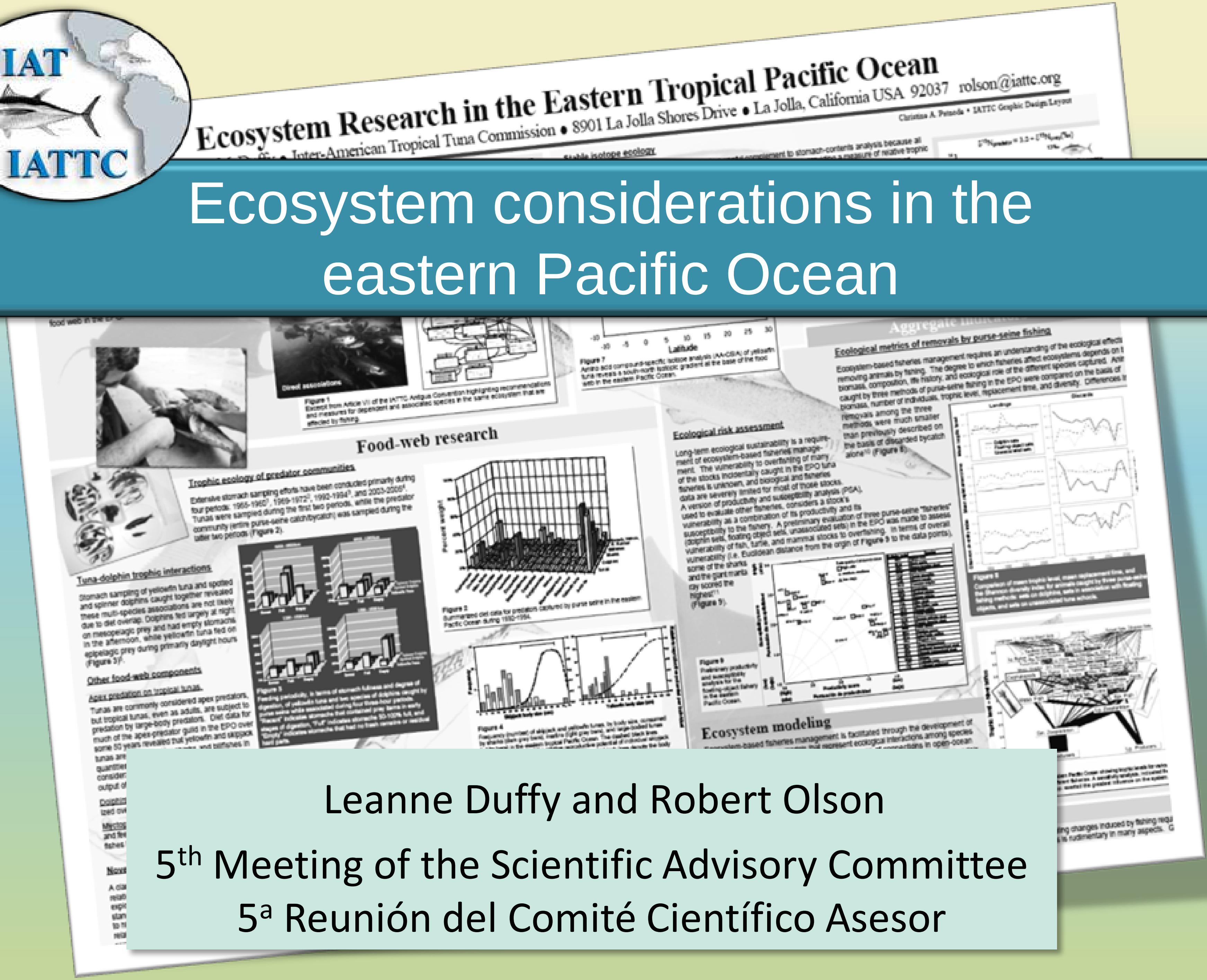
Ecosystem considerations in the eastern Pacific Ocean

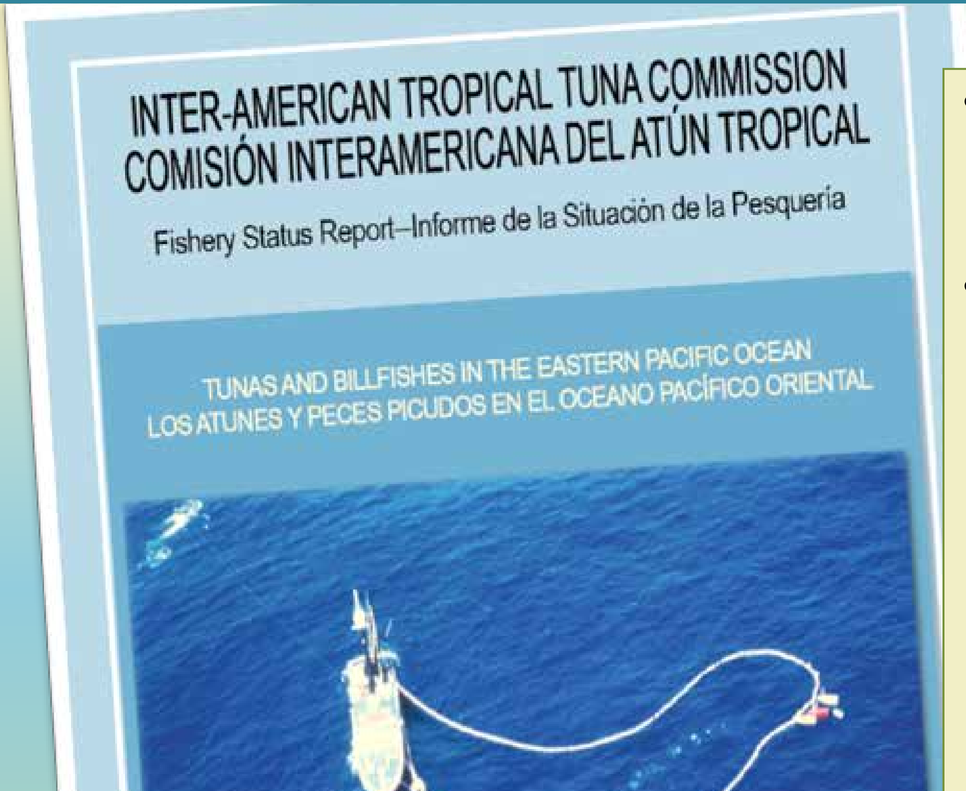


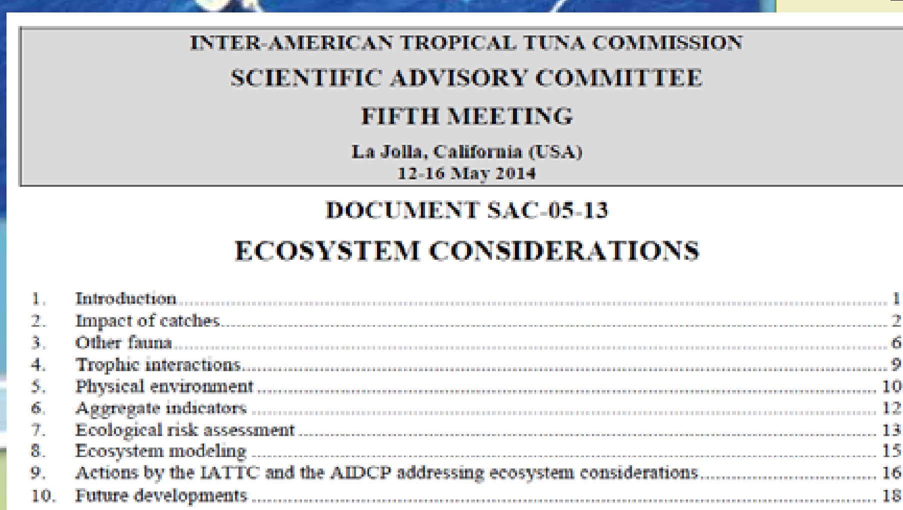
Leanne Duffy and Robert Olson

5th Meeting of the Scientific Advisory Committee

5a Reunión del Comité Científico Asesor

IATTC Fishery Status Report - SAC-05-13





INTER-AMERICAN TROPICAL TUNA COMMISSION

SCIENTIFIC ADVISORY COMMITTEE

FIFTH MEETING

La Jolla, California (USA)
12-16 May 2014

DOCUMENT SAC-05-13

ECOSYSTEM CONSIDERATIONS

- Call attention to the “Ecosystem Considerations” section of Fishery Status Report
- Review concepts, recent data, and research
  - International calls for “Ecosystem-based Management”
    - Biological and physical marine environment
    - Human activity in the marine environment
  - Focus on the ecosystem as a whole
    - Direct effects of fisheries on species – sustainability
    - Indirect effects of fisheries act through the food web – sustainability
    - Physical environment – inter-annual and long-term variability

Ecosystem Research in the Eastern Tropical Pacific Ocean

Robert J. Olson, Leanne M. Duffy • Inter-American Tropical Tuna Commission • 8901 La Jolla Shores Drive • La Jolla, California USA 92037 rolson@iattc.org

Christine A. Patnode • IATTC Graphic Design/Layout

The Inter-American Tropical Tuna Commission (IATTC) is charged with management of the tropical tuna and billfish stocks in the eastern Pacific Ocean (EPO), while taking into account other components of the ecosystem that are 1) affected by fishing or 2) dependent upon or associated with the target fish stocks (Figure 1). Fisheries effects on ecosystems encompass both direct effects (e.g. catch of non-target species) and indirect effects (*i.e.* interactions via the food web).

Investigating fisheries effects on ecosystems requires accurate representations of pelagic food webs in ecosystem models. Defining trophic connections is a prerequisite for gaining insight into the role of predators and commercial fisheries in influencing food web structure and ecosystem dynamics. IATTC's ecosystem research program is largely focused on understanding the pelagic food web in the EPO.

ARTICLE VII. FUNCTIONS OF THE COMMISSION

(f) 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;

(g) adopt appropriate measures to avoid, reduce and minimize waste, discards, catch by lost or discarded gear, catch of non-target species (both fish and non-fish species) and impacts on associated or dependent species, in particular endangered species;

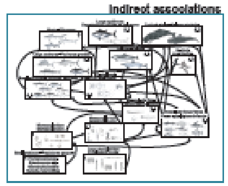


Figure 1
Excerpt from Article VII of the IATTC Antigua Convention highlighting recommendations and measures for dependent and associated species in the same ecosystem that are affected by fishing.

