Diet compositions of fish species in the Northern Gulf of California

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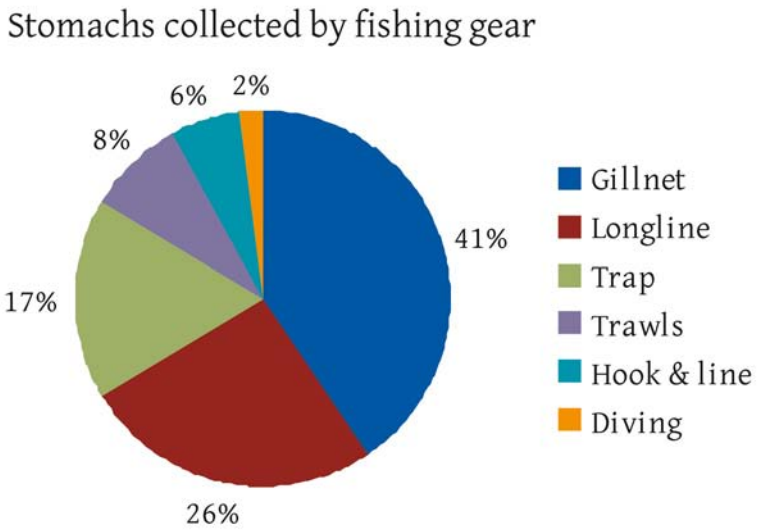
We developed feeding relationships and a preliminary food web in the Northern Gulf of California to parameterize an Atlantis ecosystem model (Box 1). Diet compositions were based of fish stomachs sampled and analyzed by researchers at the Centro Intercultural de Estudios de Desiertos y Oceános, A.C. and Conservación y Biodiversidad, A.C. in communities of the Northern Gulf and on literature sources.

Fish stomachs were collected between February and August 2008

Box 1. What is Atlantis?

Atlantis is a spatially explicit modeling platform that integrates physical, chemical, ecological and socioeconomic dynamics. The core of Atlantis is a three-dimensional biophysical module which follows nutrient flows (Nitrogen) through the main biological groups in the system. Other modules cover the major steps in the adaptive management cycle (industry, monitoring, assessment, management and implementation). The trophic resolution is at the functional group level. An 'availability matrix' describes the rates of flow of material between functional groups, by defining the contribution of each prey type to the diets of predators and considering density dependent effects relating to interaction rates, predator feeding mode, prey avoidance behavior and other factors. The availability matrix is calculated using the percent contribution of prey to predator diet, taken as an annual average over the whole study area.

Stomachs were sampled with a variety of gear types and at several locations to reduce intra-haul correlation as a source of error. Of the 444 stomachs sampled, 209 had identifiable stomach contents.



Fish stomachs for common commercial and bycatch species of the Northern Gulf of California were obtained from local markets, directly from fishermen or from a trawl sampling study (Ainsworth et al., unpublished data). Fish used came from a variety of baited and unbaited fishing gear types and were frozen prior to dissection in the laboratory. Prey items were identified to functional group level, i.e. species similar in trophic role, morphology, behaviour, physiology or other niche characteristics, and weighed together. The rates of digestion or gastric evacuation were not considered, so it is possible that the contribution of soft-bodied organisms (e.g., jellyfish) and high-energy content organisms are underestimated relative to chitinous organisms (e.g., crustaceans).

Taxa from which usable stomach content information was obtained

Species	Common name
Atractoscion nobilis	white seabass
Balistes polylepis	finescale triggerfish
Calamus brachysomus	Pacific porgy
Caulolatilus affinis	bighead tilefish
Caulolatilus princeps	ocean whitefish
Dasyatis dipterura	diamond stingray
Epinephelus acanthistius	gulf coney
Micropogonias megalops	bigeye croaker
Mycteroperca jordani	gulf grouper
Paralabrax maculatofasciatus	spotted sand bass
Raja inornata	California ray
Scomberomorus sierra	Pacific sierra
Semicossyphus pulcher	California sheephead
Sphoeroides annulatus	bullseye puffer fish
Cynoscion spp.	weakfishes
Mustelus spp.	smooth-hound sharks
Paralabrax spp.	rock-basses
Paralichthys spp.	southern flounders
Sphoeroides spp.	common puffers

We used a statistical fitting procedure (Box 2) to combine the field sampling results with available diet information from *FishBase*, a global archive of diet and life history information. This data was used to determine diet contributions for predator fish species. Estimates from simple averages are lower than estimates from the maximum likelihood method for major prey items (i.e., those constituting more than ~12% of the predator's diet) and higher for minor prey items.

