible objective of management. A fisheries management body could, for example, establish a regime that maintains the biomass of one or more stocks at levels below or above those required to achieve their respective MSYs, while simultaneously achieving MSY (or some other target) from another stock (Ricker 1975).

The IATTC staff has used SSIs for providing management advice on skipjack tuna since 2008 due to the inability to estimate their absolute abundance (Maunder and Deriso 2008). SSIs have also been proposed for silky shark (Aires-da-Silva *et al.* 2014). However, the SSIs used by the IATTC have not been validated and no formal reference points or harvest control rules based on these SSIs have been developed. The choice of SSI should take into consideration how it will be used to provide management advice. For example, will it be used in a formal harvest control rule or just to indicate that further investigation of the stock status is warranted? The use of SSIs for management advice will require extensive testing such as that conducted in management strategy evaluation (MSE; *e.g.* Punt *et al.* 2001).

The report is structured with several sections covering a number of general topics, including: 1) description and sources of existing data, 2) assessments and SSIs, 3) reference points and harvest control rules, and 4) general recommendations.

2. FISHERIES AND DATA

2.1. Fisheries of the EPO

About 90% of the documented catch of tropical tunas in the EPO is taken on the high seas by large purse-seine vessels, mostly from nations bordering the EPO, which mainly target yellowfin, bigeye, and skipjack tuna for canning. Large industrial longline vessels, predominantly flagged in the Far East, take most of the rest of the catch; they target albacore, bigeye, Pacific bluefin, and yellowfin tunas, as well as marlins and swordfish, and supply mainly the sushi/sashimi market. In the coastal regions of the EPO, smaller longline vessels, and gillnet, harpoon, and recreational fisheries also target tunas, marlins, swordfish, and sharks. All of these fisheries have bycatches of species other than those targeted.

The industrial fleets are generally monitored by governments and regional fisheries management organizations such as the IATTC, and detailed data on catch and fishing effort are compiled. The artisanal and recreational fisheries are generally not as well monitored, for a number of reasons, among them widespread landing locations, lack of licensing or landings reporting requirements, and relatively low direct economic value from trade.

The non-industrial fisheries, which use many gears, including handlines, longlines, and various types of seines, can exert considerable impacts on the stocks. For instance, the recreational fishery for billfishes off Baja California Sur and southern Mexico catches about 1,050 metric tons (t) of striped marlin annually (Hinton and Maunder 2011), about half the MSY, and more than the industrial longline and purse-seine fisheries in the northern EPO.

2.2. Data sources for EPO fisheries

Data on total catches (which include discards) are a key component for determining the status of a population, but they are unavailable for many of the species caught in the tuna fisheries in the EPO, particularly for bycatch species. Detailed data on bycatches in the EPO are available only for large purse-seine vessels. IATTC resolution C-03-05 outlines the type and spatio-temporal resolution of data that IATTC Members are required to provide to the Commission staff for the main tuna species as follows:

Category	Level	Resolution	Data
Catch and effort	1	Set-by-set, logbook data with information on gear configuration and target species	Total catch in numbers, and weight if available; fishing effort
	2	1°x1°–month, with information on gear configuration and target species	
	3	5°x5°–month, with information on gear configuration and target species	
Length frequency	1	Set position, start or end of set	Length or weight of individual fish
	2	Grid position, best possible spatial-temporal resolution of area of capture	

More detailed data are also often collected by Members and provided to the Commission staff on request.

2.2.1. Longline fisheries

The longline fisheries of the EPO are divided into those operating in or near coastal waters and those operating principally on the high seas.

2.2.1.a High seas longline

The vast majority of the large (> 24 m) longline vessels that operate in the EPO are from China, Japan, Korea, and Chinese Taipei, and target mainly albacore, bigeye, and yellowfin tuna, swordfish, and marlin.

The data available for these fisheries, mostly from national logbook and sampling programs, include data on fishing effort and catch, and sometimes data on length or weight of fish taken by time-area strata. Catch data for other species, if available, is generally pooled in categories such as 'shark' or 'other'. In 2013, the 5% coverage of these vessels by scientific observers mandated by Resolution C-11-08 was implemented, which will provide more detailed information on longline bycatches (Section 2.2.3a).

2.2.1.b Coastal longline

Artisanal and industrial longline fisheries taking tunas and a multitude of other species operate along the coast of the Americas from Mexico to Chile. Some target tunas, while in others tunas are an opportunistic catch. The full scope of the artisanal fisheries is not well known, though in places they may constitute a significant source of fishing mortality on a wide range of species. Compared to other regions, their operations in the EPO are relatively well documented as part of efforts to reduce incidental mortality of sea turtles (Largacha *et al.* 2005, Hall *et al.* 2008) and to develop information on fisheries for dorado and sharks (Martínez-Ortíz and Zúñiga-Flores 2012, Martinez-Ortiz 2012).

Surface longlines principally target tuna, billfish, sharks, and dorado, while bottom longlines target sharks and rays, snappers, and groupers. Fisheries at higher latitudes tend to fish for dorado in the summer, while those at lower latitudes are more opportunistic.

Nearly all the catch of these fisheries is utilized: in the Ecuadorian artisanal longline fishery, less than 0.5% of the catches is discarded (Largacha *et al.* 2005).

The data and their availability differ among nations. Several extensive data collection programs exist at the national level, and OSPESCA coordinates data collection at a regional level throughout Central America. Nonprofit organizations also collect data for special projects (*e.g.* the WWF circle- vs. J-hook study), which generally include more detailed data. The data collected includes catch for a number of species and, in many cases, effort and length-composition data.

2.2.2. Purse-seine fisheries

The purse-seine fishery in the EPO has been monitored directly by the IATTC since the 1950s, and recovered historical records of logbooks and landings of the pole-and-line fishery extend to the 1920s.

The fleet is divided into two categories, smaller vessels with carrying capacities of 363 metric tons or less, and large vessels with greater than 363 t carrying capacity. This differentiation is related to the ability of a large vessel to fish for tunas associated with dolphins. The smaller vessels fish generally closer to land, and their fishing areas generally do not significantly overlap with the high-seas regions fished by the large vessels (Figure 2). Some small purse seiners target Pacific bluefin tuna. The composition of the bycatches by the small vessels is unknown, but is probably different to that of the large vessels.

Three types of sets are made by purse-seine vessels, sets on unassociated schools, on floating objects (including fish-aggregating devices), and on tunas associated with dolphins. The spatial distribution of these set types is not homogeneous, and specific set types form the majority in sub-regions of the fishing grounds (Figure 3). The species caught also vary by set type. During 2008-2012, 99% of the catch of bigeye and 64% of the catch of skipjack was taken in floating-object sets, 35% of the skipjack was taken in unassociated sets, and 68% of the catch of yellowfin was taken in dolphin sets. The remainder of the yellowfin catch was split about equally between unassociated and floating-object sets (Anonymous 2013).

The principal sources of data on purse-seine fisheries other than the observer programs (section 2.2.3) are vessel logbooks, cannery unloading weights, and the IATTC port sampling program. Logbook records cover over 85% of the skipjack and 95% of the yellowfin landed, but contain little to no information on catches of non-target species or discards of tunas, and unloadings rarely contain non-target species. Data on small purse-seine vessels and the few remaining pole-and-line vessels in the fishery are obtained from logbooks.

2.2.3. Observer programs

Purse-seine vessels of carrying capacities greater than 363 t have been required to carry observers since 1992. In 2013, observers started covering some trips by industrial longline vessels.

2.2.3.a Longline observer program

IATTC Resolution C-11-08 requires that, as of 2013, at least 5% of the fishing effort by each Member's longline vessels greater than 20 m in length overall be monitored by scientific observers. It specifies that the observers' main task is to record "any available biological information, the catches of targeted fish species, species composition and any available biological information as well as any interactions with non-target species such as sea turtles, seabirds and sharks." It also requires that the Director, in cooperation with the Scientific Advisory Committee, "draw up a common reporting format detailing the required data to be collected by scientific observers".