Stable isotope ecology

Stable carbon and nitrogen isotope analysis is a useful complement to stomach-contents analysis because all components of the assimilated diet are integrated into an animal's tissues, providing a measure of relative trophic position (Figure 6). The spatial distribution of stable isotope values of yellowfin tuna in relation to those of copepods in the EPO showed an increasing trophic position of the tuna from inshore to offshore, a characteristic of the food web never detected in diet data[9]. Additional insight is provided by compound-specific isotope analysis of amino acids (AA-CSIA). In samples of consumer tissues, "source" amino acids (e.g. phenylalanine, glycine) retain the isotopic values at the base of the food web, and "trophic" amino acids (e.g. glutamic acid) become enriched in ^{15}N by about 7‰ relative to the baseline (Figure 7). Trophic position can be derived from samples of consumer tissues alone (*i.e.* not necessary to sample the food-web base).

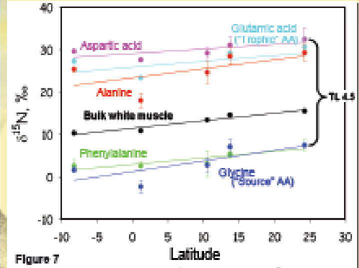
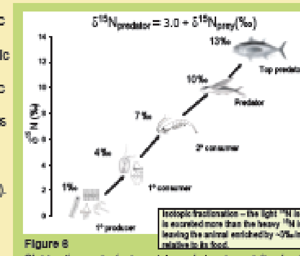


Figure 7
Amino acid compound-specific isotope analysis (AA-CSIA) of yellowfin tuna reveals a south-north isotopic gradient at the base of the food web in the eastern Pacific Ocean.



Isotopic fractionation – the light ^{14}N isotope is excreted more than the heavy ^{15}N isotope, leaving the animal enriched by ~3‰ in $\delta^{15}N$ relative to its food.

Figure 6
Stable nitrogen isotopic enrichment showing relative trophic positions of various animals in a hypothetical food chain.

Food-web research

Trophic ecology of predator communities

Extensive stomach sampling efforts have been conducted primarily during four periods: 1955-1960[1], 1969-1972[2], 1992-1994[3], and 2003-2005[4]. Tunas were sampled during the first two periods, while the predator community (entire purse-seine catch/bycatch) was sampled during the latter two periods (Figure 2).

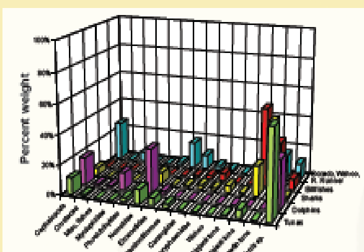


Figure 2
Summarized diet data for predators captured by purse seine in the eastern Pacific Ocean during 1992-1994.

Tuna-dolphin trophic interactions

Stomach sampling of yellowfin tuna and spotted and spinner dolphins caught together revealed these multi-species associations are not likely due to diet overlap. Dolphins fed largely at night on mesopelagic prey and had empty stomachs in the afternoon, while yellowfin tuna fed on epipelagic prey during primarily daylight hours (Figure 3)[5].

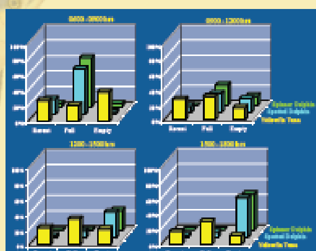


Figure 3
Feeding periodicity, in terms of stomach fullness and degree of digestion, of yellowfin tuna and two species of dolphins caught by purse seine while associated during four three-hour periods. "Recent" indicates stomachs that contained prey items in early stages of digestion, "Full" indicates stomachs 50-100% full, and "Empty" indicates stomachs that had no fresh remains or residual hard parts.

Other food-web components

Apex predation on tropical tunas. Tunas are commonly considered apex predators, but tropical tunas, even as adults, are subject to predation by large-body predators. Diet data for much of the apex-predator guild in the EPO over some 50 years revealed that yellowfin and skipjack tunas are consumed by sharks and billfishes in quantities and at sizes that can make a considerable contribution to the reproductive output of the populations[6] (Figure 4).

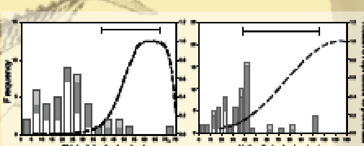


Figure 4
Frequency (number) of skipjack and yellowfin tunas, by body size, consumed by sharks (dark gray bars), marlins (light gray bars), and large-bodied tunas (white bars) in the eastern tropical Pacific Ocean. The dashed black lines represent estimates of the relative reproductive potential of individual skipjack and yellowfin tunas across size classes. The solid black lines denote the body sizes that comprise 90% of tuna catches.

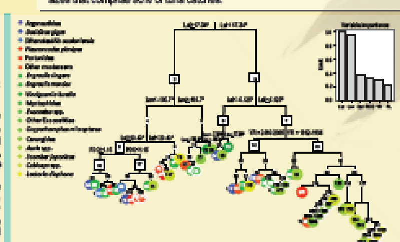
Dolphinfish. Food habits and consumption rates of these abundant, ubiquitous predators have been characterized over a large portion of the EPO[3].

Myctophid fishes. Prey preference, diet partitioning, feeding chronology, and feeding selectivity of three species of this important group of mesopelagic fishes have been described[7].

Novel method of diet data analysis

A classification tree modeling framework for investigating complex feeding relationships has been developed. The non-parametric method is both exploratory and predictive, and uses a bootstrap approach to provide standard errors of predicted prey proportions, variable importance measures to highlight important covariates, and partial dependence plots to explore the relationships between explanatory variables and predicted prey composition[8] (Figure 5).

Figure 5
Pruned classification tree that predicts the diet composition of yellowfin tuna in the eastern Pacific Ocean for the 1992-1994 and 2003-2005 sampling periods. The prey groups identified at each terminal node (colored circles) are those with the highest proportion weight composition among a suite of prey in the diet. Results for the top tree splits indicated that spatial and temporal covariates latitude (Lat), longitude (Lon), and year (YR) were important variables in predicting the diet composition. The diets of yellowfin in the extreme northern and southern regions of the sample distribution were explained by zoogeography of the prey fauna, while a major decadal diet shift was detected in the large, central sampling region.



Aggregate indicators

Ecological metrics of removals by purse-seine fishing

Ecosystem-based fisheries management requires an understanding of the ecological effects of removing animals by fishing. The degree to which fisheries affect ecosystems depends on the biomass, composition, life history, and ecological role of the different species captured. Animals caught by three methods of purse-seine fishing in the EPO were compared on the basis of biomass, number of individuals, trophic level, replacement time, and diversity. Differences in removals among the three methods were much smaller than previously described on the basis of discarded bycatch alone[10] (Figure 8).

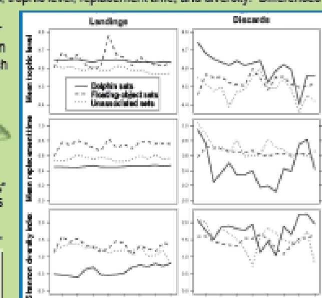
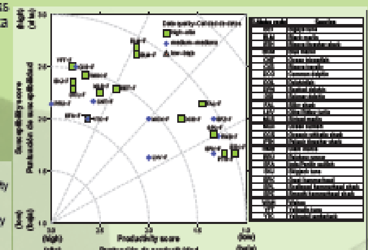


Figure 8
Comparison of mean trophic level, mean replacement time, and the Shannon diversity index for animals caught by three purse-seine fishing methods: sets on dolphins, sets in association with floating objects, and sets on unassociated tuna schools.

Ecological risk assessment

Long-term ecological sustainability is a requirement of ecosystem-based fisheries management. The vulnerability to overfishing of many of the stocks incidentally caught in the EPO tuna fisheries is unknown, and biological and fisheries data are severely limited for most of those stocks. A version of productivity and susceptibility analysis (PSA), used to evaluate other fisheries, considers a stock's vulnerability as a combination of its productivity and its susceptibility to the fishery. A preliminary evaluation of three purse-seine "fisheries" (dolphin sets, floating object sets, unassociated sets) in the EPO was made to assess vulnerability of fish, turtle, and mammal stocks to overfishing. In terms of overall vulnerability (i.e. Euclidean distance from the orgin of Figure 9 to the data points), some of the sharks and the giant manta ray scored the highest[11] (Figure 9).

Figure 9
Preliminary productivity and susceptibility analysis for the floating-object fishery in the eastern Pacific Ocean.



Ecosystem modeling

Ecosystem-based fisheries management is facilitated through the development of multi-species ecosystem models that represent ecological interactions among species or guilds. Our understanding of the complex maze of connections in open-ocean ecosystems is at an early stage, and, consequently, the current ecosystem models are most useful as descriptive devices and for exploring hypothetical indirect effects of fishing based on best estimates of trophic links and energy pathways. The IATTC staff developed a model of the pelagic ecosystem in the tropical EPO[12] to represent 1993-1997. A sensitivity analysis indicated that changes in the parameters for two components at middle trophic levels, cephalopods and *Auxis* spp., exerted the greatest influence on the ecosystem (Figure 10).

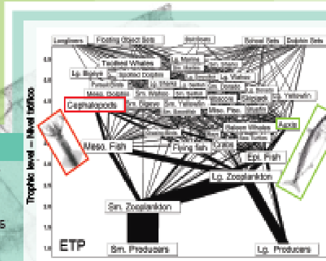


Figure 10
Ecosystem model for the eastern Pacific Ocean showing trophic levels for various animals captured by the different fisheries. A sensitivity analysis, indicated that cephalopods and *Auxis* spp. exerted the greatest influence on the system.

Conclusions

Trophic structure represented in food webs is thought to be the central organizing concept in ecology. Anticipating changes induced by fishing requires improved understanding of food web structure and function. Knowledge of pelagic food webs in all oceans is rudimentary in many aspects. Greater understanding of the trophodynamics of pelagic food webs is needed, specifically the relative strength of the trophic links and the pathways of biomass flow.