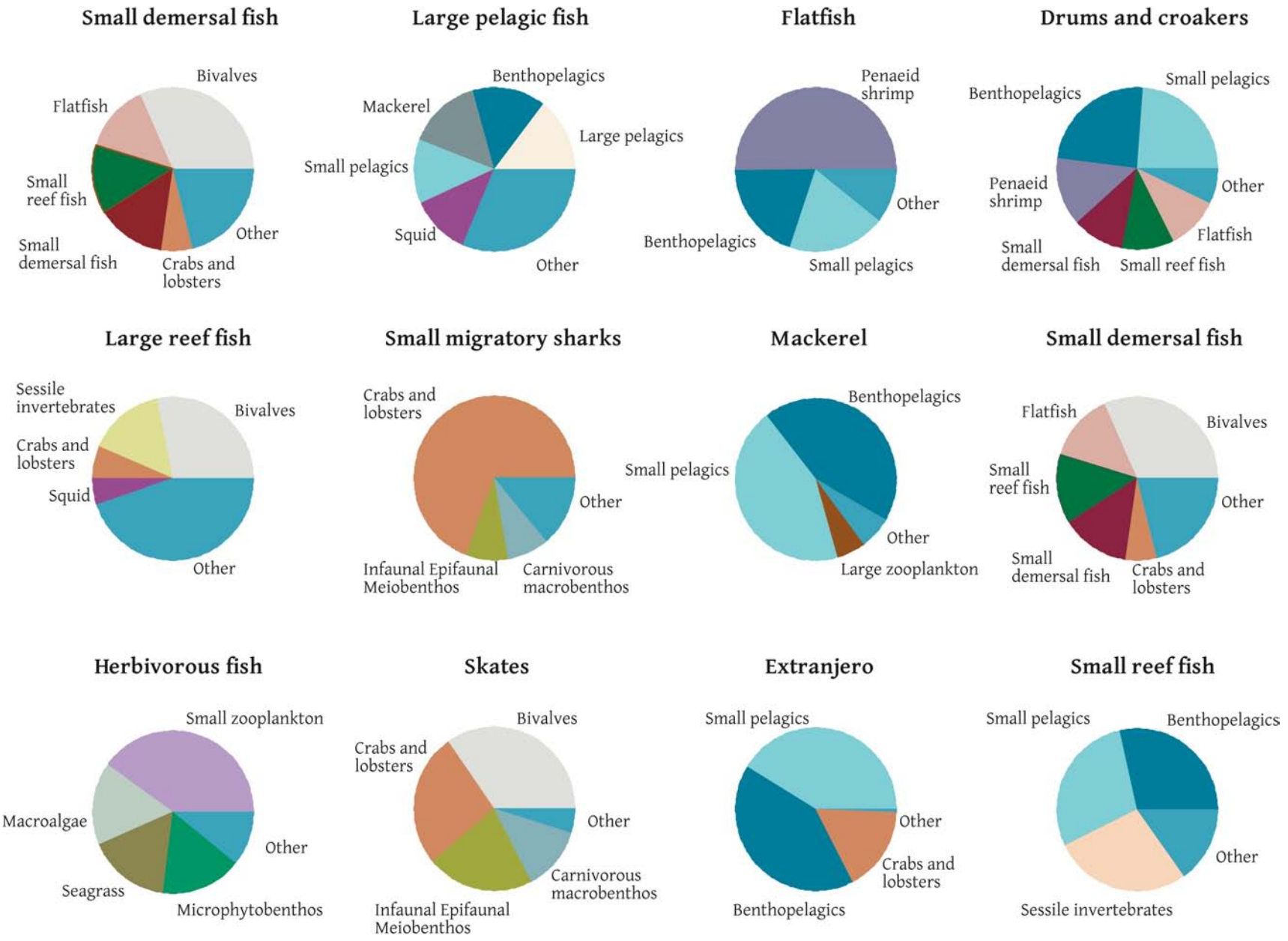
We included functional groups in the analysis represented by at least 10 observations, either stomachs containing food in the case of field results, individual studies in *FishBase*, or a combination of field observations and literature values. We used references from 60 studies in FishBases, including 101 species and 23 of the Atlantis model's 27 fish functional groups. *FishBase* diet values were treated as a single stomach observation so that field observations had more weight.

Diversity (Shannon index - SW) of prey items generally increases with the number of species represented in the predator functional group.