Various IATTC members, including China, Japan, Korea, and Chinese Taipei, have deployed observers on longline vessels in the EPO in support of fisheries investigations and research, and reports of activity in 2013 have been received from China, Japan, and the United States[1]. Japan has placed observers on a number of longline fishing trips in the EPO during 2007-2013, and a European Union observer program monitors the fishery for swordfish by Spanish longline vessels in the EPO, compiling data on catch, effort, size frequencies, and bycatch (Mejuto and García-Cortes 2001, 2005). The United States operates an observer program to monitor interactions between longline vessels and protected species, particularly sea turtles, in the Pacific, but these vessels operate mainly outside the EPO.

These observer programs collect a variety of information, including catches of target species, interactions with non-target species, details of fishing operations (dates, times, duration, and location), vessel attributes, gear configuration, and bycatch mitigation measures.

2.2.3.b Purse-seine / AIDCP Observer Program

The AIDCP observer program, which covers all trips by large purse-seine vessels in the EPO, is the principal source of information on bycatches of non-target species in purse-seine fisheries in the EPO (Anonymous 2013).

Originally, data were recorded for only 22 species and five groups of identified species (Table 1). Observers have collected data on flotsam since 1987, billfishes since 1989, sea turtles since 1990, bycatch since 1993, and sharks since 2004. Not all the national observer programs have always collected complete bycatch data, but since 2009 bycatch data have been collected for every set made by every vessel operating under the program (Figure 4, Table 2). All programs now use a common data format.

It is important to note that observers have direct access only to bycatches that remain on the deck after the completion of a set. Most bycatch is dumped overboard as soon as it is brought aboard, which prevents access to confirm species identifications and contributes significantly to imprecision in estimates of numbers of individuals.

Whenever possible observers record:

1. Identification of individuals to species or species group;
2. Characteristics used to make the identification of billfish, sharks, and turtles;
3. The number of individuals (tons for tunas) by size category (small, medium, and large); and
4. Length measurements of billfishes (since late 1988) and sharks (since late 2004).

[1] China: http://iattc.org/Meetings/Meetings2014/MAYSAC/PDFs/SAC-05-INF-C-China-observer-annual-report-2013.pdf
Japan: http://iattc.org/Meetings/Meetings2014/MAYSAC/PDFs/SAC-05-INF-B-Japans-scientific-observer-program-for-tuna-longline-fishery.pdf
United States: http://www.iattc.org/Meetings/Meetings2014/MAYSAC/PDFs/SAC-05-INF-G-United-States-observer-program-annual-report-2013.pdf

Originally, observers recorded bycatches of fauna other than billfishes, sharks, and turtles in either numbers of fish or tons, but since 2004 they report all species in numbers, except for tunas, which continue to be reported in tons. Therefore, pre-2004 data recorded in tons need to be converted to numbers in order to present long-term trends in catch or catch rate, using the three-category size classification (small, medium, and large). Because the range of lengths of marine species is so large (from an average of 50 cm for triggerfish to 300 cm for blue marlin, for example), two levels of this size classification are used to improve the accuracy of the data collected using this scale. Observers estimate these sizes by eye, so their precision is low.

	Small	Medium	Large
Tunas	<2.5 kg	2.5 - 15.0 kg	>15.0 kg
Billfishes, sharks, rays	<90 cm	90 - 150 cm	>150 cm
All other species	<30 cm	30 - 60 cm	>60 cm

There have been changes in the nature and quality of information collected by the observers, thus time series may be inconsistent or biased over certain time periods. For instance, originally only individuals killed were recorded causing a negative bias in estimated catch-per-unit-effort (CPUE), but since 2005 observers are required to record all bycatches and their subsequent disposition. For some species, particularly sharks, observers might record individuals showing any sign of life when returned to the sea as alive, but a recent study (Poisson *et al.* 2014) found that some 50% of the silky sharks brought on board in purse-seine operations and released "alive" subsequently died, resulting in an underestimate of mortality.

Misidentification of species is a standing problem in the observer data. The causes vary: for instance, Román-Verdesoto and Orozco-Zöller 2005 report that during 1993-2004, observers taking species identification cues from Spanish-speaking fishermen recorded silky sharks (*Carcharhinus falciformis*) as "*punta negra*", blacktip, which is the English common name of *C. limbatus*.

Misidentification of species also occurs when observers are unable to discern identifying characteristics, as for instance when they have to make identifications from afar, or from few samples, thus missing the rare species in a mix. For example, the common dolphinfish or dorado (*Coryphaena hippurus*) reaches maximum sizes of about 210 cm, while the pompano dolphinfish (*C. equiselis*) reaches only about 50 cm. However, externally a small common dolphinfish is nearly indistinguishable from a pompano dolphinfish, and without close access to samples, observers cannot reliably separate the two species. Also, since the pompano is less common in catches, a large number of individuals need to be examined to obtain precise estimates of the number of this species. Other well-documented examples of misidentification include black marlin (*Istiompax indica*) identified as blue marlin (*Makaira nigricans*), and rainbow runner (*Elagatis bipinnulata*) identified as yellowtail (*Seriola* spp.). Such possible misidentifications must be taken into account when analyzing bycatch data from observers.

2.2.4. Recreational fisheries

There is little documentation on the recreational fisheries for tunas and billfishes in the EPO. The best-known target billfishes, principally marlin off Baja California Sur and the central coast of Mexico (Fleischer *et al.* 2009), and sailfish off Central America from Guatemala to Panama (Ehrhardt and Fitchett 2006). There are also recreational fisheries for tuna, particularly Pacific bluefin and yellowfin, off the coast of north-central Baja California, Mexico. All vessels participating in the Mexican recreational fishery are required to provide logbook data to the Instituto Nacional de Pesca (INAPESCA) of Mexico, which monitors the fishery, compiles and analyzes logbook data, and maintains port sampling programs. The data collected include catch, in number of fish, by species and sex, effort, in number of trips, and statistics from size measurements, by port.

Self-reported data on catch and effort of the recreational fishery in southern California are compiled by the California Department of Fish and Game. The IATTC for some years obtained size-frequency samples of Pacific bluefin and occasionally of yellowfin tuna landed by this fishery in San Diego, California, but samples are no longer being taken.

The billfish research program of the U.S. National Marine Fisheries Service's Southwest Fisheries Science Center conducts the annual International Billfish Angling Survey, which obtains self-reported catch data by species and effort from billfish anglers in the Pacific. Individual weights of striped marlin taken in the recreational fisheries of southern California have been recorded by the San Diego Marlin Club since 1960 and the Balboa Angling Club since 1945.

3. STOCK STATUS INDICATORS

Arguably, the best indicators of sustainability and status of stocks are assessments conducted using integrated (fitted to many different types of data) population dynamics models such as Stock Synthesis (SS, Methot and Wetzel 2013), a sex-specific, size-based, age-structured, integrated statistical stock assessment model. When data are insufficient for models such as SS, a next-best option is a production model, such as the Age-Structured Production Model (Restrepo and Legault 1997) or the Deriso-Schnute Delay Difference model (Quinn and Deriso 1999). As fewer and fewer data are available, the nature of indicators changes and the number that might be used decreases. In data-limited cases, the SSIs may be based simply on time series of data (*e.g*. CPUE or average size).

3.1. Catch-based indicators

Catch-based indicators are perhaps the least data-intensive methods. For many species catch is the only data available, but often the data are incomplete. Due to the focus on ecosystem-based management and the requirement to assess all species, there has been a proliferation of catch-based indicators. Many of these methods are simple ways to set "sustainable" quotas. They can vary from simple averages of historical catch to more sophisticated methods like depletion-corrected average catch. Other approaches look at the trend in catch to determine if it has been sustainable and, in simple terms, treat a decline in catch as an indication that the population is over-exploited. However, some of the catch-based methods need a time series of catch data going back to when exploitation began, which prevents their use in many cases.

Carruthers *et al.* (2012) evaluated the reliability of two catch-based indicators (Froese and Kesner-Reyes 2002, Kleisner and Pauly 2011) for correctly identifying stock status. They simulated populations with various biological characteristics and with various exploitation histories, and found that, on average, these indicators were incorrect about 67% of the time and that estimates of status were negatively biased, *i.e*. more pessimistic than was the reality. These findings were consistent with those of Branch *et al.* (2011) and others regarding the reliability of catch-based indicators.