Food-web structure and function

- Ecological research at the IATTC largely focused on the structure and function of the pelagic food web in the EPO

- Effects of tuna fisheries on ecosystem
  - Direct effects: e.g. bycatches of non-target species (some sensitive)
  - Indirect effects: e.g. predator-prey connections and competition via the food web

- Anticipating changes induced by fishing requires understanding of food web structure and function

- Diet studies are necessary for investigating pathways of energy flow in exploited ecosystems

- Knowledge of trophic position and linkages is essential for informing ecosystem models

- Knowledge of <u>pelagic</u> food webs is still rudimentary, in many aspects

Trophic interactions

- Predation habits of yellowfin tuna: a wide-ranging generalist predator with high energy requirements (samplers of forage community)

  Olson RJ, Duffy LM, Kuhnert PM, Galván-Magaña F, Bocanegra-Castillo N, Alatorre-Ramirez V (2014) Decadal diet shift in yellowfin tuna (*Thunnus albacares*) suggests broad-scale food web changes in the eastern tropical Pacific Ocean. Marine Ecology Progress Series 497: 157-178

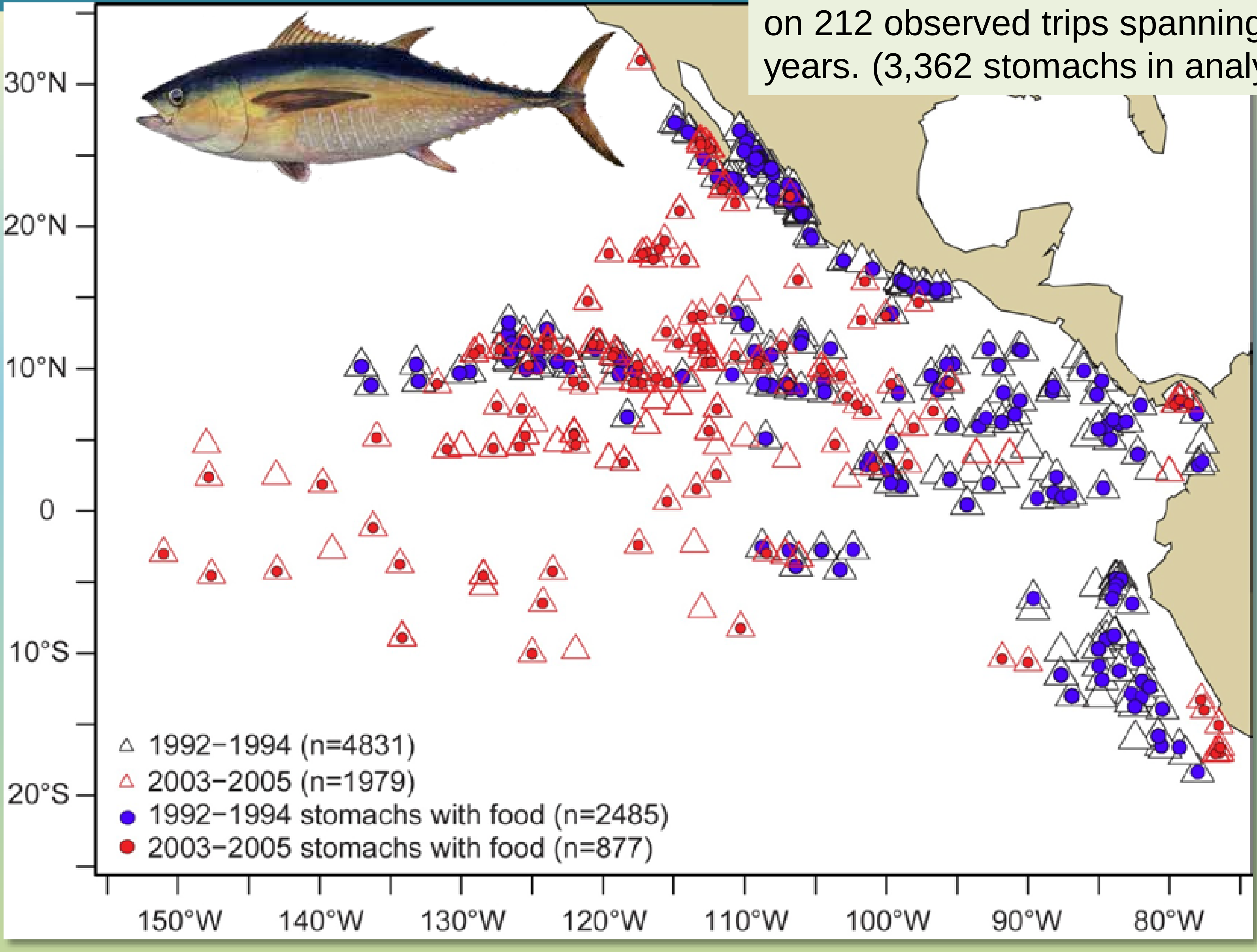
- Novel classification tree methodology developed for analyzing complex diet data

  Kuhnert P, Duffy L, Young J, Olson R (2012) Predicting fish diet composition using a bagged classification tree approach: a case study using yellowfin tuna (*Thunnus albacares*). Marine Biology: 1-14

- Two sets of diet data separated by a decade
  - 1992-1994
  - 2003-2005

Trophic interactions: set locations, yellowfin tuna diet study (1990s, 2000s)

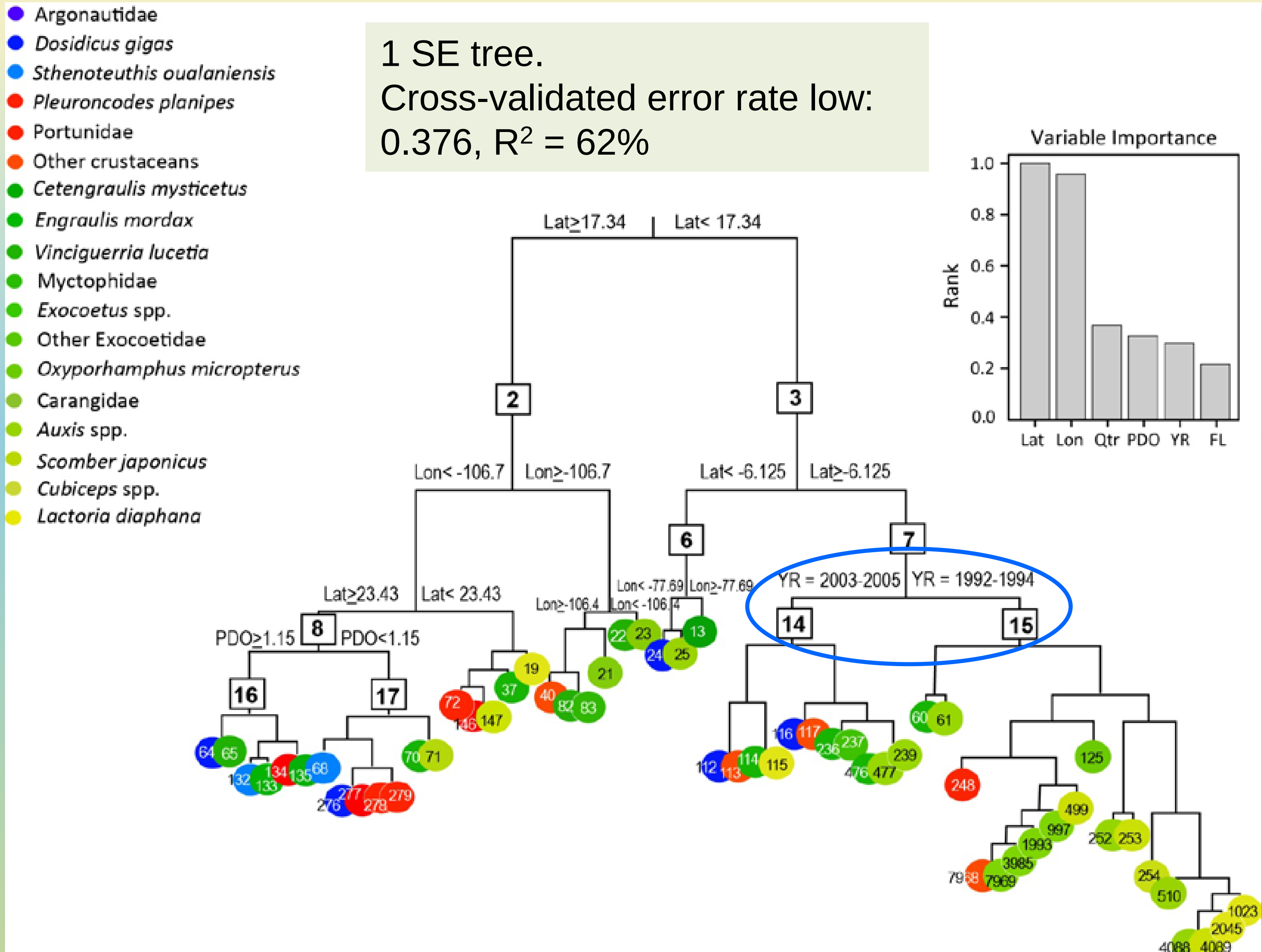
6,810 YFT sampled from 300 PS sets on 212 observed trips spanning 4 years. (3,362 stomachs in analysis)



Olson et al. 2014

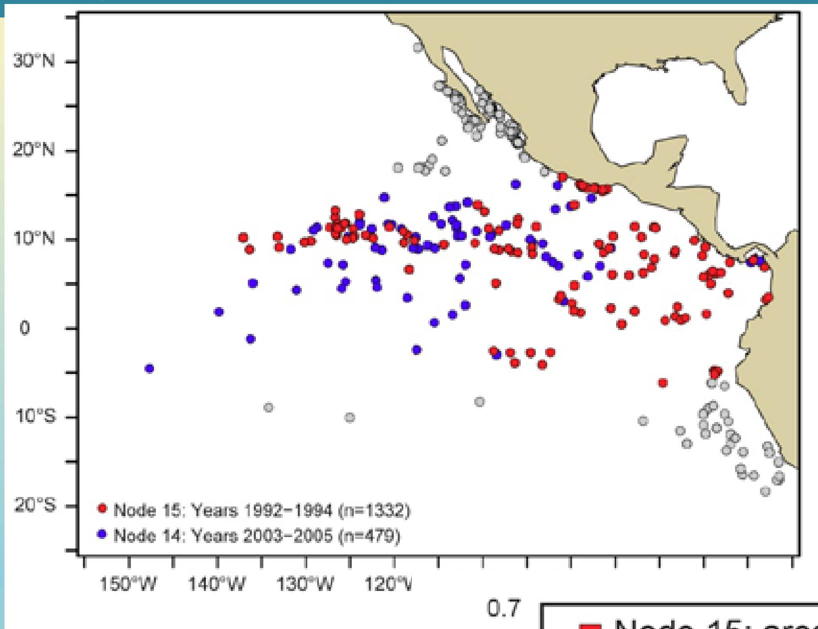
Trophic interactions: classification tree analysis (YFT)