Functional group	SW	Number of prey groups	Number of species in predator group	Number of diet records
Large pelagic fish	2.76	23	37	82
Large reef fish	2.71	8	58	37
Small demersal fish	2.14	9	130	43
Drums and croakers	2.02	19	29	40
Herbivorous fish	1.72	49	14	12
Small reef fish	1.71	35	106	33
Skates	1.58	20	23	24
Flatfish	1.34	28	33	9
Small migratory sharks	1.23	25	4	10
Mackerel	1.2	17	5	20
Extranjero	1.07	25	2	21

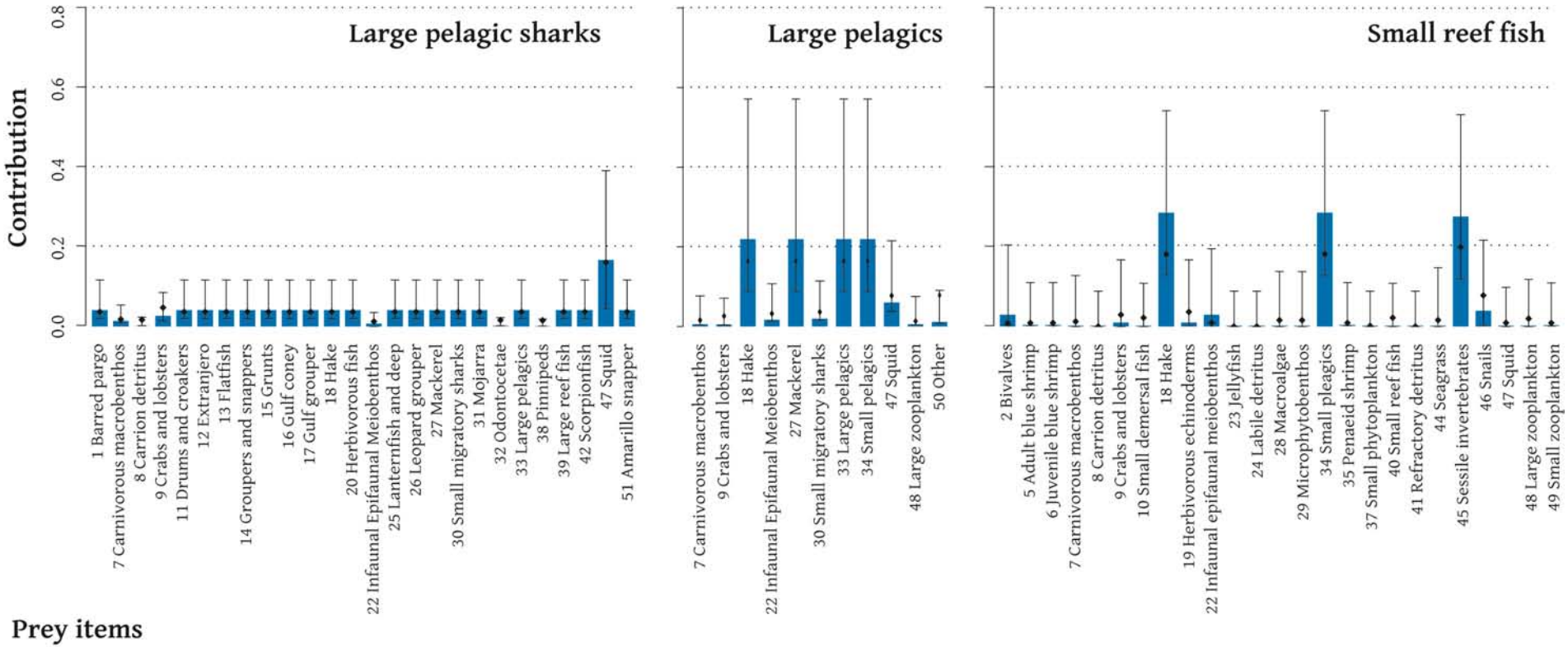
Box 2. Statistical analysis

The statistical method involved using a resampling techinque (bootstrapping) on the stomach content data to create statistical distributions describing the likely contribution of each prey item to the diets of predators. Both predator and prey were analyzed at the level of Atlantis functional groups. For each predator, these distributions were then fit to a probablity function (a Dirichlet function). We then estimated a maximum likelihood value representing the contribution of each prey item to the diet of the predator. This statistical method minimizes the importance of rare events (i.e. stomachs full of a single prey item due to opportunistic feeding on prey with patchy spatial distributions, or when potentially important prey are rare in predator stomachs), so it may be a more robust way of analyzing data containing fewer observations. The method also allows the estimation of a confidence interval for final diet composition.