No matter which SSI method is used, without an estimate of total catch, it is difficult to estimate potential yield or yield-based management parameters that depend on catch, such as MSY. Frequently, there are no reliable estimates of the total catch (retained catch plus discards) or retained catch of a bycatch species. In some instances, such as with the principal tuna species, the retained catch is so large in comparison that including the discards would not change the results of the assessments.

3.2. Presence-only and presence/absence indicators

For some bycatch species presence/absence in the catch is known, but patchiness in the data causes errors in the assumed proportional relationship between CPUE and abundance. The predictive ability of presence/absence-based models is often low and therefore in many instances misleading (Manel *et al.* 2001). This is the case particularly in regions such as the EPO, where the location and abundance of the populations shift over time (Manel *et al.* 2001) (Section 3.1). Frequently, applications of these models has been inappropriate (Pearce and Boyce 2006), and two of their properties that may impact their use for the EPO and which need further investigation are (1) observations of presence are directly impacted by variation in abundance (Royle and Nichols 2003), and (2) there is no information on locations where a species is absent (Manel *et al.* 2001). Indices based on presence/absence data may be hyper-stable if the range does not contract with abundance (*e.g.* school size decreases faster than the number of schools).

3.3. Catch-rate-based indicators

CPUE data are often assumed to be proportional to abundance, and are therefore used to evaluate trends in abundance. There are many factors other than abundance that can influence CPUE (*e.g.* season, area, fishing method, environmental conditions) and it is therefore common to "remove" these influences by standardizing the CPUE by these factors (Hinton and Maunder 2004). Unfortunately, for many fisheries the detailed data needed to standardize the CPUE is not recorded. Even if it is available, data for the most influential factors may not be available. In addition, Harley *et al.* (2001) showed that most indices of abundance derived from CPUE are hyper-stable and will underestimate declines in abundance. Survey data are more reliable because they have a standardized design and are less impacted by these factors, but they are only available for a limited number of stocks.

3.4. Age- and length-based indicators

Length is a comprehensible, natural and easily-obtained measure of a fish, and length-frequency data are easily collected. However, it is less informative than age data, which are more difficult to obtain. Changes in age- and length-frequency distributions indicate changes in a population, but do not translate directly into status indicators. In general, higher exploitation rates cause the fish to die before they can grow large, therefore decreases in the size of fish (*e.g.* average length) might indicate high exploitation rates. However other factors, like a large recruitment or an increasing trend in recruitment, could also translate into smaller-size fish. The indicators could be based on time series of size-based statsitics (*e.g.* average length) or comparison of current size to factors such as size at maturity, or more model-based factors such as the size that maximizes yield per recruit, which require biological information (*e.g.* growth and natural mortality).

Froese (2004) presents a simple SSI based on length which, if correctly implemented, would allow all fish to reproduce once, and harvest them at within 10% of the optimum length. It requires information on the proportion of mature fish in the catch and the proportion of the catch caught at the optimum length, neither of which is available for most of bycatch species. Cope and Punt (2009) conducted a detailed evaluation of this indicator in the management scheme of the U.S. West Coast groundfish fishery, and found that under certain circumstances it may encourage overfishing.

Punt *et al.* (2001) found that the length-based indicators were imprecise, but performed better than did catch-rate-based indicators (Sec. 3.3 above).

3.5. Mortality-based indicators

Age- or length-frequency data can be used to estimate the mortality history of a population. Catch-curve analysis is commonly used for estimating total mortality from age-composition data. Several methods have been developed to calculate mortality from size-based data. For example, Gedamke and Hoenig (2006) derived a method to estimate the non-stationary mortality rate history of a fishery using such data, and showed that this provides a means of determining the rate of increase or decline in a population and changes in fishing mortality. Historical records of mean lengths are often available, so this method could be used to reconstruct the fishing mortality history of a population. However, these approaches typically include a number of implicit assumptions (*e.g.* constant recruitment and fishing mortality) that are not necessarily satisfied.

4. SPATIAL AND TEMPORAL STRATA

Spatial patterns and distributions of populations need to be taken into account when developing assessments and indicators. Since both assessments and indicators are usually based on fisheries data, they provide information on only that portion of a population that is vulnerable to fishing. The spatial distribution of the fleet and the population may change over time, complicating the interpretation of SSIs.

In the case of the fishery for tunas in the EPO, we are faced with "… the least tractable [of] populations,… pelagic species which appear in varying proportions in different parts of their range in different years" (Ricker 1975).

Therefore, spatial and temporal structure must be considered when developing assessments or indicators for populations impacted by the tuna fisheries of the EPO, regardless of whether the indicator is based on catch rate or on another measure. If indicators from various areas and times are synchronous and proportional, then a single indicator using data from all strata may be considered for use, but is unlikely that this will be the case for a widely-distributed pelagic population.

Data-collection programs are designed in order that the information obtained will be representative of the removals from the population, and thus of that portion of the population subjected to the fishery. In many instances, what appears to be a single population is in fact a number of populations or stocks: for instance, genetic analyses have confirmed that striped marlin (Hinton 2009, Purcell and Edmands 2011) and swordfish (Hinton and Deriso 1994, Alvarado Bremer *et al.* 2006) in the EPO consist of multiple stocks that do not share reproductive areas, although sometimes the catch from a particular area will include individuals from multiple stocks.

The distributions of silky shark characteristics in purse-seine catches provide an example of the unique spatial distributions of set types in the EPO and of the spatially-differentiated distributions of characteristics of individual species and of bycatch community structures. Small silky sharks are caught mainly in floating-object sets in the northern EPO (Figure 5); they are rarely caught in the southern EPO, and rarely seen in dolphin or unassociated sets in the same areas in which they appear in floating-object sets. It is not known whether the population of silky shark in the EPO consists of one or two stocks, but in either case the spatial properties of the population must be considered when developing an SSI for the species.

Combining multiple stocks into a single indicator may result in the more vulnerable stock being overexploited. Therefore, it is important to identify the different stocks and provide indicators for each stock so that it can be managed seperately. There are a variety of definitions of stock structure and methods for identifying it. However, the focus should be on stock structure that is important in a management context and not in a purely biological sense. For example, it might be important to manage separately stocks that are not genetically distinct because of a small exchange of genetic material if fishing on one stock has little effect on the other stock. Lennert-Cody *et al.* (2013) developed methods to determine stock-structure based on differences in CPUE and length composition, but it is not clear whether these methods define stock units appropriate for SSIs.

5. APPLICABILITY AND LIMITATIONS OF METHODS TO EPO POPULATIONS

The detailed data available for target species in the EPO tuna fisheries make it possible to use most of the indicators described above. Which indicator to use should be determined by testing it in the setting of the EPO tuna fisheries. They also make it possible to examine the stability of indicators for species with similar life histories and behavior or distribution patterns. The performance of an indicator for tunas would perhaps indicate how it would perform for pelagic schooling species such as rainbow runner.

Catch-based SSIs are generally highly inaccurate and negatively biased (Sec. 3.1 above). Data on total catch are generally not available for EPO bycatch species, particularly for those species that may be caught in high numbers in fisheries not monitored by the IATTC. Therefore, catch-based methods are not considered further.

Age data other than that used for specific growth studies is not available for species in the EPO, and are therefore not considered further.

Length-composition data are available for the main target species and for a few bycatch species, and SSIs based on such data are possible candidates for these species. However, the three size categories used by observers (small-medium-large, in two size ranges) are of little use in analyses: for many species the majority of observations fall in only one or two of the categories, and it is unlikely that these data will produce useful SSIs.

Since observers do not have access to the majority of the bycatch, it is likely that they often do not record the presence of a species in the discards. This may make presence-only or presence/absence models imprecise and potentially unsuitable as indicators for relative abundance or SSIs. Also, without access to the majority of the bycatch, there is no set method for estimating the number of fish being discarded. Consideration needs to be given to this problem because, without such a standard, the data become only a record of presence of a species in the catch with negative bias.