1 SE tree.
Cross-validated error rate low:
0.376, R^2 = 62%

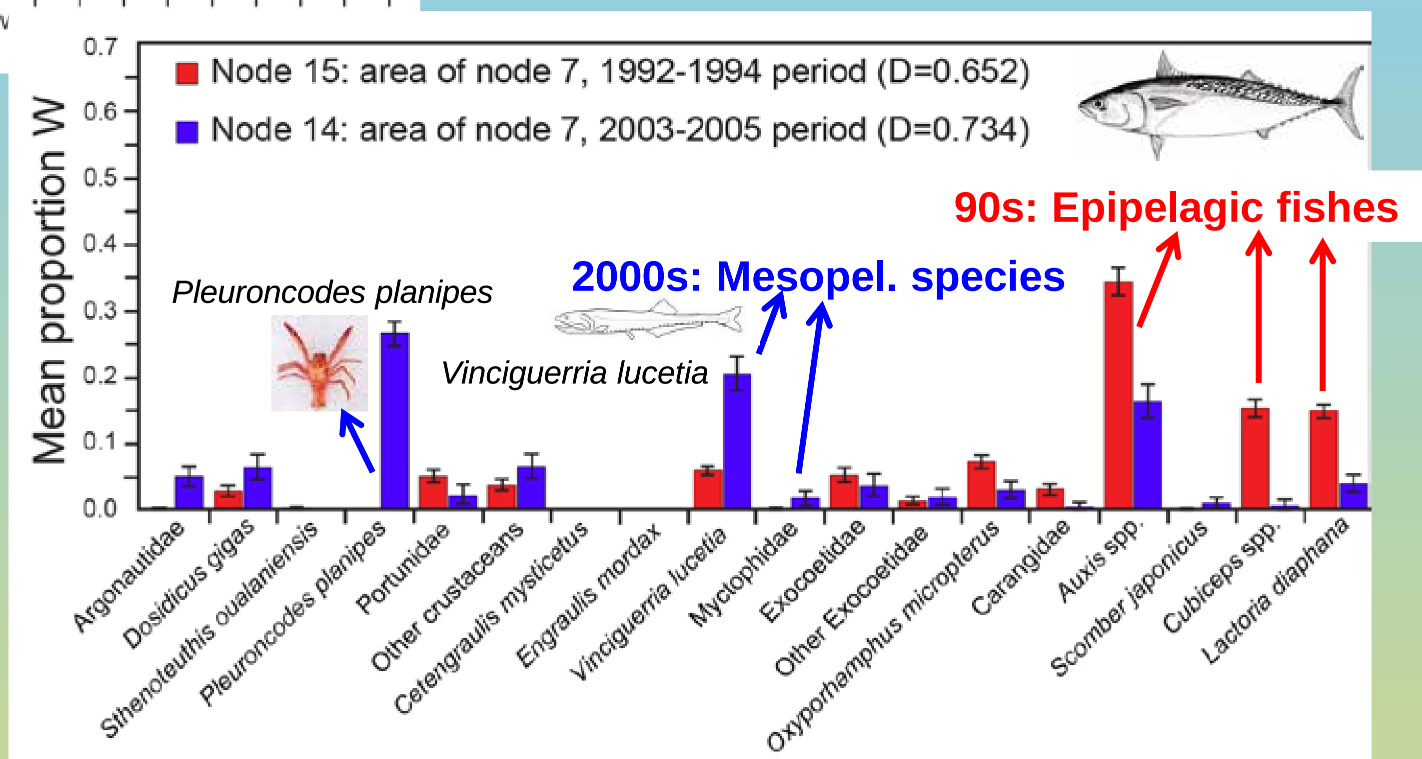


Olson et al. 2014

Trophic interactions: classification tree analysis (YFT) diet shift

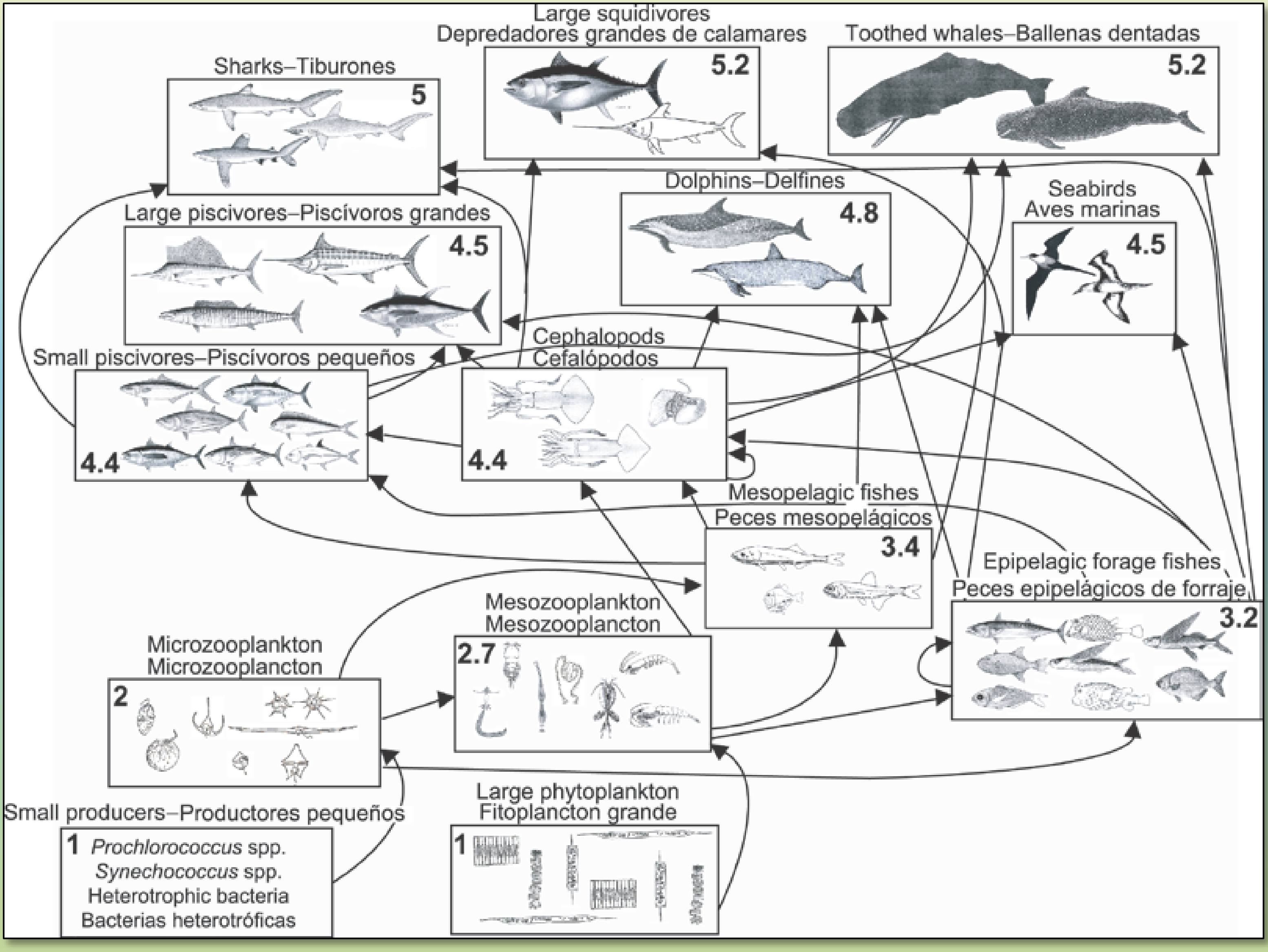


Simultaneously widespread reductions in:
Biological production
Phytoplankton community composition
Expansion & intensification of OMZ

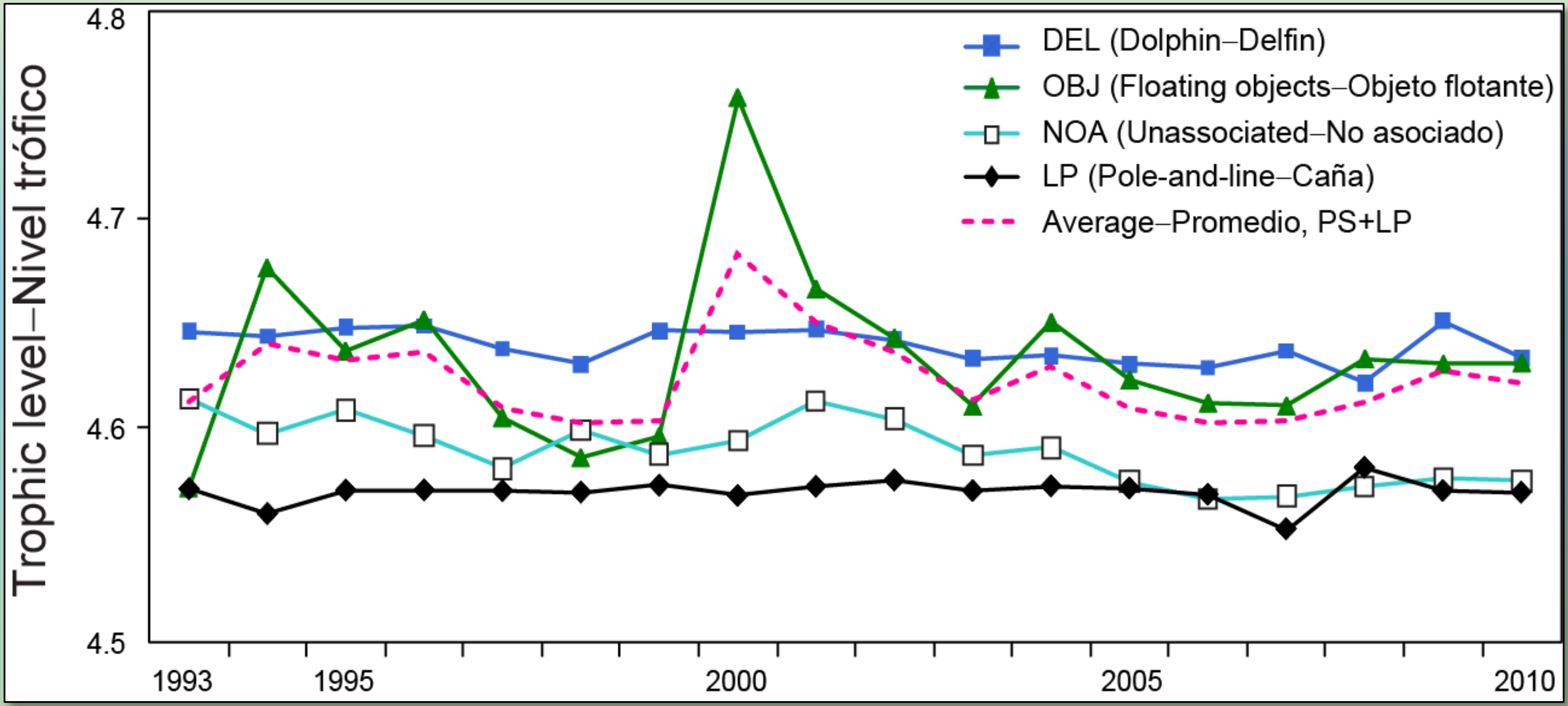


Olson et al. 2014

Aggregate indicators: trophic levels and a simplified food-web diagram in the EPO



