

Summary: update of ecosystem considerations SAC-06-09

Trophic interactions

- Silky shark foraging ecology in the tropical EPO

Aggregate indicators

- Mean trophic level of organisms taken by the purse-seine and pole-and-line fisheries in the EPO

Ecological risk assessment (ERA)

- Modifications made to the Productivity and Susceptibility Assessment (PSA) during 2014 – proof of concept
- Future work on the ERA

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 pelagic food webs is still rudimentary, in many aspects

Trophic interactions

- Novel classification tree methodology developed for analyzing complex diet data

Kuhnert PM, Duffy LM, Young JW, Olson RJ (2012) Predicting fish diet composition using a bagged classification tree approach: a case study using yellowfin tuna (*Thunnus albacares*). *Marine Biology* 159: 87-100 doi 10.1007/s00227-011-1792-6

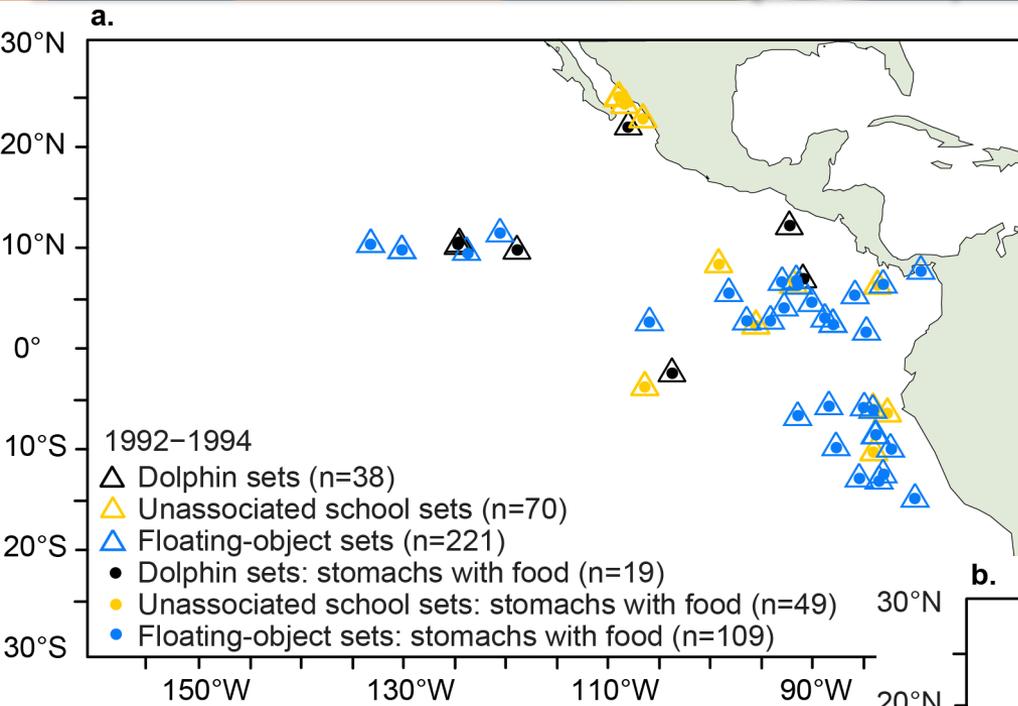
Olson RJ, Duffy LM, Kuhnert PM, Galván-Magaña F, Bocanegra-Castillo N, Alatorre-Ramírez V (2014) Decadal diet shift in yellowfin tuna *Thunnus albacares* suggests broad-scale food web changes in the eastern tropical Pacific Ocean. *Marine Ecology Progress Series* 497: 157-178 doi 10.3354/meps10609

- Predation habits of silky sharks

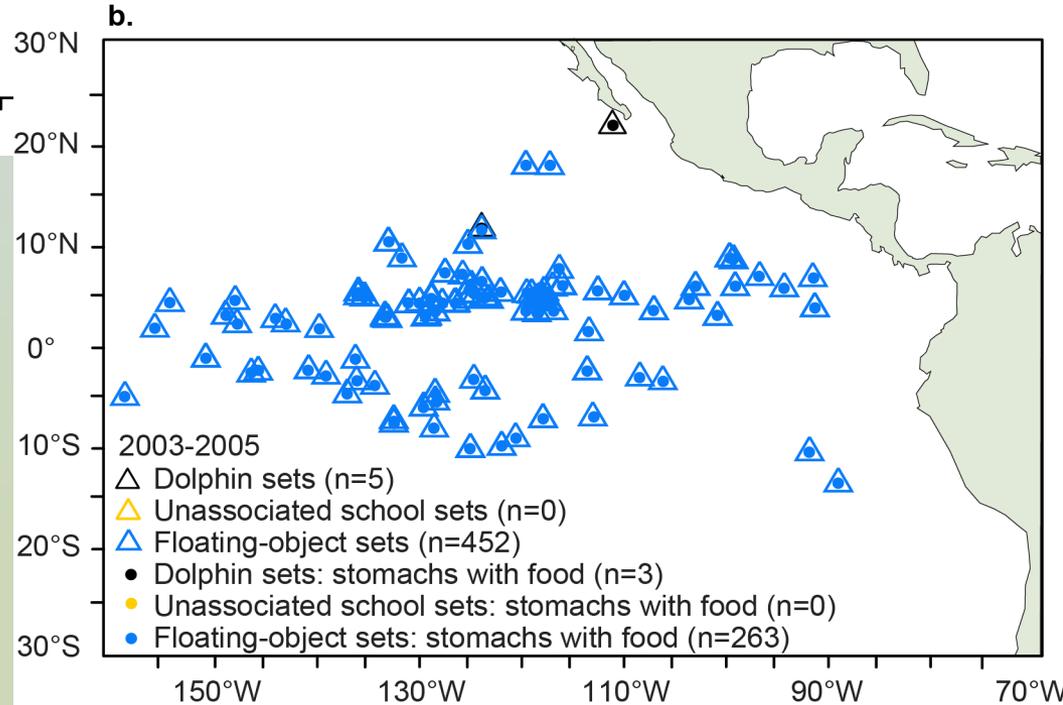
Duffy L, Olson R, Lennert-Cody C, Galván-Magaña F, Bocanegra-Castillo N, Kuhnert P (2015) Foraging ecology of silky sharks, *Carcharhinus falciformis*, captured by the tuna purse-seine fishery in the eastern Pacific Ocean. *Marine Biology* 162: 571-593 doi 10.1007/s00227-014-2606-4