The data available are often not of sufficient quality for computing indicators based on catch rates. This is particularly true of species of lower economic value to the fisheries. Nevertheless, catch-rate indices from the purse-seine fisheries may be one of the only SSIs for most bycatch species. The unit of effort used in the assessments of target species is day fishing, which is essentially a measure of search time. However, vessels are not searching for bycatch species, which may or not be associated with schools of target species and which may have spatial and temporal distributions significantly different than those of the target species. Therefore, purse-seine CPUE measures for bycatch species should not be expected to be directly proportional to search-time-based measures of effort, but may be proportional to set-based measures of effort. An SSI based on catch-per-set (CPS) should be considered for bycatch species. Note also that the number of sets that can be made in a day is fairly constant, so there is some correlation between the catch-per-day and catch-per-set for a given abundance level. In this situation it may be expected that an SSI for target species that is based on catch-per-set would provide results consistent with an SSI based on catch-per-day fishing.

Tagging data could also be used for developing SSIs, but are only available for the main target species, which are generally assessed using conventional stock assessment models.

5.1. Catch-rate-based indicators for skipjack and yellowfin tunas

Catch-rate-based indicators were developed for yellowfin and skipjack tuna. These species were chosen because high-quality data for these species are available to develop SSIs, and because the results of IATTC stock assessments are available against which to gauge SSI performance. Indicators using set-based effort were choosen over those using search-time-based effort because it was desireable to see performance of an indicator which might be considered for use on a bycatch species.

The annual effort-weighted-average nominal CPS in tons, and the quantiles of the annual distributions of the nominal CPS were compared to the trends in the stock biomass (*B*) of skipjack and of yellowfin tuna, and to the spawning biomass ratio (SBR) of yellowfin, which were obtained from the most recent stock assessments for these species. The decision to use quantiles of CPS was based on a schooling mechanism. As population size increases, the likelihood that schools will encounter other schools and merge into yet larger schools increases resulting in increased numbers of large schools and the likelihood of a vessel encountering schools with relatively high biomass increases. Thus, there is a positive correlation between quantiles of CPS and population biomass (*cf*. Willis' [2008] simulation of a universal schooling model with southern bluefin tuna).

The average size of the fish in the catch varies by set type, with the smallest fish taken in floating object sets, the largest fish taken in dolphin sets, and intermediate-sized fish taken in unassociated sets. These differences reflect the differences in age groups of tuna that are taken by each set type, and as the age structure of the population changes over time, it may be expected that an indicator based on catches pooled across set types would vary due to the proportion of each age group in the population as well as due to shifts in the distribution of sets-by-type. Therefore the indicators were developed by set type.

For yellowfin, the annual median nominal CPS in dolphin sets outperformed the other SSI candidates for both B_t and SBR_t. Trends in B_t and SBR_t of yellowfin, and in the two indicators, annual nominal median CPS and effort-weighted-average nominal CPS, are shown in Figure 6.

For skipjack tuna, the 70^{th} quantile of nominal CPS in floating-object sets outperformed the other SSI candidates. Trends in B_t of skipjack and indicators are shown in Figure 7.

5.2. Catch-rate-based indicators for bycatch species

The data available for bycatch species are usually insufficient for estimating catch per set. However, the encounter rate of a species is positively correlated with abundance, so it is likely that a bycatch species that is relatively abundant and widespread in the fishing area will be seen and recorded in at least one set during a fishing trip. This suggests that it may be reasonable to use a trip as the unit for effort in a catch-rate-based indicator of abundance for a number of bycatch species, despite problems of species identification and lack of access to the fish.

Two indicators, one based on the number of fish taken per set and the other on the proportion of trips on which the species was observed, were computed for a number of species. Representative results for two of these species are shown in Figure 8. Wahoo (*Acanthocybium solandri*) was chosen because it is readily identifiable and that has been recorded since the beginning of the AIDCP observer program. Dolphinfish was chosen because the genus consists of two species that are difficult to distinguish and were originally recorded at the genus level (*Coryphaena* spp.), but which since late 2004 have been recorded by species (*Coryphaena hippurus* and *C. equiselis*) (Section 2.2.3b). For both species, the trends for each indicator are clearly different. The reasons for the difference are hard to determine: both of these species school, and changes in the probability of detection would be expected to trend with abundance, but this does not appear to be the case. It may be related to the fact that observers do not have access to bycatches until the set is completed, which may affect the probability of detection.

Any catch-rate-based indicator should be evaluated for performance in the setting in which it will be used. Punt *et al.* (2001) caution that, in Australian swordfish fisheries, catch-rate-based indicators performed extremely poorly in comparison to length-based indicators, probably due to the variability in the nominal catch-rate series used and to the fact that swordfish was not a target species in the Japanese longline fishery whose data they analyzed. Using standardized catch rates may improve performance.

6. REFERENCE POINTS AND HARVEST CONTROL RULES

SSIs may be a useful measure of stock status, and can be used in isolation to look at trends in status and compare current status to historical status, but they may not provide a measure of status with respect to the unexploited population. Each SSI requires a measure that it can be compared against to determine the status of the stock. Results from stock assessments are compared against standard target and limit reference points such as B_{MSY} and F_{MSY}. However, equivalent reference points may not be available for most SSIs. In addition, SSIs and reference points are of little use, difficult to define, and hard to understand unless the action to be applied when the SSI-based reference point has been exceeded has been defined.

One obvious interpretation of SSIs and consideration in the development of relevant reference points is that if the SSI was at a particular level in the past and the stock did not “collapse”, then as long as that level is not exceeded the stock is “safe”. This assumption and interpretation may be reasonably general for a number of SSI time series. Other reference points may be suitable for a particular SSI, such as the use of average length as a SSI and age at maturity as a reference point. It is expected that reference points will be specific to the data available and the objectives of the management. The reference point will also depend on the management action to be taken when it is exceeded. In any case, the SSI, reference point, and harvest control rule, if used, should be fully tested, using management strategy evaluation (MSE).

7. SUMMARY OF POINTS AND RECOMMENDATIONS

1. Indicators should be developed, and evaluated for performance and reliability prior to adoption. Standards for these evaluations need to be established.
2. The IATTC Productivity and Susceptibility Analysis (PSA), which identifies species expected to be

vulnerable to fisheries, such as most of the sharks taken in the purse-seine fisheries, should be taken into account when establishing priorities for developing indicators.

3. Priority should be given to changes in the experimental design of the purse-seine observer program in order to obtain data needed for developing indicators; for example, collecting data on whether species are present rather than on the size of discarded fish.
4. Assign specific tasks to observers on an *ad hoc* basis to obtain the data needed for developing indicators for a given species, as was done for billfish size-frequency data.
5. When developing SSIs, the spatial and temporal structure and distribution of the pelagic resources of the EPO should be taken into account, since this may at times result in local depletions of a population that indicators may help to identify.