Aggregate indicators: yearly mean trophic level of the catches



Antigua Convention

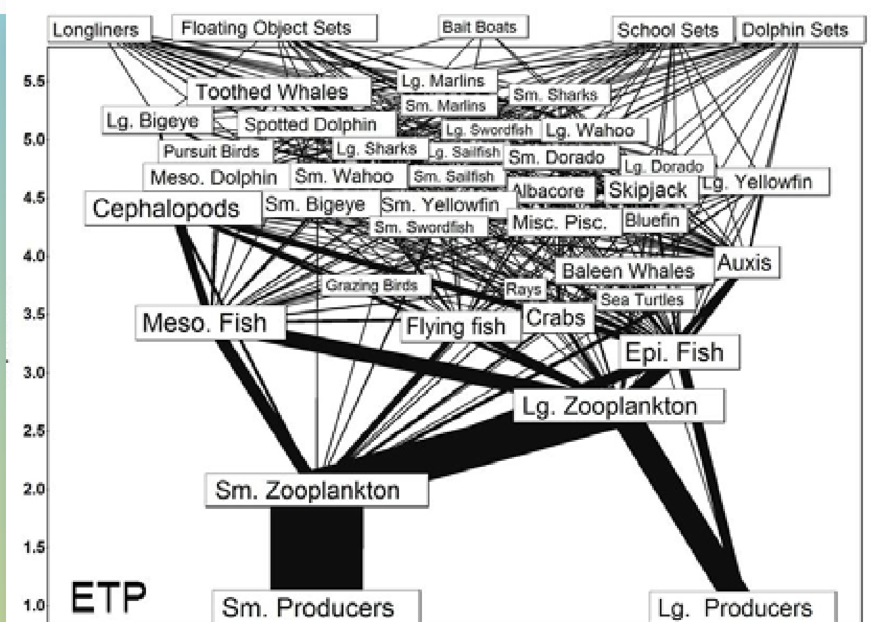
ARTICLE VII. FUNCTIONS OF THE COMMISSION

(f) 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;

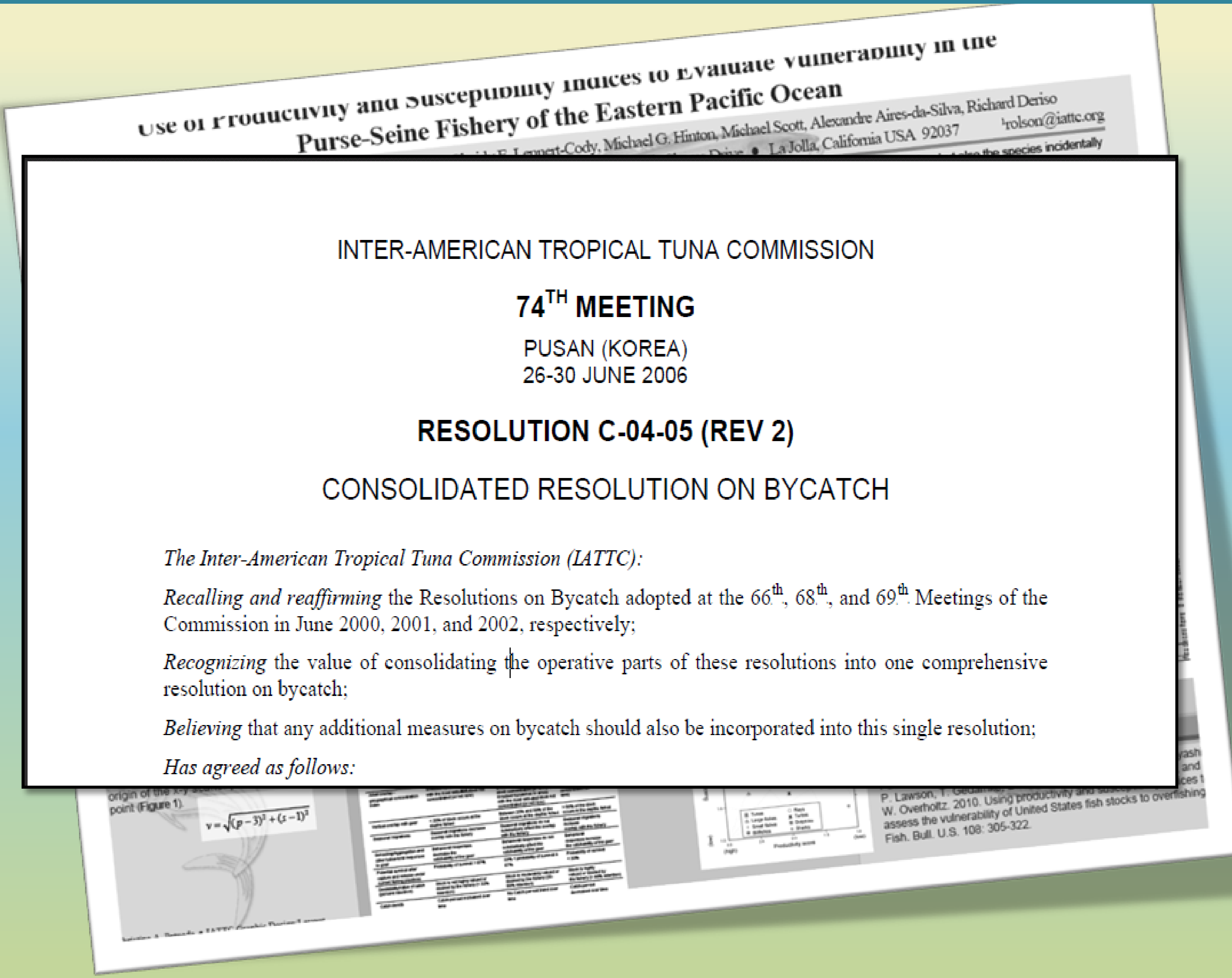
(g) adopt appropriate measures to avoid, reduce and minimize waste, discards, catch by lost or discarded gear, catch of non-target species (both fish and non-fish species) and impacts on associated or dependent species, in particular endangered species;

Direct associations

Indirect associations



Resolutions to reduce incidence of bycatch of non-target species



INTER-AMERICAN TROPICAL TUNA COMMISSION

74TH MEETING

PUSAN (KOREA)
26-30 JUNE 2006

RESOLUTION C-04-05 (REV 2)

CONSOLIDATED RESOLUTION ON BYCATCH

The Inter-American Tropical Tuna Commission (IATTC):

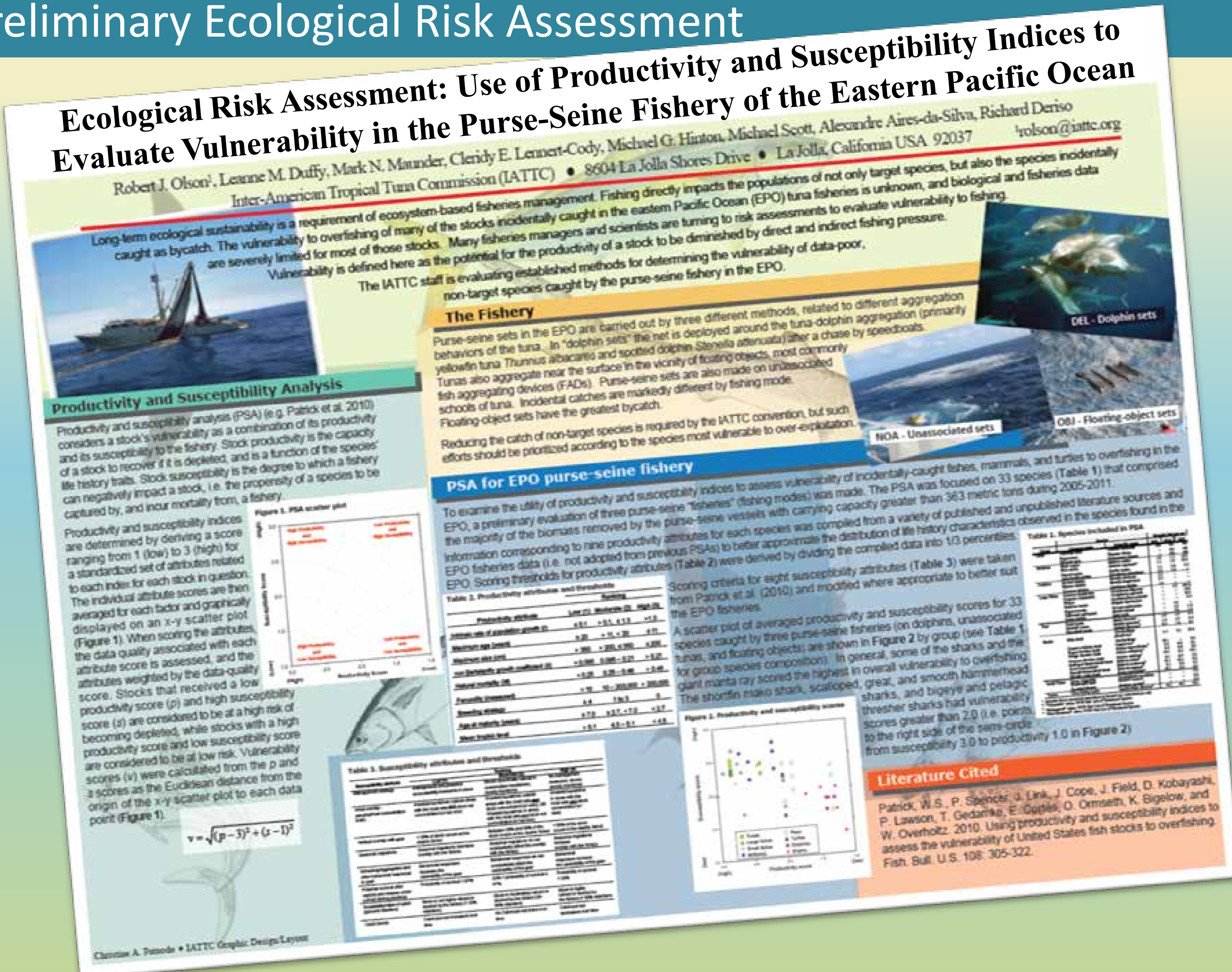
Recalling and reaffirming the Resolutions on Bycatch adopted at the 66th, 68th, and 69th Meetings of the Commission in June 2000, 2001, and 2002, respectively;