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

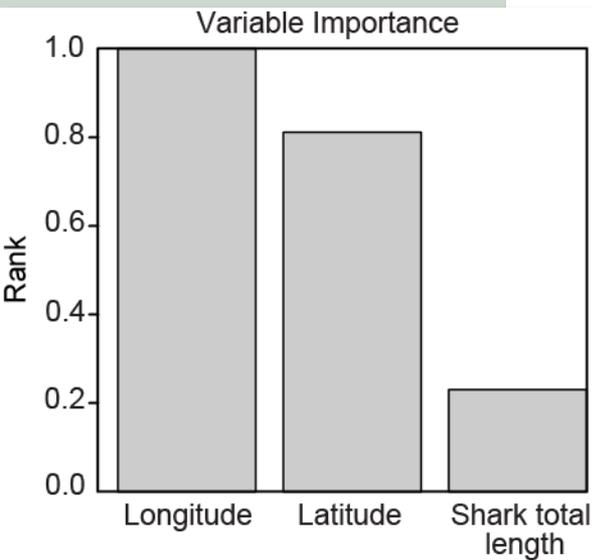
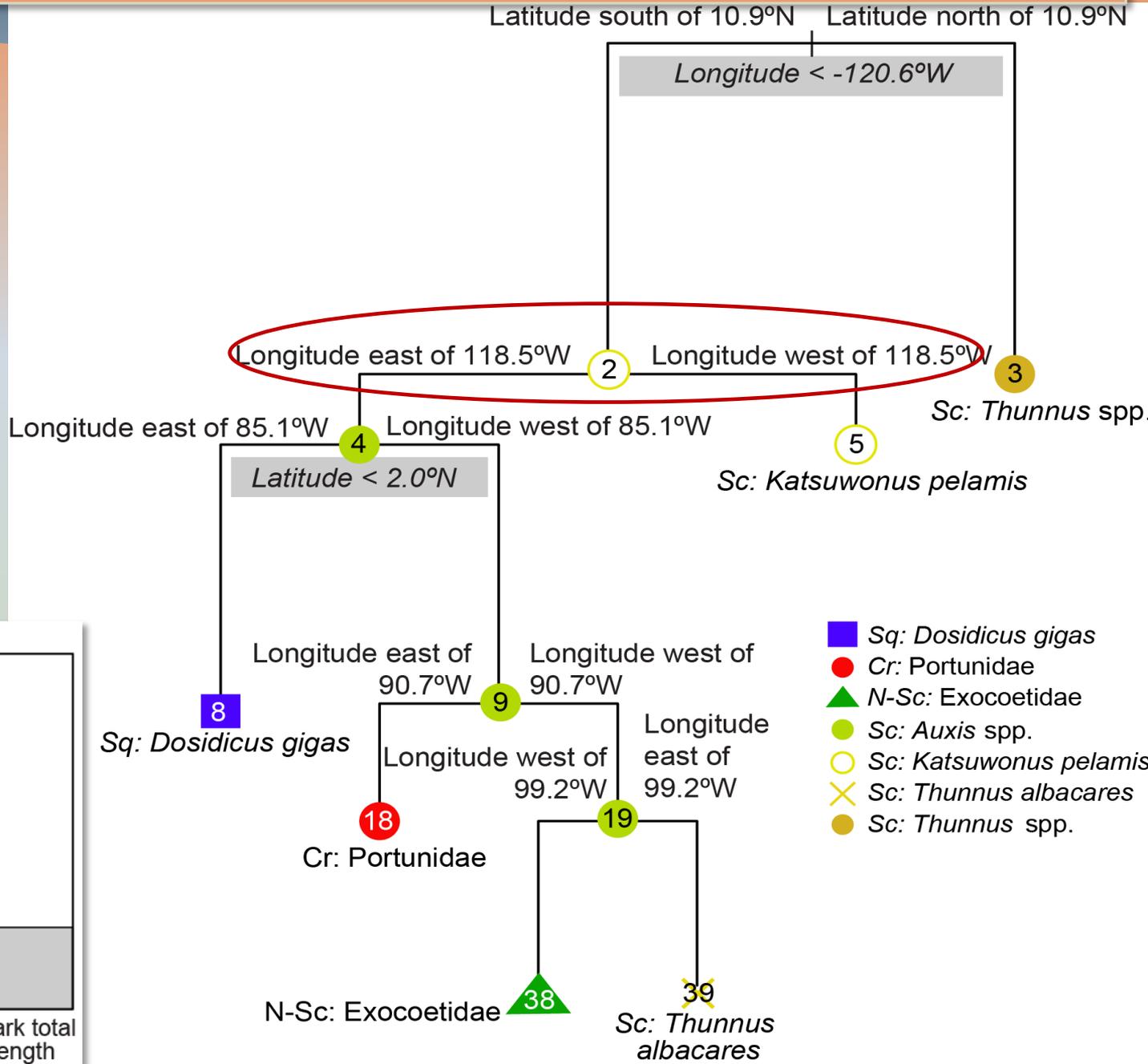
Trophic interactions: set locations, silky shark diet study (1990s, 2000s)



786 silky sharks sampled from 144 PS sets on 70 observed trips spanning 4 years. (289 stomachs from sharks captured as bycatch in sets on floating objects used in analysis)