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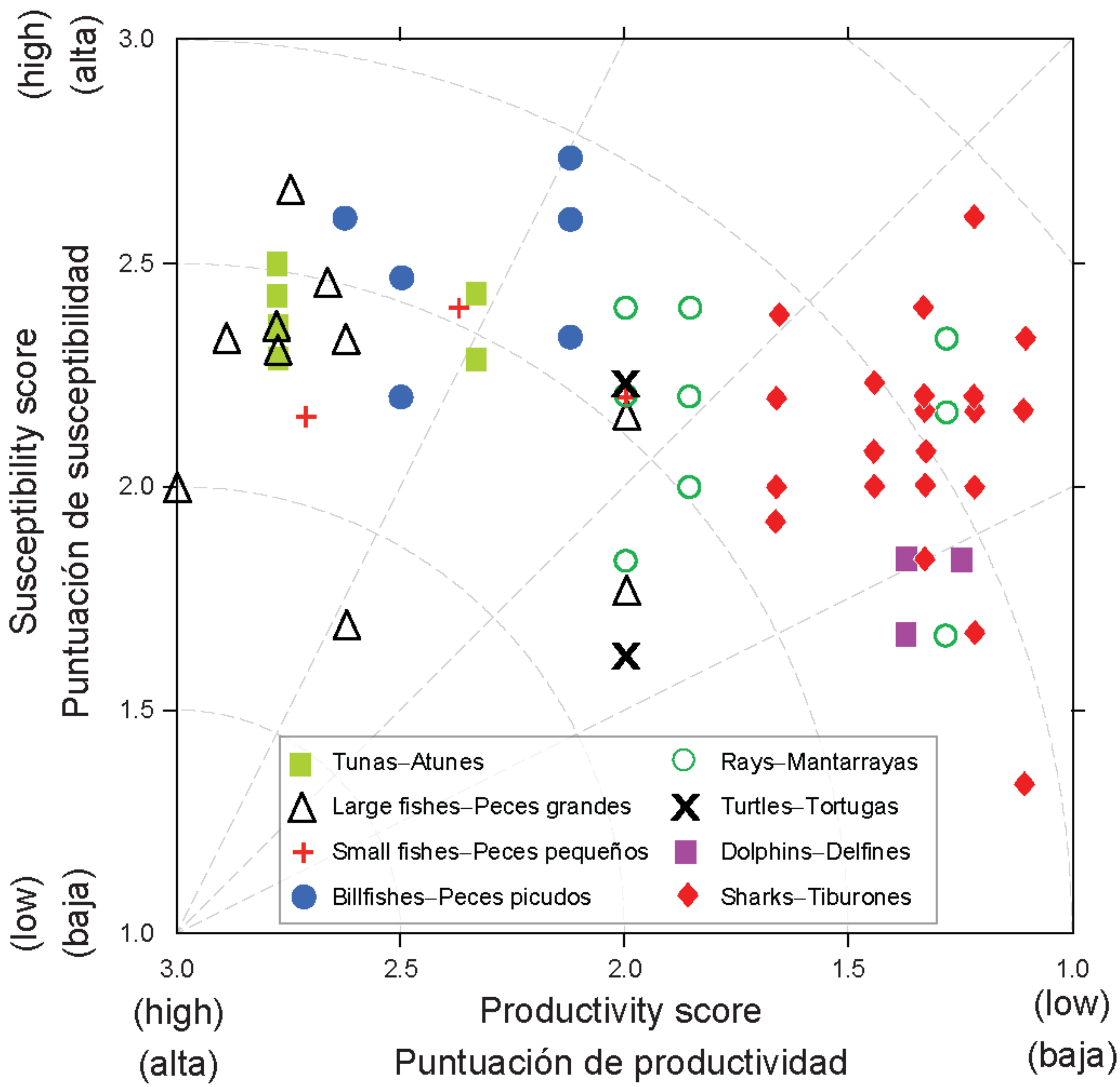

FIGURE 1. Productivity and susceptibility x-y plot for target and bycatch species caught by the purse-seine fishery of the EPO during 2005-2011. (From SAC-05-13 Fig. J-4. See SAC-05-13 Table J-1 for Group definitions)

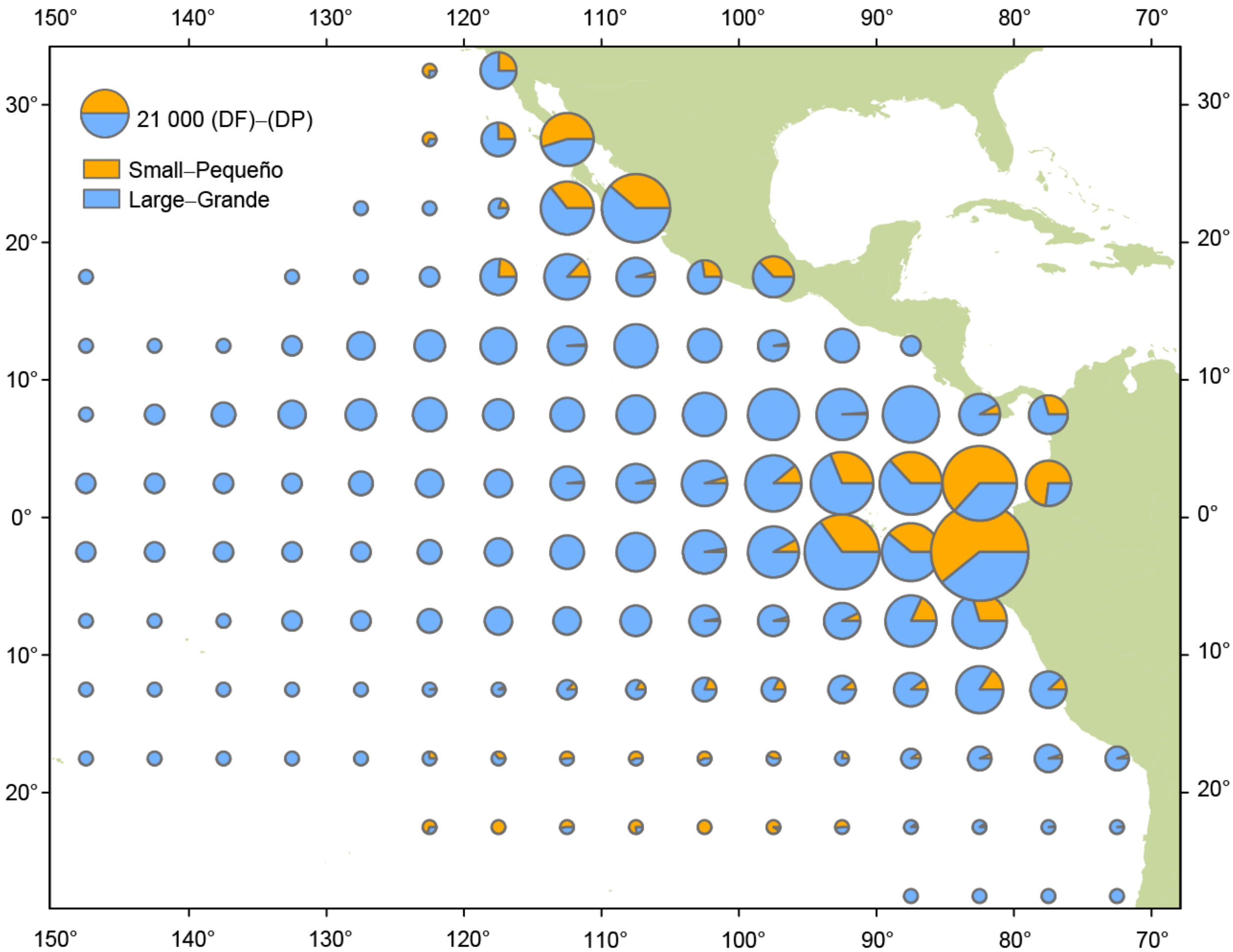

FIGURE 2. Total days fishing (DF) during 1995-2012 by small (carrying capacity ≤363 t) and large (carrying capacity >363 t)) purse-seine vessels, by 5° x 5° area. The size of the circles is proportional to the effort.