Recognizing the value of consolidating the operative parts of these resolutions into one comprehensive resolution on bycatch;

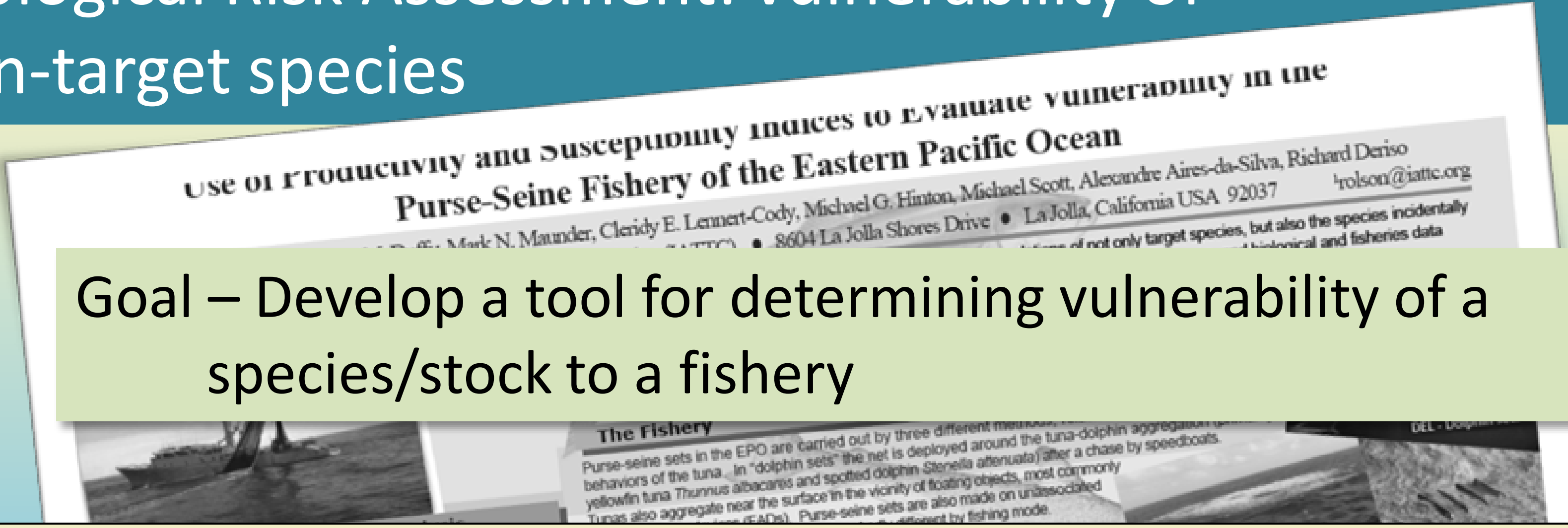
Believing that any additional measures on bycatch should also be incorporated into this single resolution;

Has agreed as follows:

Preliminary Ecological Risk Assessment



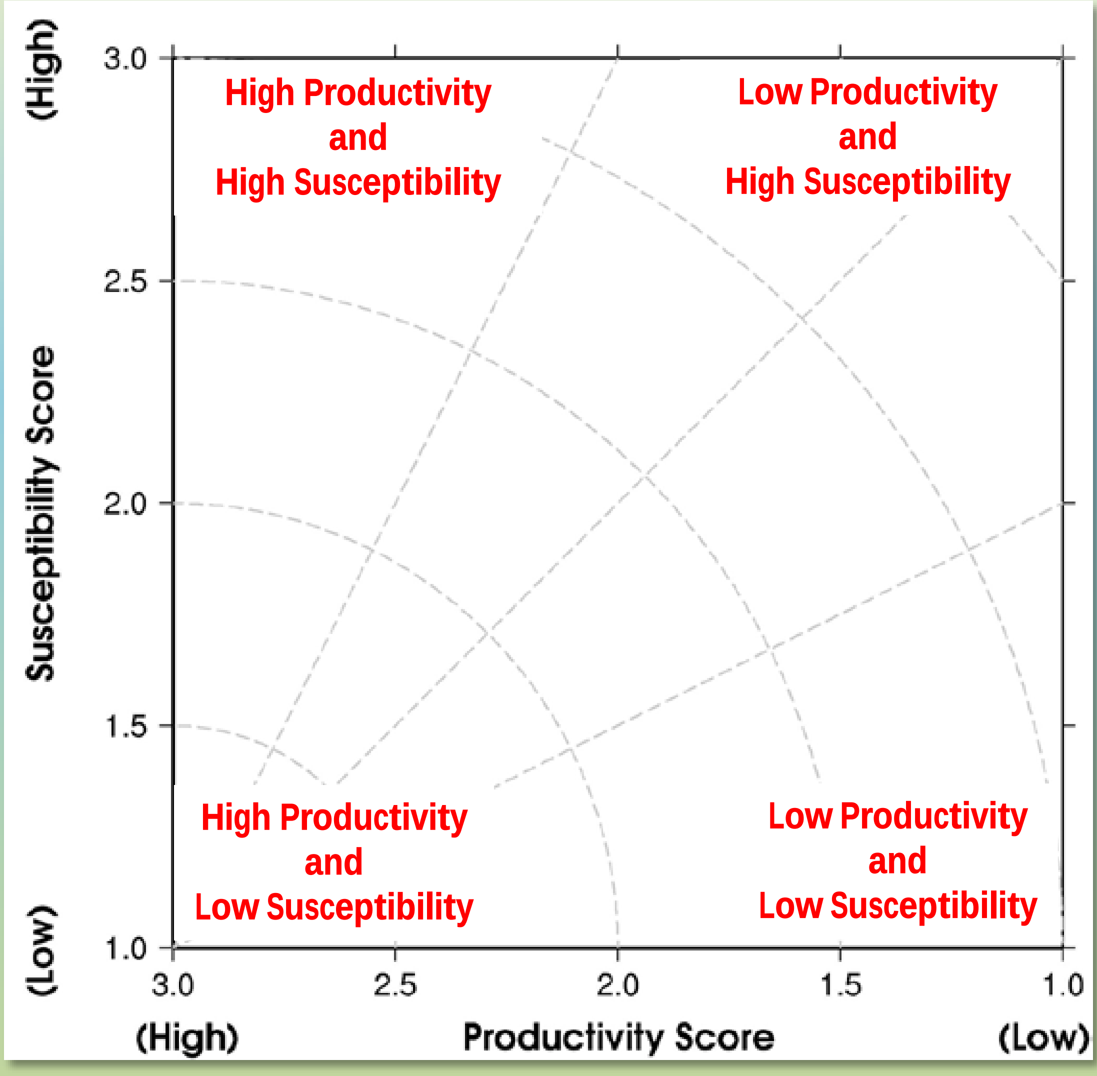
Ecological Risk Assessment: vulnerability of non-target species



Goal – Develop a tool for determining vulnerability of a species/stock to a fishery

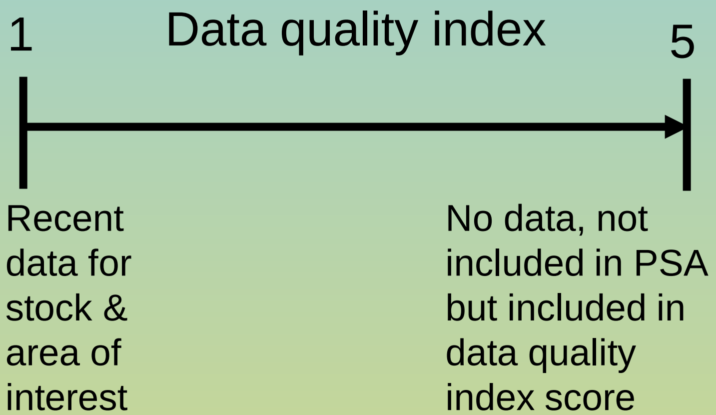
- **Vulnerability**: potential for the productivity of a stock to be diminished by direct and indirect fishing pressure. PSA: vulnerability is combination of a stock's productivity and its susceptibility to the fishery.
- **Productivity** – capacity to recover if stock is depleted (function of life history characteristics)
- **Susceptibility** – degree to which a fishery can negatively impact a stock (propensity of species to be captured by and incur mortality from a fishery). Can differ by fishery.