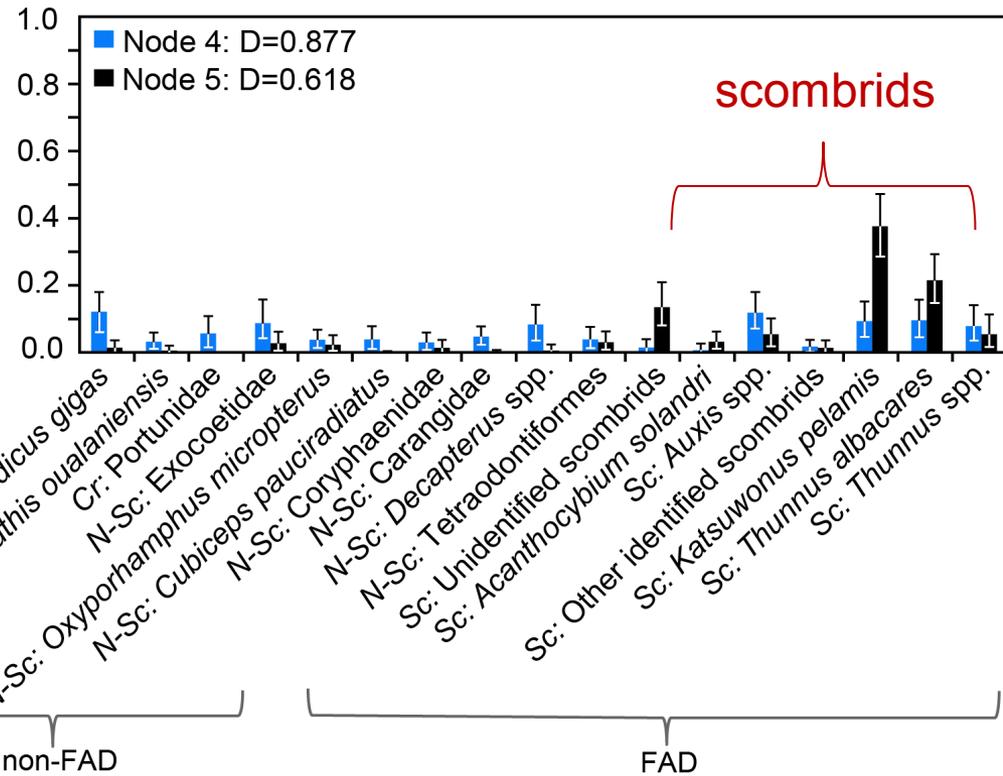
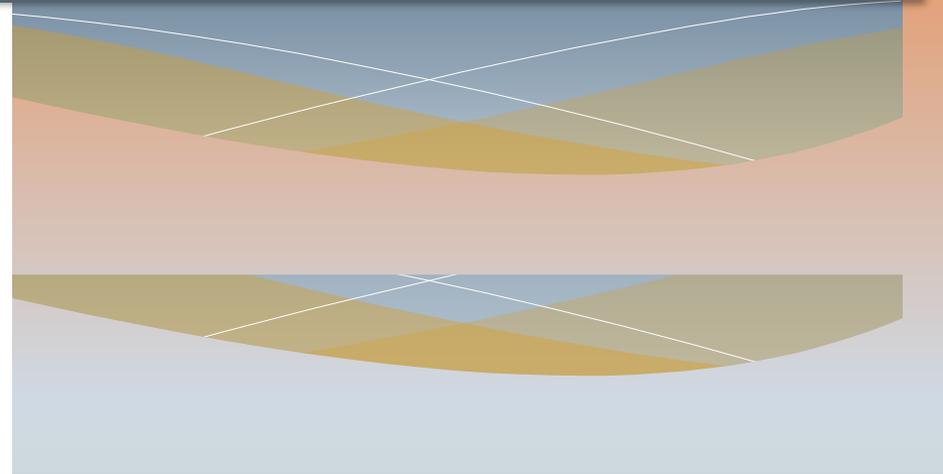
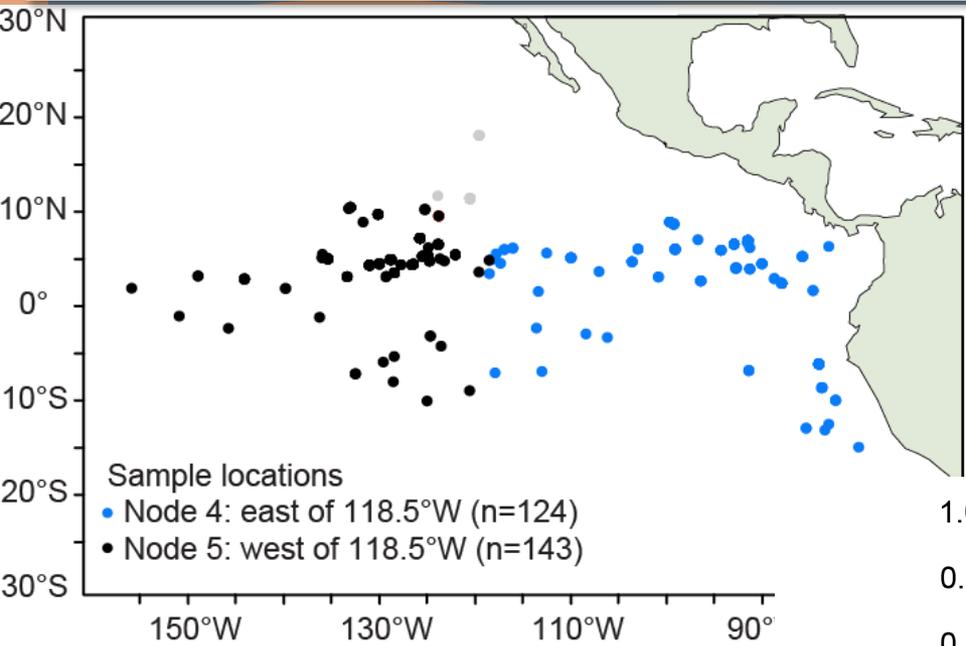


Trophic interactions: classification tree analysis (silky sharks)