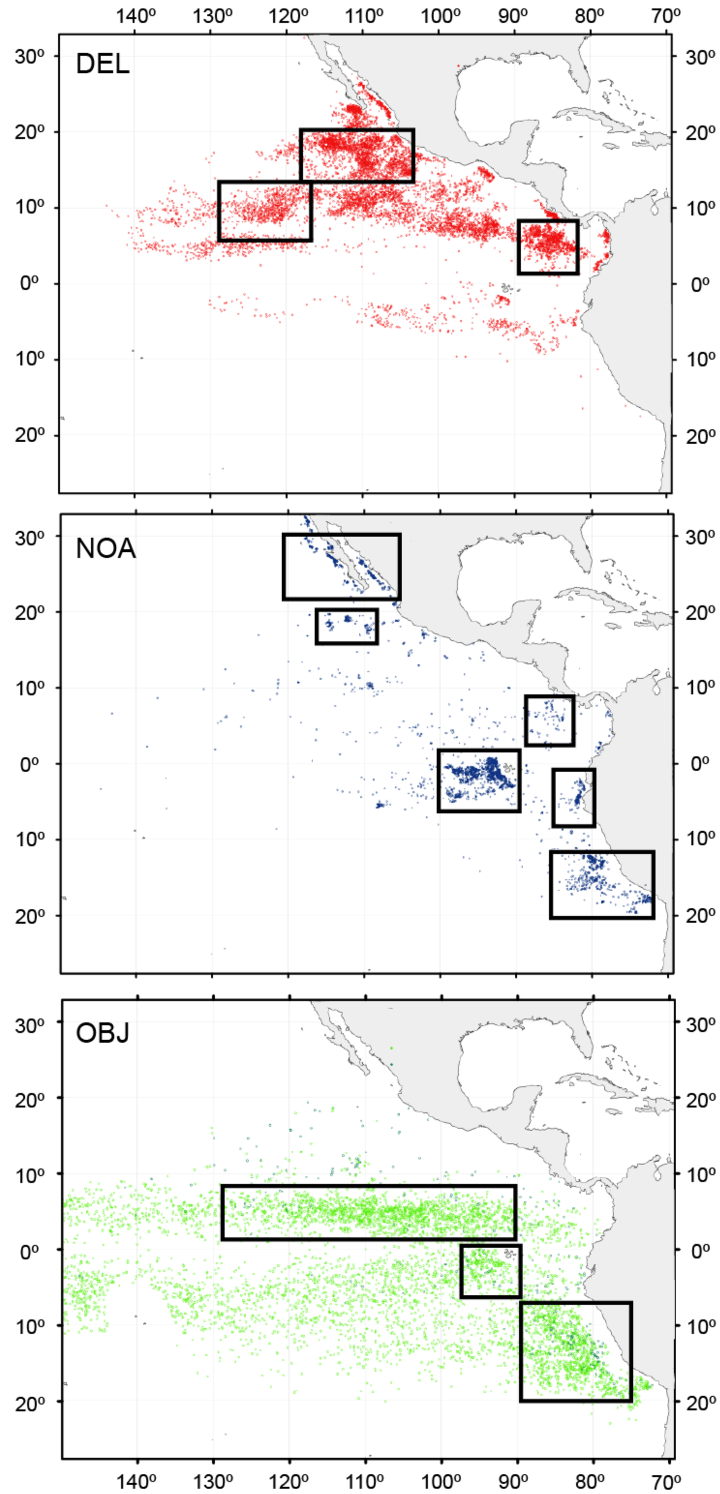

FIGURE 3. Distribution of sets by type in 2011, and principal areas in which bycatch species composition may be expected to differ within set type.

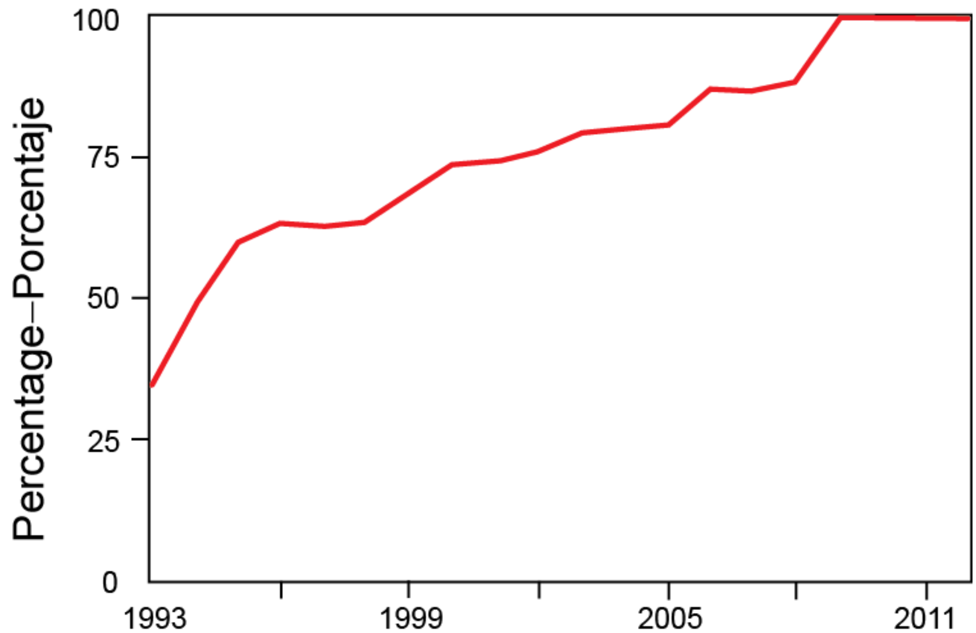

FIGURE 4. Percent of trips by large (carrying capacity > 363 t) purse-seine vessels in the eastern Pacific Ocean for which observer records of bycatch and discards are available, 1993-2012.

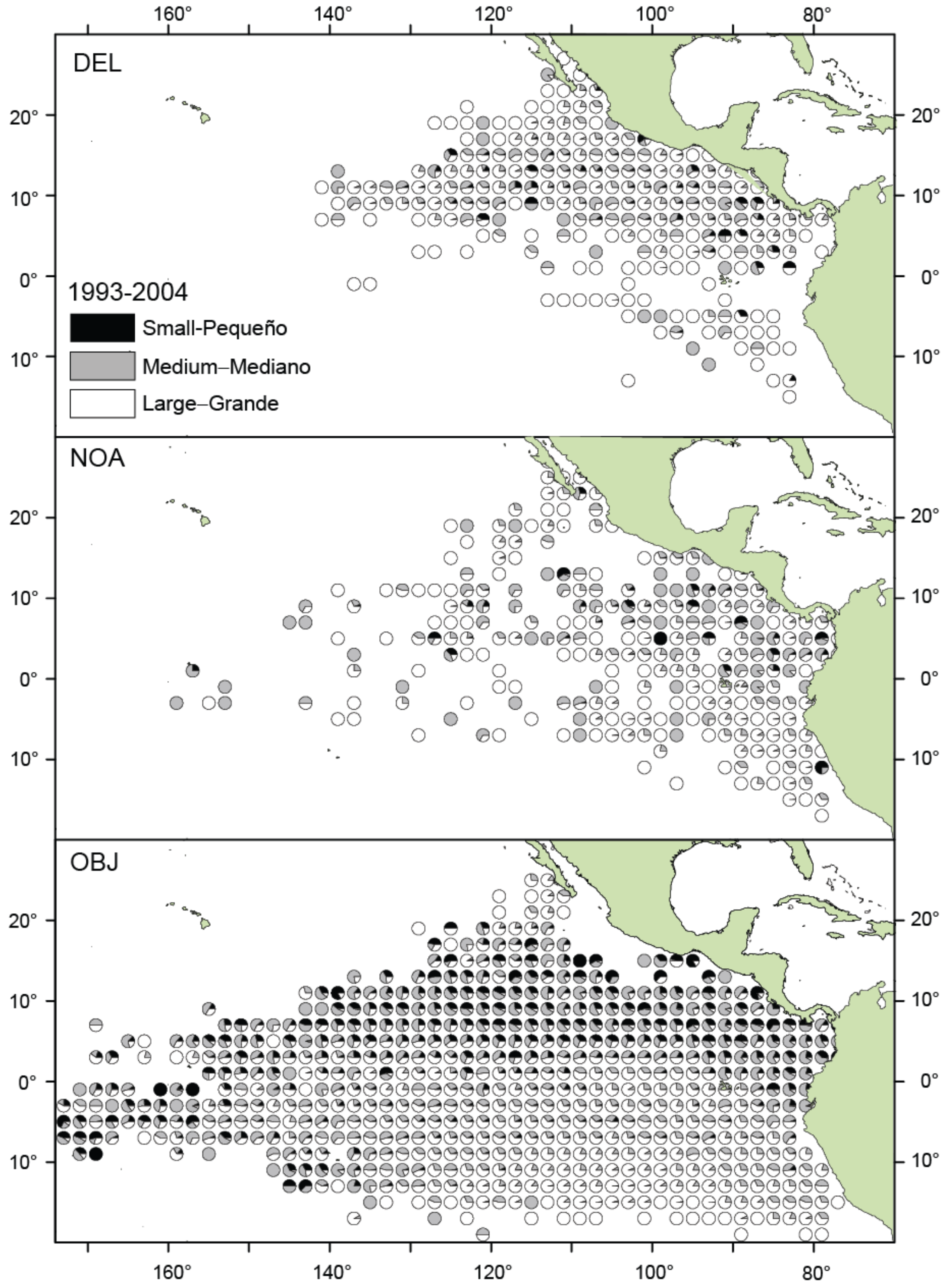

FIGURE 5. Sizes of silky sharks caught in purse-seine sets, by set type and by 2° x 2° area, 1993-2004 (from Román-Verdesoto and Orozco-Zöller 2005)