Summary of diet contributions. Charts show main prey items for each functional group. The complete diet contributions, detailing the items in the category"Other" and error estimates are shown in the following pages.

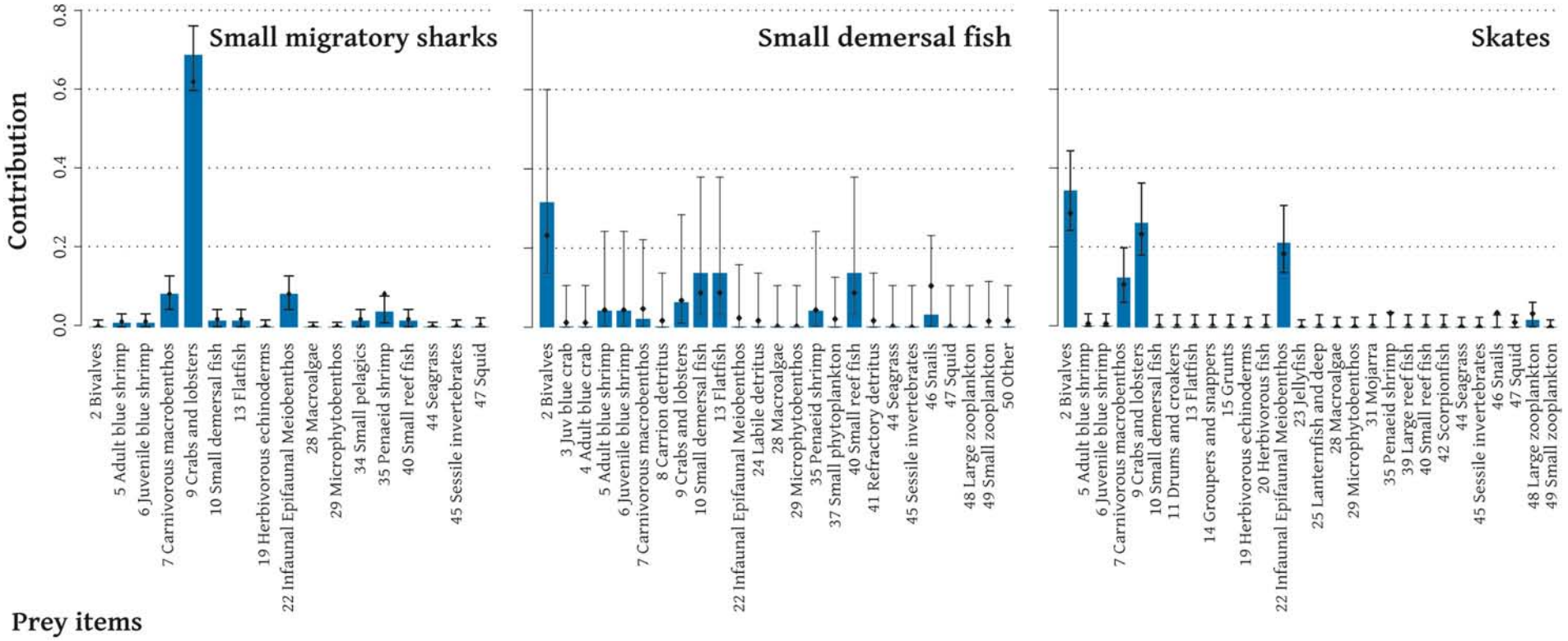
Diet contributions



We identified 51 prey items, bars are ordered and show item number for easier comparison. Error bars show upper and lower 95% confidence intervals. Circles show results of simple averages, i.e. the contribution of prey to a predator's diet is the mean of all available stomachs.

Diets were based on:
Large pelagic shark - *Alopias superciliosus, Alopias vulpinus, Carcharhinus leucas, Carcharhinus limbatus, Carcharhinus obscurus, Carcharhinus porosus, Carcharodon carcharias, Ginglymostoma cirratum, Isurus oxyrinchus, Rhizoprionodon longurio, Sphyrna lewini, Sphyrna mokarran* and *Sphyrna zygaena*.
Small reef fish - *Aluterus scriptus, Arothron hispidus, Arothron meleagris, Caulolatilus affinis, Caulolatilus princeps, Chaetodipterus zonatus, Diodon holocanthus, Diodon hystrix, Fistularia commersonii, Forcipiger flavissimus, Heteropriacanthus cruentatus, Lactoria diaphana, Ostracion meleagris* and *Zanclus cornutus*. Small pelagics were used to bait these predators, thus their contribution to the diet may be overestimated.
Large pelagics - *Carangoides otrynter, Caranx sexfasciatus, Chloroscombrus orqueta, Coryphaena hippurus, Katsuwonus pelamis, Oligoplites altus, Oncorhynchus tshawytscha, Remora remora, Rhincodon typus, Sarda chiliensis chiliensis, Seriola lalandi, Sphyraena ensis* and *Xiphias gladius*.