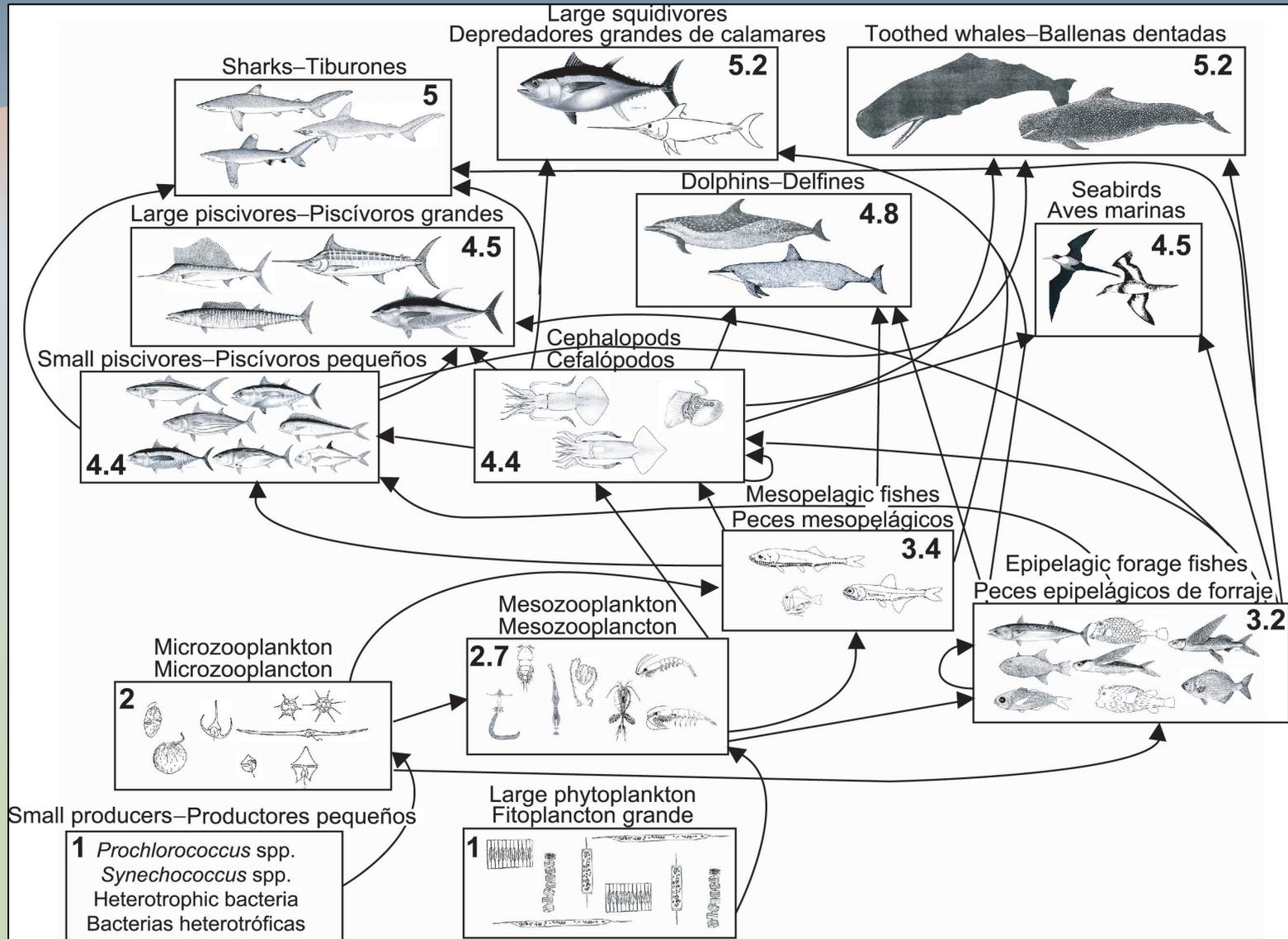


- *Sq: Dosidicus gigas*
- *Cr: Portunidae*
- ▲ *N-Sc: Exocoetidae*
- *Sc: Auxis spp.*
- *Sc: Katsuwonus pelamis*
- ✕ *Sc: Thunnus albacares*
- *Sc: Thunnus spp.*

Trophic interactions: classification tree analysis (silky sharks)

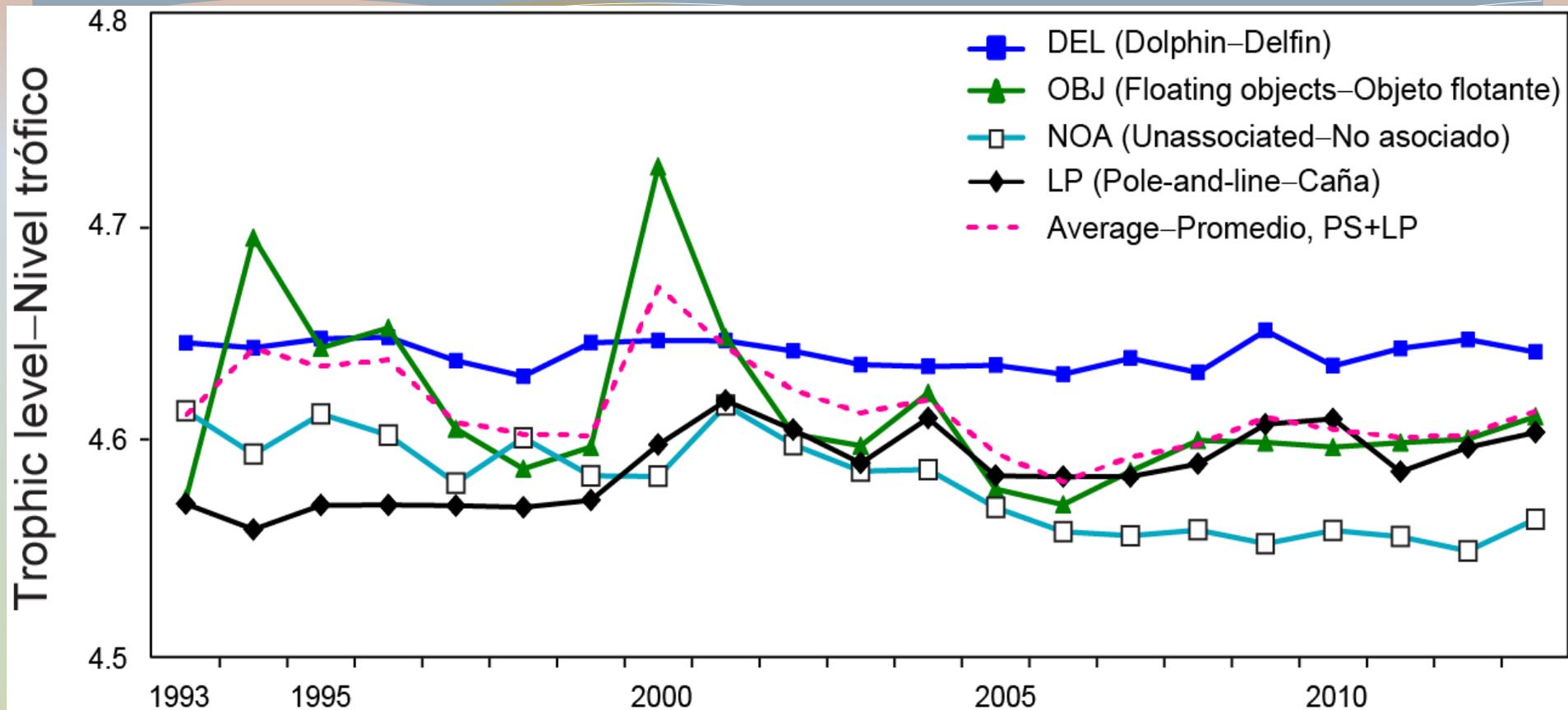


Aggregate indicators: trophic levels and a simplified food-web diagram in the EPO



Aggregate indicators: yearly mean trophic level of the catches

Mean trophic level – useful metric of ecosystem change and sustainability



Ecological Risk Assessment: vulnerability of non-target species

Use of Productivity and Susceptibility Indices to Evaluate Vulnerability in the Purse-Seine Fishery of the Eastern Pacific Ocean

Robert J. Olson¹, Leanne M. Duffy, Mark N. Maunder, Clerydy E. Lennert-Cody, Michael G. Hinton, Michael Scott, Alexandre Aires-da-Silva, Richard Deriso