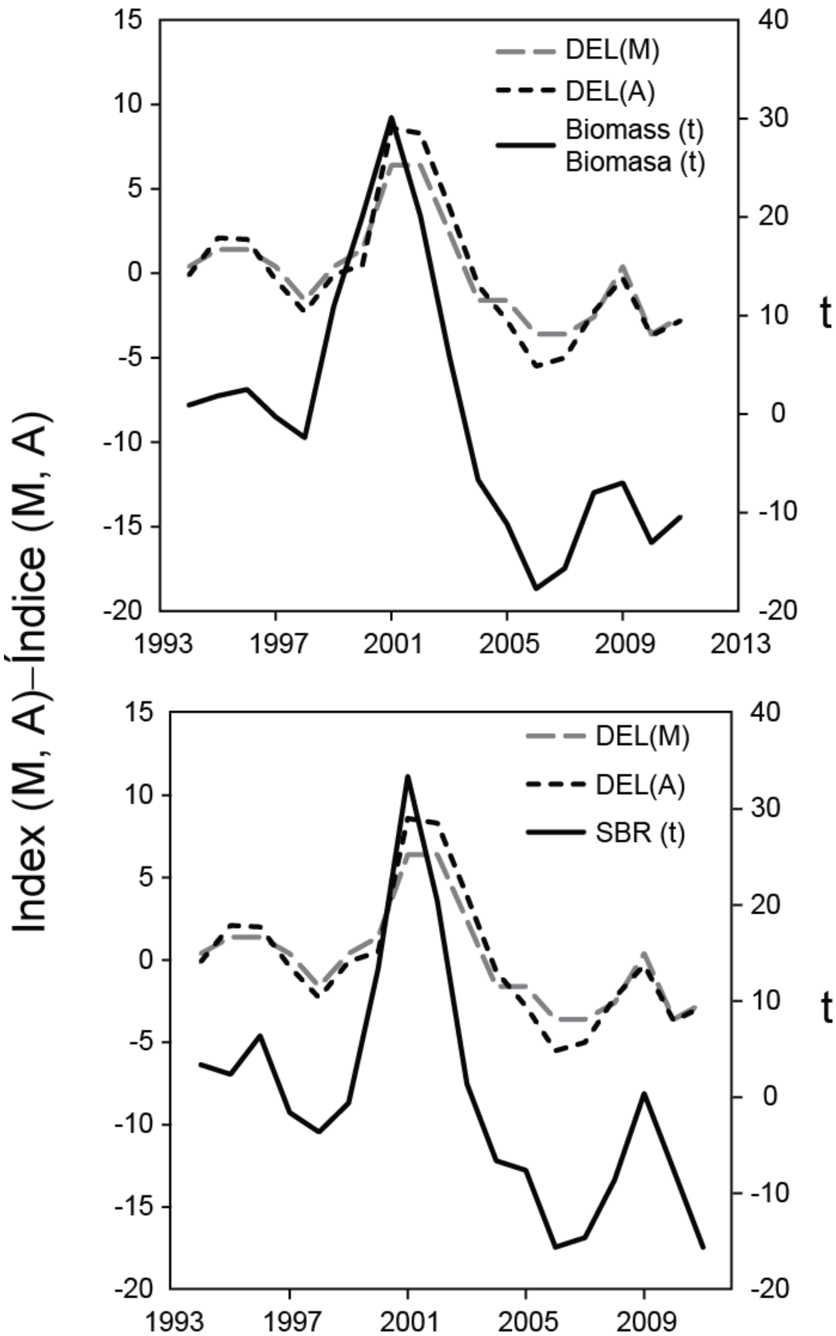

FIGURE 6. Trends in (a) nominal median catch per set and (b) weighted-average nominal catch per set, in dolphin sets, and the biomass (B: upper panel) and spawning biomass ratio (SBR: lower panel) from the 2012 yellowfin stock assessment. Values were scaled to the respective series average.

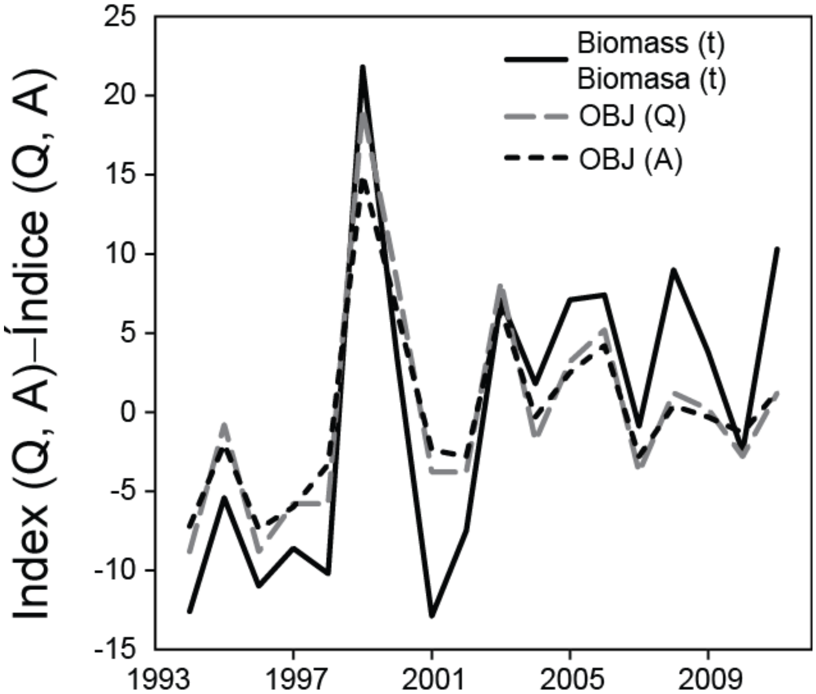

FIGURE 7. Trends in the 70th quantile nominal catch per set [OBJ(Q)] and the weighted-average nominal catch per set [OBJ(A)] for floating-object sets, and the stock biomass from the 2012 skipjack assessment. Values were scaled to the respective series average.