Ecological Risk Assessment: PSA scatter plot



Vulnerability (v) is measured as Euclidian distance from plot origin

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



Preliminary Ecological Risk Assessment: productivity attributes for EPO PSA

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

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

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

Preliminary Ecological Risk Assessment: susceptibility attributes for EPO PSA

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

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

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

Preliminary Ecological Risk Assessment: species for EPO PSA

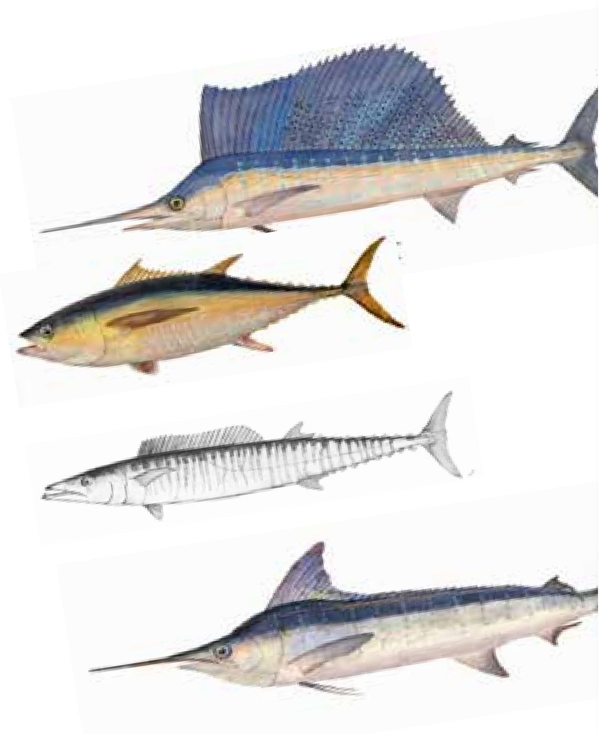
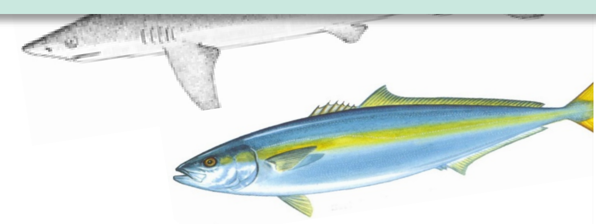


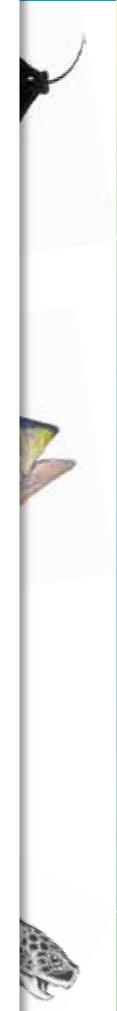
TABLE J-1. Annual bycatch per set (in kilograms) averaged over 2005-2011 for purse-seine vessels with carrying capacity greater than 363 metric tons, by three set methods. "n/a" indicates the tuna species that were included in the PSA analysis, but no values were given because tunas are not bycatches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

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

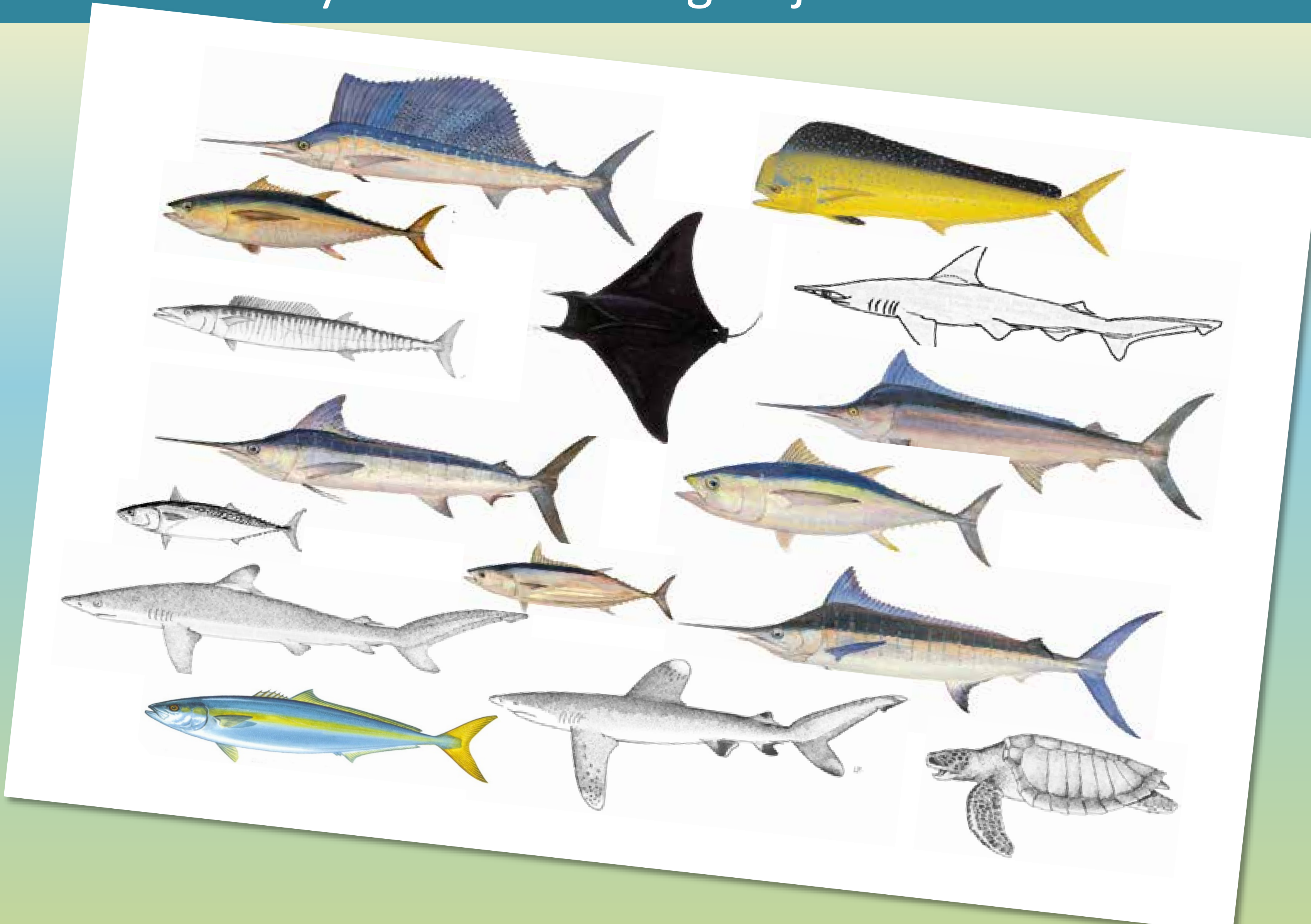
[1] Included due to numerical importance in bycatch (≥1 individual per set)
[2] "Vulnerable" status, IUCN Red List of Threatened Species
[3] "Endangered" status, IUCN Red List of Threatened Species
[4] "Near threatened" status, IUCN Red List of Threatened Species

Biomass importance (>1 t/set)
1. Numerical importance
2. "Vulnerable" IUCN status
3. "Endangered" IUCN status
4. "Near threatened" IUCN status

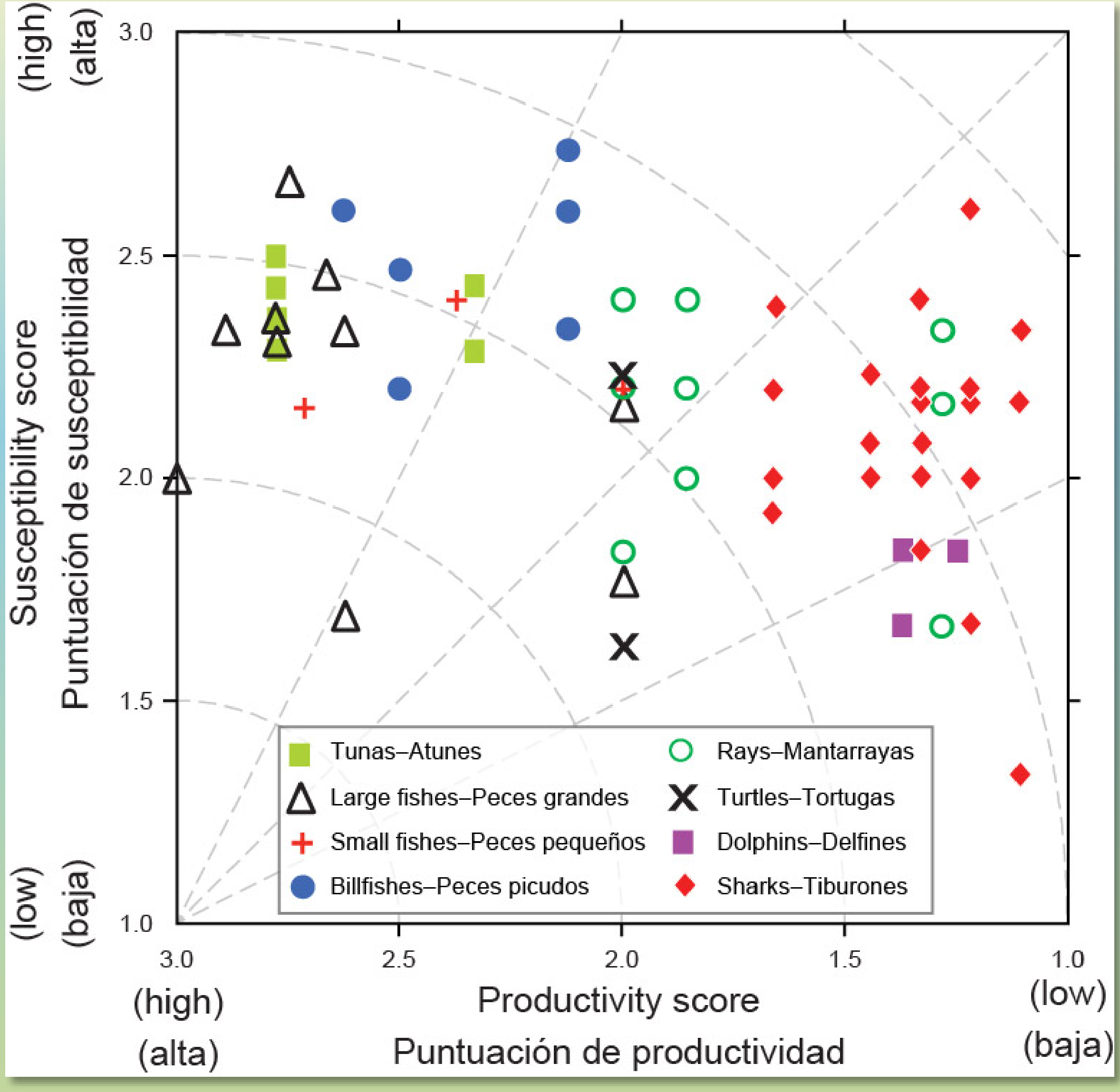




Preliminary Ecological Risk Assessment: species for EPO PSA
Tuna catch and bycatch in floating-object sets