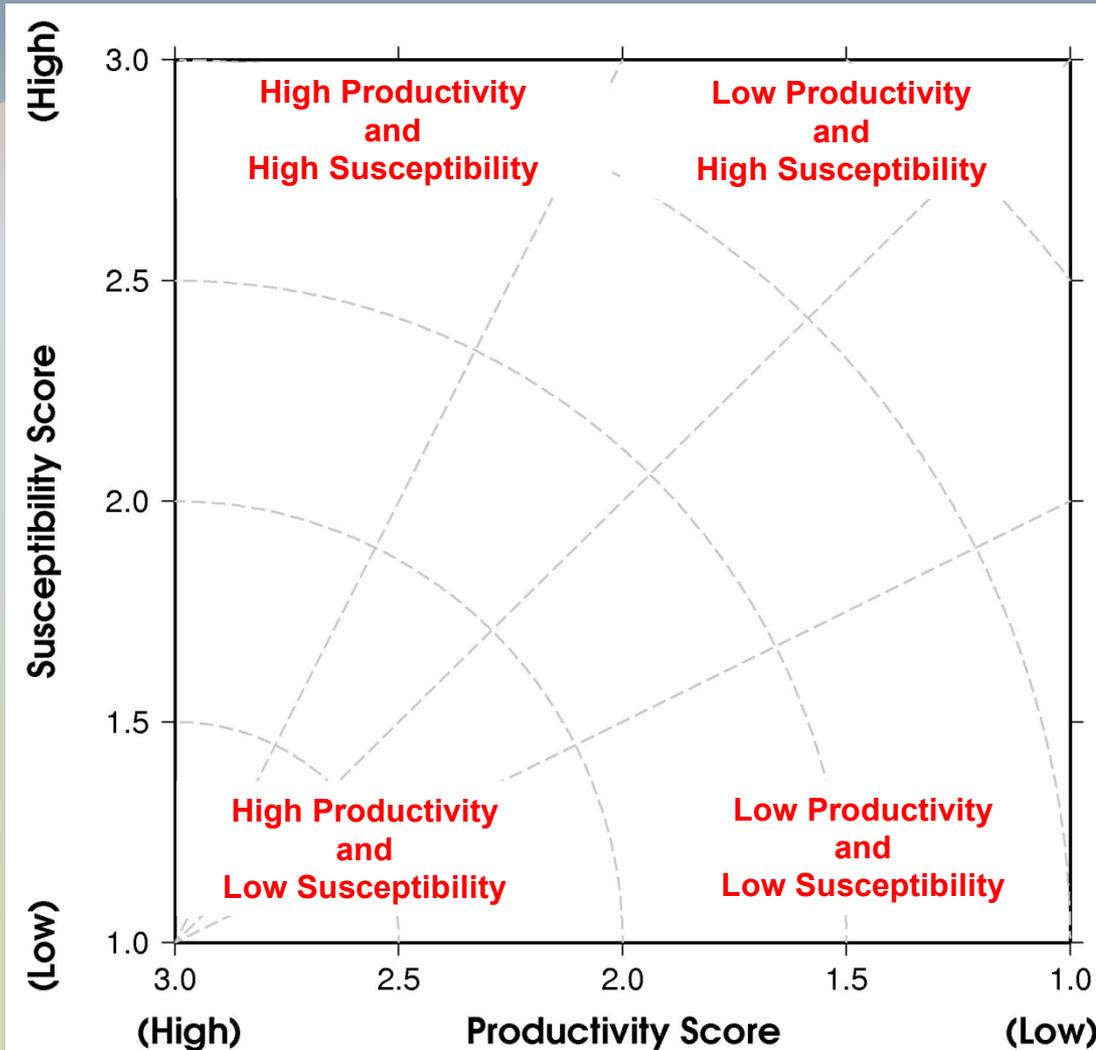
Goal – Develop a tool for determining vulnerability of a species/stock to a fishery

The Fishery

Purse-seine sets in the EPO are carried out by three different methods, related to different aggregation behaviors of the tuna. In "dolphin sets" the net is deployed around the tuna-dolphin aggregation (primarily yellowfin tuna *Thunnus albacares* and spotted dolphin *Stenella attenuata*) after a chase by speedboats.

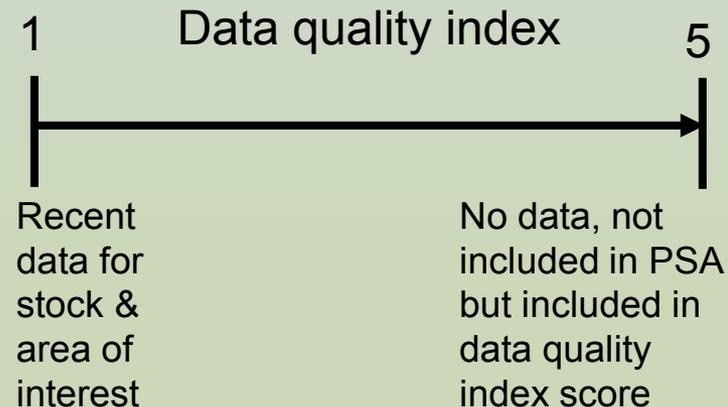
- **Vulnerability:** potential for the productivity of a stock to be diminished by direct and indirect fishing pressure. PSA: vulnerability is combination of a stock's productivity and its susceptibility to the fishery.
- **Productivity** – capacity to recover if stock is depleted (function of life history 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: Productivity and Susceptibility Assessment (PSA) scatter plot



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

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



Ecological Risk Assessment: Proof of concept modifications to the EPO PSA for the purse-seine fishery

- Established 2-step procedure to identify and exclude rare species
 1. If biomass was never $> 0.05\%$ in any year (2005-2013), species was excluded
 2. If proportion catch was $< 5\%$ in any set type, the set type for that species was excluded

Precautionary approach - include IUCN red listed species even if they are rare in the bycatch

- Combined, for each species, the susceptibility values corresponding to each fishery to produce one overall susceptibility value for each species
- The use of bycatch and catch information in the formulation of susceptibility was modified (created 2 alternate susceptibilities)
 1. Current catch information used as an alternate susceptibility
 2. Long-term catch trend information used as an alternate susceptibility

Ecological Risk Assessment: productivity attributes

TABLE J-1 Productivity attributes and scoring thresholds used in the IATTC PSA

Productivity attribute Atributo de productividad	Ranking – Clasificación		
	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	$> 0.1, \leq 1.3$	> 1.3
Maximum age (years) Edad máxima (años)	≥ 20	$> 11, < 20$	≤ 11
Maximum size (cm) Talla máxima (cm)	> 350	$> 200, \leq 350$	≤ 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	$\geq 2.7, < 7.0$	< 2.7
Mean trophic level Nivel trófico medio	> 5.1	$4.5 - 5.1$	< 4.5

Ecological Risk Assessment: modified susceptibility attributes

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

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

Ecological Risk Assessment: EPO PSA preliminary proof of concept susceptibility calculation

Proof of concept goals:

- Create one overall susceptibility score for the purse-seine fishery
- Explore variations in the calculation of susceptibility
- Approach 1

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

where,

s_j^1 is the combined susceptibility for species j

s_{jk} is the susceptibility for species j in set type k , computed using only the attributes in Table J-2. s_{jk} ranges from 1 (lowest) to 3 (highest)

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

Ecological Risk Assessment: Preliminary species list, productivity, susceptibility and vulnerability scores

Approach 1 combined susceptibility: $s_j^1 = \sum_k s_{jk} p_k$

Table J-3a Preliminary productivity and susceptibility scores used to compute the overall vulnerability

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

Ecological Risk Assessment: EPO PSA

Preliminary proof of concept alternate susceptibility calculation

Proof of concept: Approach 2 bringing catch information into formulation of susceptibility