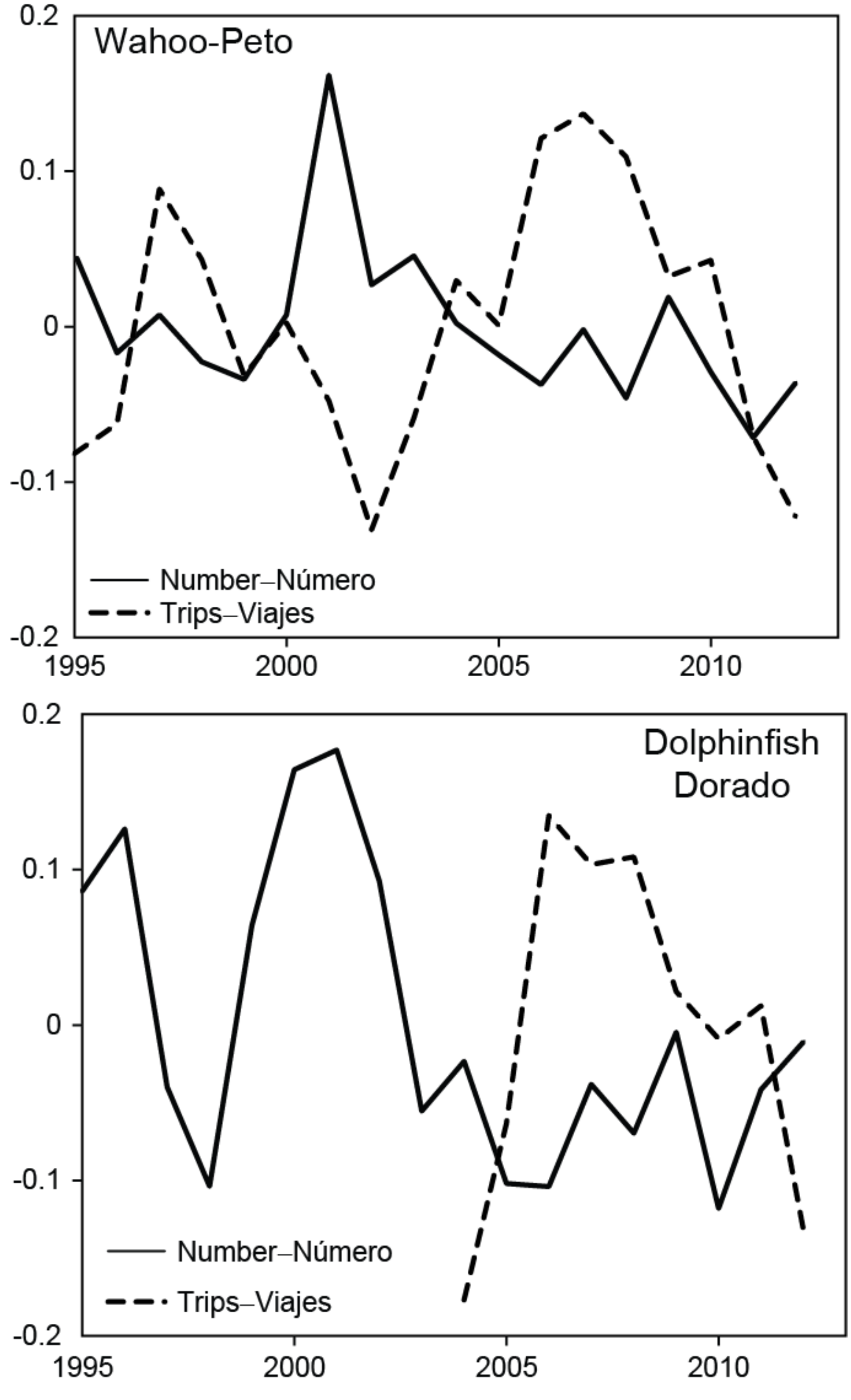

FIGURE 8. Trends of the nominal catch-in-numbers per set and in the proportion of trips with observations of a species, for wahoo and dolphinfish, 1995-2012. For dolphinfish, the 2004-2012 series Trips includes only common dolphinfish, which provides a comparison to the common dolphinfish-dominated series (Number) of *Coryphaena* spp. (common and pompano) over the same period. Values were scaled to the respective series average.

TABLE 1. Bycatch species and species groups, other than marine mammals, recorded at the inception of the bycatch monitoring program.

Group / Common Name	Scientific Name
Fishes	
Black marlin	*Istiompax indica*
Blue marlin	*Makaira nigricans*
Dorado / Dolphinfish	*Coryphaena* spp.
Rainbow runner	*Elagatis bipinnulata*
Sailfish	*Istiophorus platypterus*
Shortbill spearfish	*Tetrapturus angustirostris*
Striped marlin	*Kajikia audax*
Swordfish	*Xiphias gladius*
Triggerfishes	Balistidae, Monocanthidae
Wahoo	*Acanthocybium solandrii*
Yellowtail	*Seriola* spp., *Caranx* spp.
Sharks and rays	
Blacktip shark	*Carcharhinus limbatus*
Hammerhead shark	*Sphyrna* spp.
Manta rays	Mobulidae
Oceanic whitetip shark	*Carcharhinus longimanus*
Silky shark	*Carcharhinus falciformis*
Stingray	*Dasyatis violacea*
Turtles	
Green (aka black) turtle	*Chelonia mydas*
Hawksbill turtle	*Eretmochelys imbricata*
Leatherback turtle	*Dermochelys coriacea*
Loggerhead turtle	*Caretta caretta*
Olive ridley turtle	*Lepidochelys olivacea*
Other	
Invertebrates	Invertebrata
Other identified	Large fish; Shark; Small fish
Unidentified	Billfish; Fish; Shark; Turtle

TABLE 2. Bycatch species and species groups recorded by observers in 100 or more sets by large purse-seine vessels on trips departing during 1995-2012.

English	Spanish	Scientific name	No. of sets
Wahoo	Peto	*Acanthocybium solandri*	74,528
Common dolphinfish	Dorado común	*Coryphaena hippurus*	47,563
Dolphinfish, mahi mahi nei	Dorado nep	*Coryphaena* spp.	42,723
Silky shark	Tiburón sedoso	*Carcharhinus falciformis*	35,147
Rainbow runner	Salmonete, salmón	*Elagatis bipinnulata*	22,234
Triggerfishes, filefishes nei	Pez puerco, lija	Balistidae, Monocanthidae	21,554
Blue marlin	Marlín aguja azul	*Makaira nigricans*	16,096
Ocean triggerfish	Pez puerco	*Canthidermis maculatus*	15,768
Silky or Blacktip shark	Tiburón sedoso o punta negra	*Carcharhinus falciformis, C. limbatus*	11,387
Oceanic whitetip shark	Tiburón punta blanca oceánico	*Carcharhinus longimanus*	9,683
Black marlin	Marlín aguja negra	*Istiompax indica*	9,463
Yellowtail nei	Jurel	*Seriola* spp., *Caranx* spp.	7,411
Tripletail	Berrugate, dormilón	*Lobotes surinamensis*	6,964
Indo-Pacific sailfish	Pez vela	*Istiophorus platypterus*	6,724
Bluestriped chub	Chopa salema	*Sectator ocyurus*	4,850
Manta rays	Mantas	Mobulidae	4,477
Pelagic stingray	Raya látigo violeta	*Pteroplatytrygon violacea*	3,960
Longfin yellowtail	Medregal limón	*Seriola rivoliana*	3,854
Striped marlin	Marlín rayado	*Kajikia audax*	3,625
Unicorn filefish	Lija barbudo	*Aluterus monoceros*	3,179
Hammerhead shark nei	Cornudas nep	*Sphyrna* spp.	1,968
Scalloped hammerhead shark	Cornuda común	*Sphyrna lewini*	1,843
Scrawled filefish	Lija trompa	*Aluterus scriptus*	1,794
Smooth hammerhead shark	Cornuda cruz	*Sphyrna zygaena*	1,704
Pompano dolphinfish	Dorado pompano	*Coryphaena equiselis*	1,588
Yellowtail amberjack	Medregal rabo amarillo	*Seriola lalandi*	1,519
Requiem sharks nei	Cazones picudos, tintoreras nep	*Carcharhinus* spp.	1,417
Ocean sunfish, Mola	Pez sol	*Mola mola*	1,349
Bigeye thresher shark	Zorro ojón	*Alopias superciliosus*	1,188
Spinetail manta	Manta de aguijón	*Mobula japanica*	1,161
Smoothtail manta	Manta diablo	*Mobula thurstoni*	1,063
Manta ray nei	Manta nep	*Mobula* spp.	993

English	Spanish	Scientific name	No. of sets
Great barracuda	Picuda barracuda	*Sphyraena* spp.	912
Pelagic thresher shark	Zorro pelágico	*Alopias pelagicus*	896
Triggerfishes, durgons nei	Peces-ballesta nep	Balistidae	884
Mackerel scad	Macarela caballa	*Decapterus macarellus*	874
Short fin mako shark	Mako de aleta corta	*Isurus oxyrinchus*	850
Thresher shark nei	Zorros nep	*Alopias* spp.	803
Cortez sea chub	Chopa Cortez (gallinaza)	*Kyphosus elegans*	802
Blue shark	Tiburón azul	*Prionace glauca*	733
Pilotfish	Pez piloto	*Naucrates ductor*	717
Leatherjacket filefishes	Lija	*Aluterus* spp.	711
Bigeye trevally	Jurel	*Caranx sexfasciatus*	656
Swordfish	Pez espada	*Xiphias gladius*	616
Whitemouth jack	Jurel lengua blanca	*Uraspis helvola*	598
Drummer	Gallinaza	*Kyphosus* spp.	542
Blue-bronze sea chub	Chopa gris (gallinaza)	*Kyphosus analogus*	521
Jacks, crevalles nei	Jureles, pámpanos nep	*Caranx* spp.	506
Chilean devil ray	Manta cornuda	*Mobula tarapacana*	470
Shortbill spearfish	Marlín trompa corta	*Tetrapturus angustirostris*	398
Thresher shark	Tiburón zorro pinto	*Alopias vulpinus*	354
Giant manta	Manta voladora	*Manta birostris*	347
Rays nei	Raya nep	Mobulidae, Dasyatidae	309
Munk's devil ray	Manta de Munk	*Mobula munkiana*	227
Mako shark nei	Tiburón mako nep	*Isurus* spp.	222
Great hammerhead	Cornuda gigante	*Sphyrna mokarran*	221
Blacktip shark	Tiburón punta negra	*Carcharhinus limbatus*	135
Copper shark	Tiburón cobrizo	*Carcharhinus brachyurus*	126
Fortune jack	Medregal fortuno	*Seriola peruana*	100