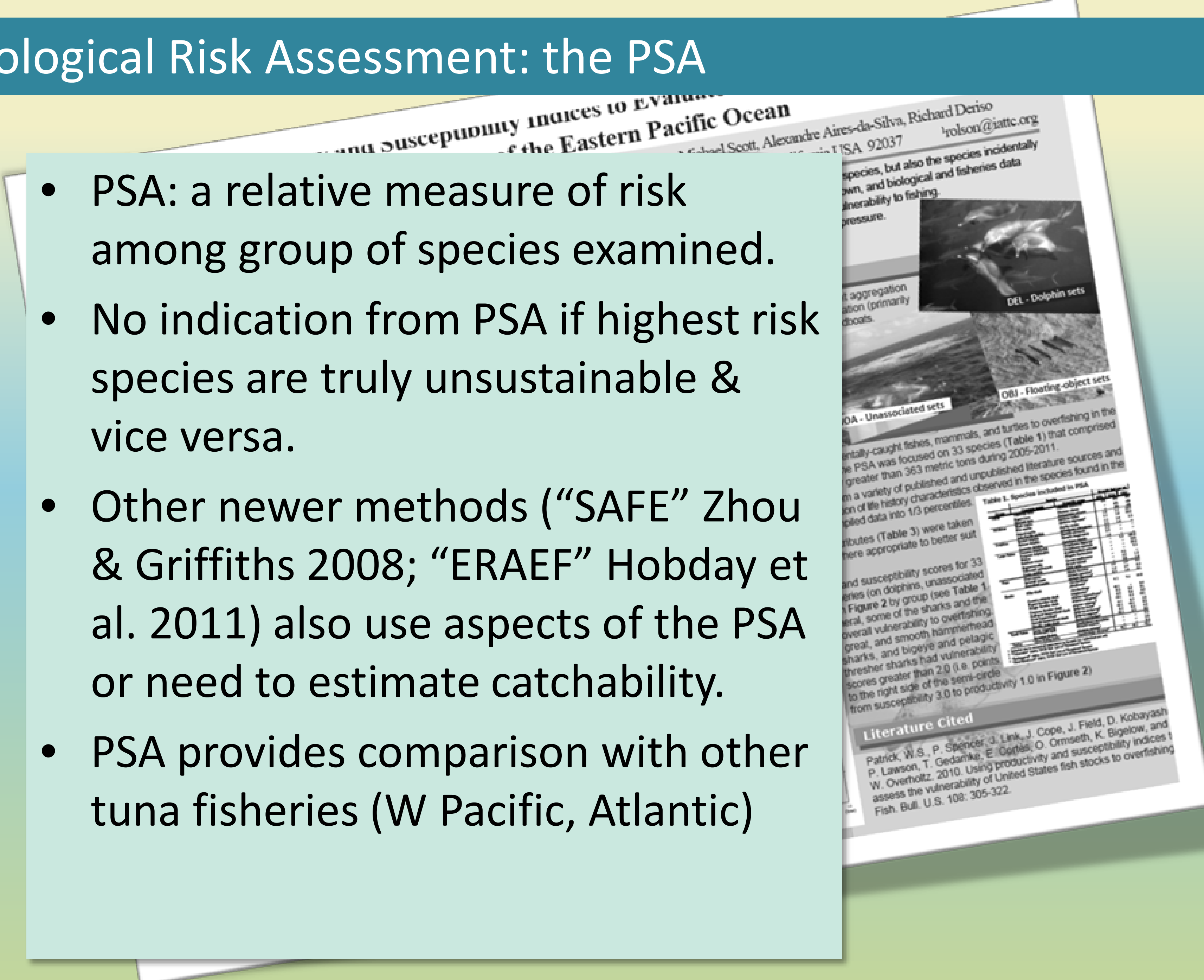


Preliminary Ecological Risk Assessment:
PSA scatter plot for all species and all purse-seine fisheries



Ecological Risk Assessment: the PSA

- PSA: a relative measure of risk among group of species examined.
- No indication from PSA if highest risk species are truly unsustainable & vice versa.
- Other newer methods ("SAFE" Zhou & Griffiths 2008; "ERAEF" Hobday et al. 2011) also use aspects of the PSA or need to estimate catchability.
- PSA provides comparison with other tuna fisheries (W Pacific, Atlantic)



Ecological Risk Assessment: PSA used by other organizations

Marine Stewardship Council
Fisheries Assessment Methodology
and
Guidance to Certification Bodies

Including Default Assessment Tree
and Risk-Based Framework

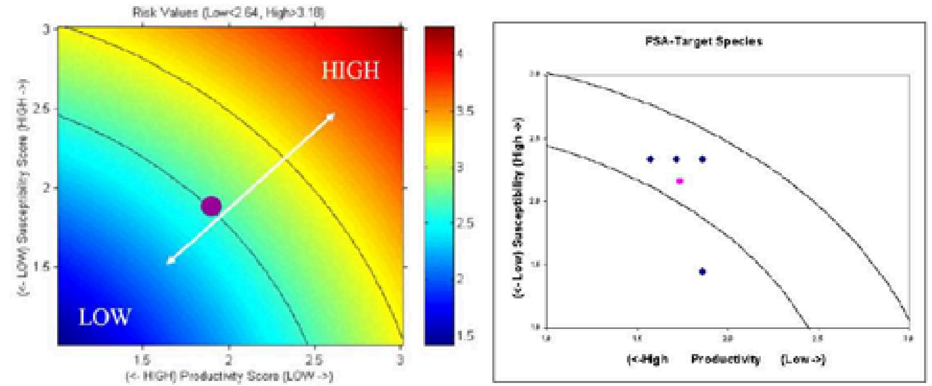


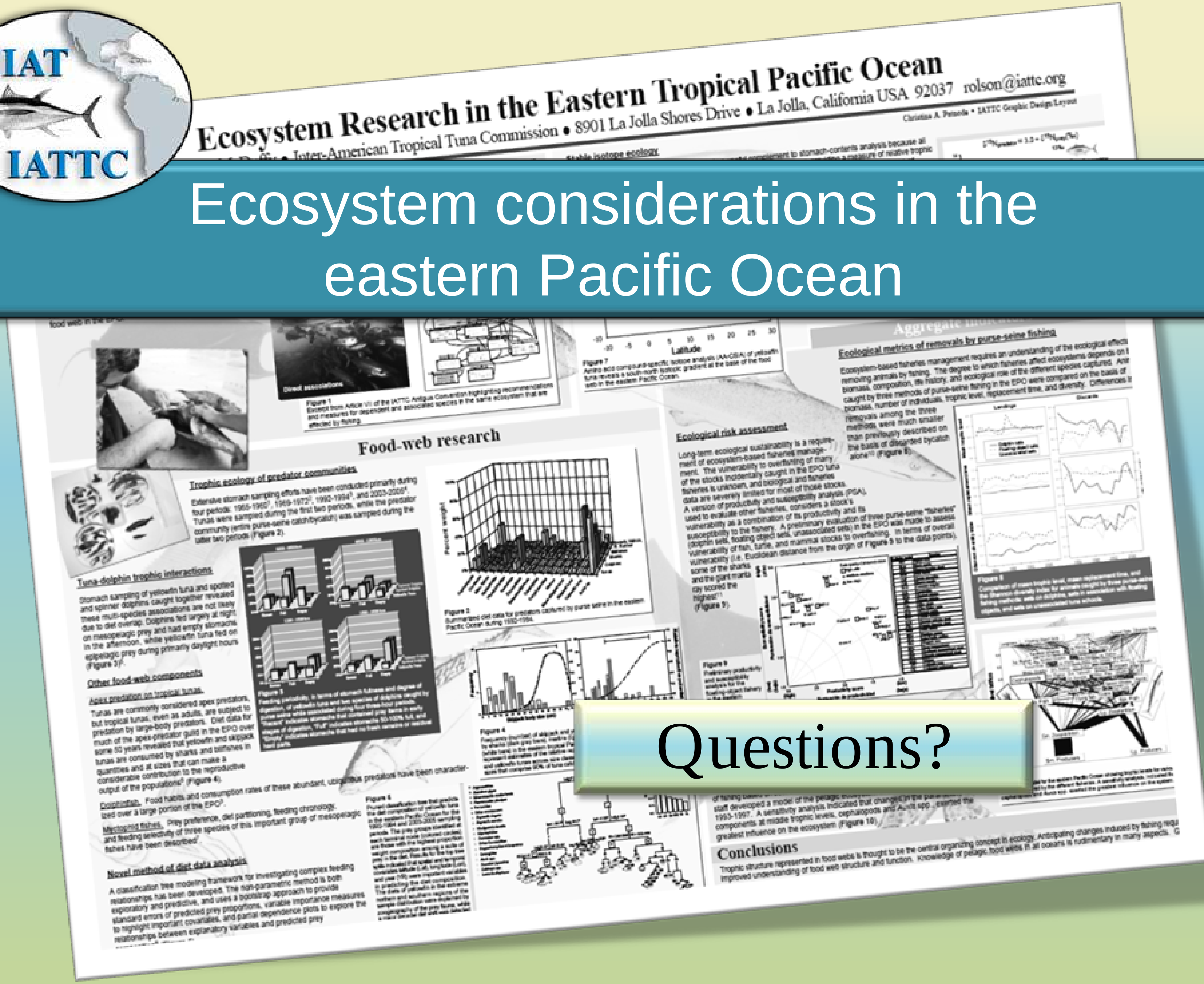
Figure A2. Examples of diagnostic charts for displaying PSA values for each species. **Left:** Low risk species have high productivity and low susceptibility, while high risk species have low productivity and high susceptibility. The curved lines divide the potential risk scores into thirds on the basis of the Euclidean distance from the origin (0,0). **Right**. Example PSA plot for a set of target species. Note the curved lines that divide the risk space into equal thirds, as described in the text

PSA Step 4: Convert PSA scores into MSC scores and feed back into default assessment tree

A3.3.31 Using the Excel worksheet PSA for MSC.xls, or the formula provided in Paragraph 4.4.2, convert the PSA scores resulting from this analysis into MSC scores. Follow guidance in Section 4.4 as well for scoring a PI using PSA results for multiple species.

CIAT
IATTC

Ecosystem considerations in the eastern Pacific Ocean



Questions?