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

where

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

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

s_{jk} is as defined for s_j^1

s_{cps_jk} is the catch rate susceptibility and takes a value of 1, 2 or 3. For non-target species, catch-per set, in number of animals per set, is used to assign a value to s_{cps_jk} :

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

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

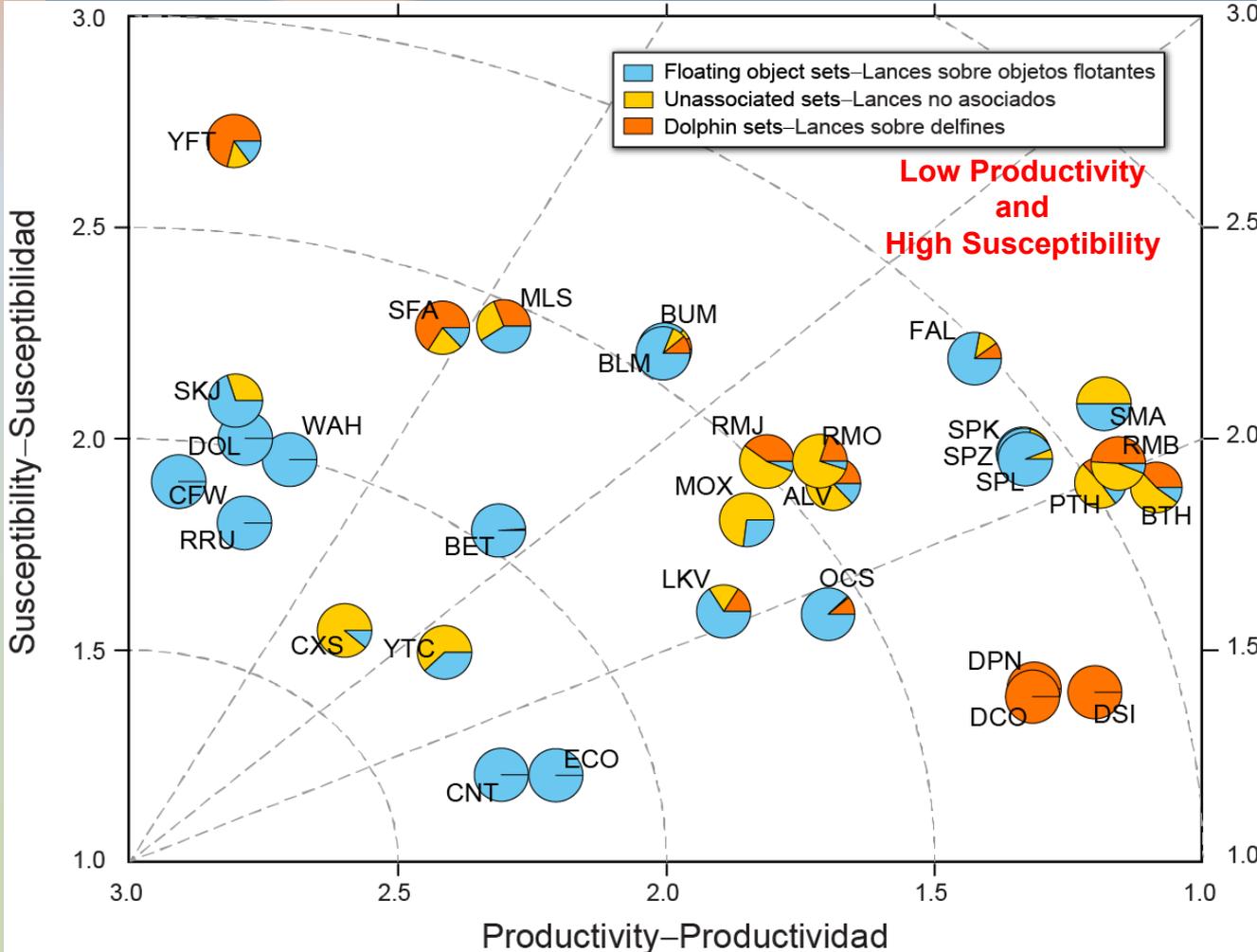
	Dolphin sets	Unassociated sets	Floating-object sets
Bigeye	1	2	3
Yellowfin	3	3	3
Skipjack	2	3	3

cps_{jk} is the catch-per-set for species j in set type k (= class-6 catch (in numbers of animals) divided by number of class-6 sets), for the most recent year (2013).

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

Ecological Risk Assessment: EPO PSA Proof of concept PSA scatter plot for all species and all purse-seine fisheries

Approach 2 combined susceptibility: $s_j^2 = \sum_k s_{jk}^* p_k$
 modifies s_j^1 to take into consideration current catch rates



Group	Species code	Common name
Tunas	YFT	Yellowfin tuna
	BET	Bigeye tuna
	SKJ	Skipjack tuna
Billfishes	BUM	Blue marlin
	BLM	Black marlin
	MLS	Striped marlin
	SFA	Indo-Pacific sailfish
Dolphins	DSI	Spinner dolphin
	DPN	Spotted dolphin
	DCO	Common dolphin
Large fishes	DOL	Common dophinfish
	CFW	Pompano dophinfish
	WAH	Wahoo
	RRU	Rainbow runner
	MOX	Ocean sunfish
	CXS	Bigeye Trevally
	YTC	Yellowtail amberjack
Rays	RMB	Giant manta ray
	RMJ	Spinetail manta
	RMO	Smoothtail manta
Sharks	FAL	Silky shark
	OCS	Ocean whitetip shark
	SPL	Scalloped hammerhead
	SPZ	Smooth hammerhead
	SPK	Great hammerhead
	BTH	Bigeye thresher shark
	PTH	Pelagic thresher shark
	ALV	Common thresher shark
	SMA	Shortfin mako shark
Small fishes	CNT	Ocean triggerfish
	ECO	Bluestriped chub
Turtles	LKV	Olive Ridley turtle

Ecological Risk Assessment: EPO PSA

Preliminary proof of concept alternate susceptibility calculation

Proof of concept: Approach 3 bringing catch trend information into formulation of susceptibility

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

where

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

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

s_{jk} is as defined for s_j^1

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

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

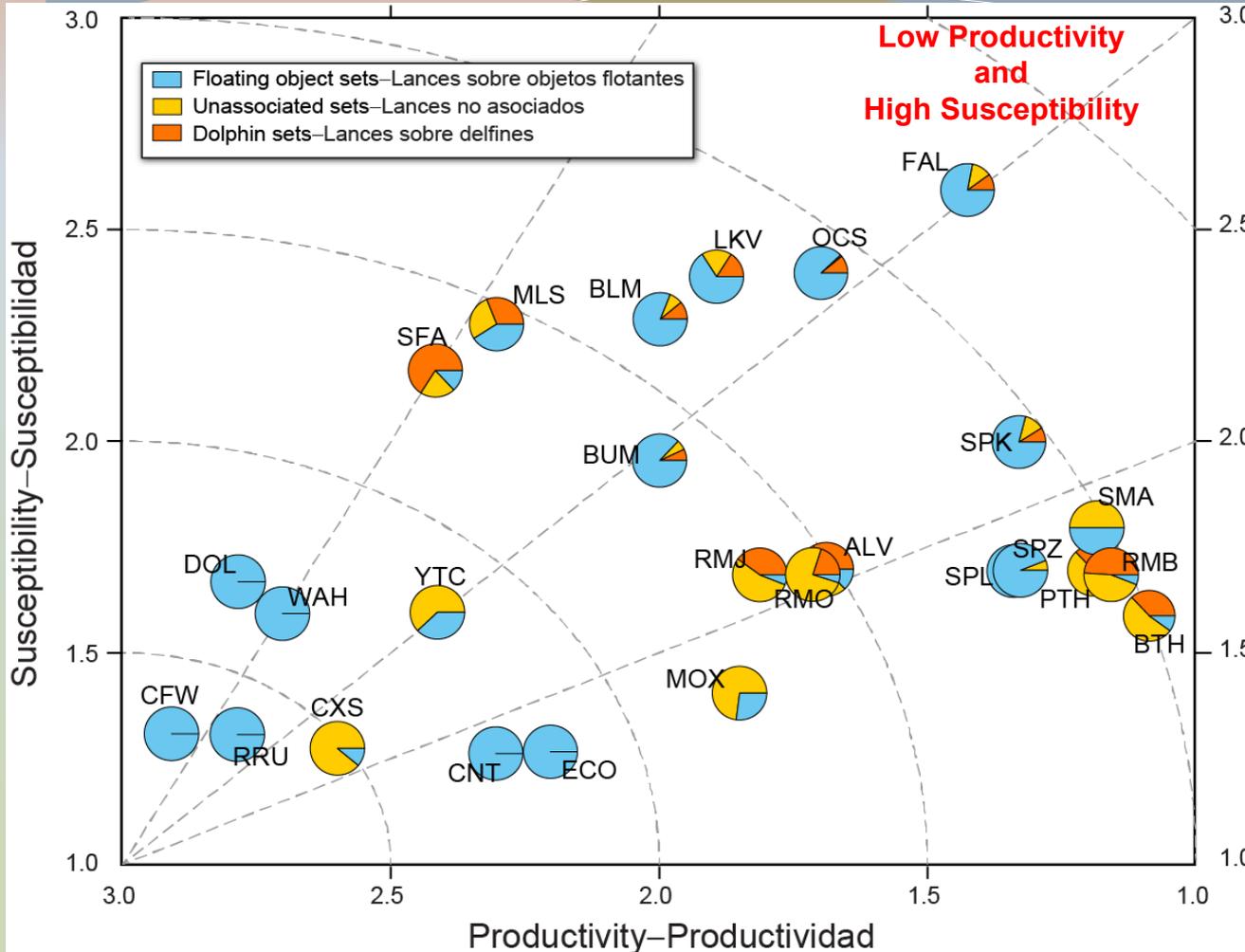
$trend_{jk}$ is the slope of the regression of $cps_{jk,y}$ and year y , from the start of the data collection (which may vary by species). A significant trend was any slope with a p -value < 0.05 .

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

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

Ecological Risk Assessment: EPO PSA Proof of concept PSA scatter plot for all species and all purse-seine fisheries

Approach 3 combined susceptibility: $s_j^3 = \sum_k s_{jk}^{**} p_k$
 modifies s_j^1 to take into consideration long-term catch trends



Group	Species code	Common name
Tunas	YFT	Yellowfin tuna
	BET	Bigeye tuna
	SKJ	Skipjack tuna
Billfishes	BUM	Blue marlin
	BLM	Black marlin
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	PTH	Pelagic thresher shark
	ALV	Common thresher shark
	SMA	Shortfin mako shark
Small fishes	CNT	Ocean triggerfish
	ECO	Bluestriped chub
Turtles	LKV	Olive Ridley turtle

Ecological Risk Assessment: EPO PSA Proof of concept - some comments

Approach 1: s_j^1

Differences among set-type specific susceptibilities do not always agree with differences among bycatch rates that we see in the fishery data

The list of susceptibility attributes does not address long-term population change

Approach 2: s_j^2

Does not account for long-term population change (e.g. Oceanic whitetip sharks)

May be compromised by differences among species in abundance

Approach 3: s_j^3

CPUE trends may not reflect changes in abundance and/or may represent the integrated affects of multiple fisheries (e.g., longline and purse-seine).

EPO PSA Proof of concept - comparing approaches

Some shark species and the giant manta have the highest vulnerability scores

Comparing s_j^1 and s_j^2 :

Percent difference between s_j^1 and s_j^2 ranges from 1 – 8% for species with highest vulnerability scores

For many species, $s_j^2 > s_j^1$ with largest differences for some of the large fishes:
e.g. Pompano dolphinfish, Bigeye trevally, Wahoo

Comparing s_j^1 and s_j^3 :

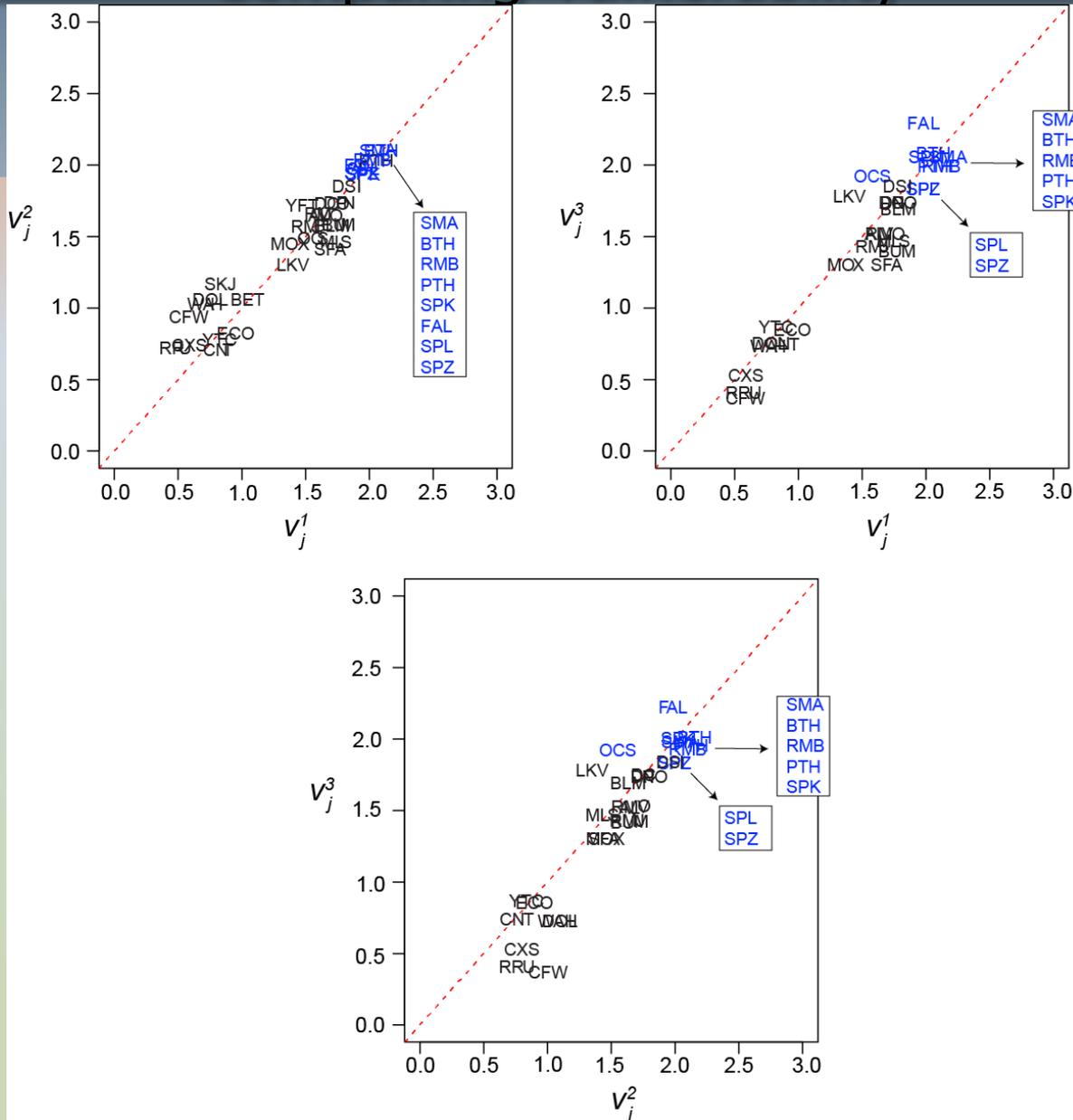
For many species, $s_j^1 > s_j^3$, with the largest differences for s_j^3 for:
Oceanic whitetip, Olive Ridley turtles, Silky sharks

Comparing s_j^2 and s_j^3 :

For many species, $s_j^2 > s_j^3$, with the largest differences for s_j^3 for:
Oceanic whitetip, Olive Ridley turtles

Comment: When using catch data for susceptibility, it is difficult to isolate the affect of the one fishery: oceanic whitetip is associated with a high value of s_j^3 because current cps is quite low compared to historical levels – the affect of all fisheries operating in the EPO, not just purse-seine.

Ecological Risk Assessment: Comparing vulnerability



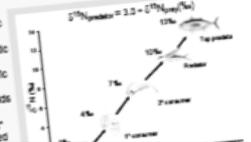
Ecological Risk Assessment: the EPO PSA – future improvements

- Further evaluate which method for calculating susceptibility is preferable and if more revisions should be made
- Thorough review of susceptibility attributes included in the analysis
- Full literature review in progress
- Carefully evaluate data on catch trends and decide if/how we can include information about depletion (e.g. Oceanic whitetip sharks)
- Explore variations on methods used by ICCAT
 - Arrizabalaga, H., P. de Bruyn, G.A. Diaz, H. Murua, P. Chavance, A.D. de Molina, D. Gaertner, J. Ariz, J. Ruiz, and L.T. Kell. 2011. Productivity and susceptibility analysis for species caught in Atlantic tuna fisheries. *Aquatic Living Resources* 24(01): 1-12.
 - Cortés, E., F. Arocha, L.R. Beerkircher, F. Carvalho, A. Domingo, M. Heupel, H. Holtzhausen, M.N. Santos, M. Ribera, and C. Simpfendorfer. 2010. Ecological risk assessment of pelagic sharks caught in Atlantic pelagic longline fisheries. *Aquat. Living Resour.* 23: 25-34.

The Inter-American Tropical Tuna Commission (IATTC) is charged with management of the tropical tuna and bilfish 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 (e.g. interactions via the food web).

Stable isotope ecology

Stable carbon and nitrogen isotope analysis is a useful complement to stomach-content analysis because all components of the assimilated diet are integrated into an animal's tissues, providing a measure of relative trophic position (Figures 4). The spatial distribution of stable isotope values of yellowfin tuna in relation to those of the food web never detected in diet data? Additional insight is provided by compound-specific isotope analysis of amino acids (AA-CSIA). In isotope analysis of amino acids, "source" amino acids (e.g. phenylalanine, glycine) retain the isotopic signature of the base of the food web, and "trophic" amino acids become enriched in $\delta^{15}N$ and $\delta^{13}C$ as they move up the food web.



Ecosystem considerations in the eastern Pacific Ocean

Questions?

Trophic ecology of predator communities

Extensive stomach sampling efforts have been conducted primarily during four periods: 1965-1967, 1969-1972, 1992-1994, and 2003-2005. Tunas were sampled during the first two periods, while the predator community (entire purse-seine catch/catcher) was sampled during the latter two periods (Figure 2).

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 primary daylight hours (Figure 3).

Other food-web components

Apex predation on tropical tunas

Tunas are commonly considered apex predators. Tunas, even as adults, are subjected to predation by large-bodied 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 (Figure 4).

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

Food-web research

Figure 2

Percent energy

Figure 4

Frequency (number) of skipjack and yellowfin tunas, by body size, consumed by sharks (dark grey bars), tunas (light grey bars), and unclassified tunas (white bars) in the eastern tropical Pacific Ocean. The dashed black line indicates the relative reproductive potential of individual skipjack and yellowfin tunas across size classes. The solid black line divides the body size that comprise 80% of tunas.

Figure 6

Partial dependence plot that predicts the diet composition of yellowfin tunas in the eastern Pacific Ocean for the 1965-1967 and 2003-2005 sampling periods. The prey groups identified at each terminal node (outlined circles) are those with the highest predicted prey proportion in the diet. Blue lines in the tree indicate the partial dependence plots for the prey groups. The x-axis represents the partial dependence plot for the prey group. The y-axis represents the predicted prey proportion.

Ecological risk assessment

Long-term ecological assessment of ecosystem-based management. The vulnerability of the stocks to overfishing, in terms of overall vulnerability of fish, turtle, and mammal stocks to overfishing, in terms of overall vulnerability (i.e. Euclidean distance from the origin of Figure 9 to the data points) and the shark marks (y scored the highest) (Figure 9).

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 matrix 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 EPO¹ to represent 1950-1997. A sensitivity analysis indicated that changes in the parameters for two components at middle trophic levels, cephalopods and Anchoa spp., exerted the greatest influence on the ecosystem (Figure 10).

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.