Diet contributions



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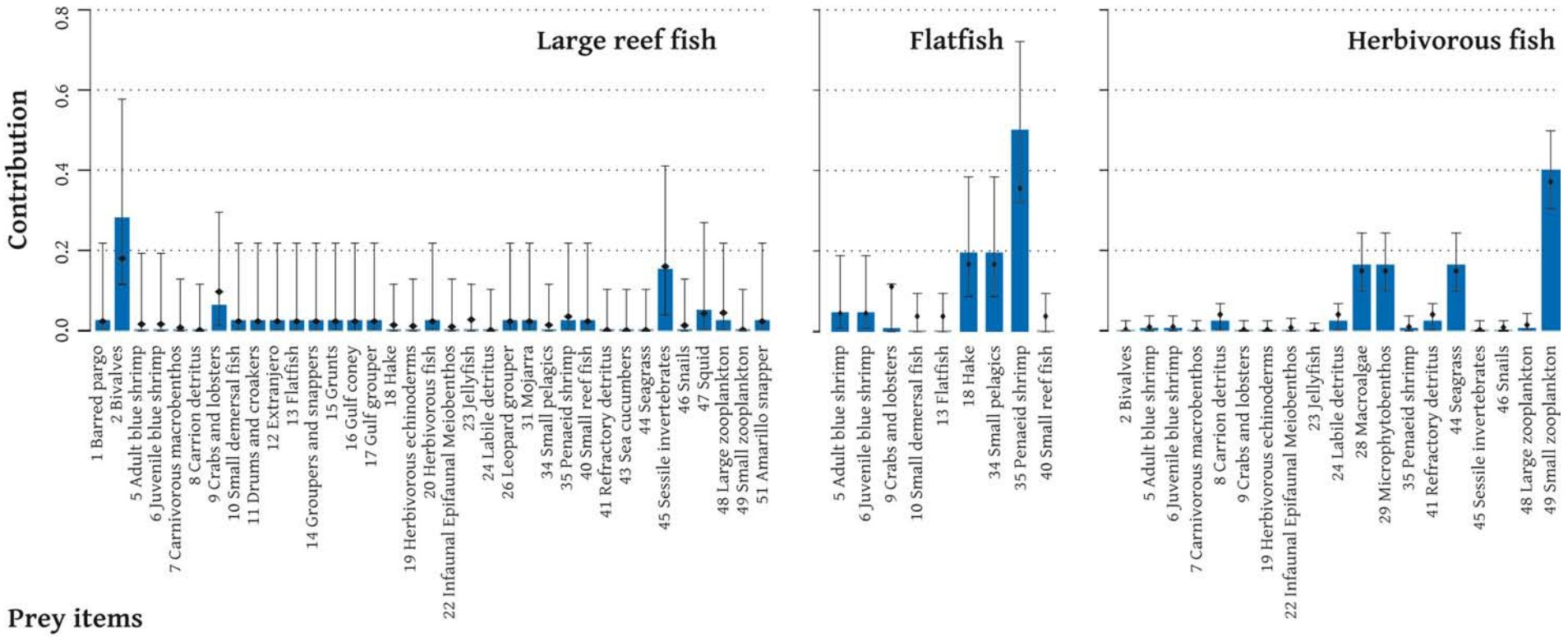
Diets were based on:
Small migratory sharks - *Mustelus californicus*, *Mustelus henlei*, *Mustelus lunulatus* and *Mustelus* spp.
Small demersal fish - *Albula vulpes, Calamus brachysomus, Centropomus nigrescens, Centropomus robalito, Gymnothorax mordax, Hexanematichthys platypogon* and *Sphoeroides* spp.
Skates - *Aetobatus narinari, Dasyatis dipterura, Heterodontus francisci, Myliobatis californica, Raja inornata , Triakis semifasciata* and *Urobatis halleri.*

Diet contributions



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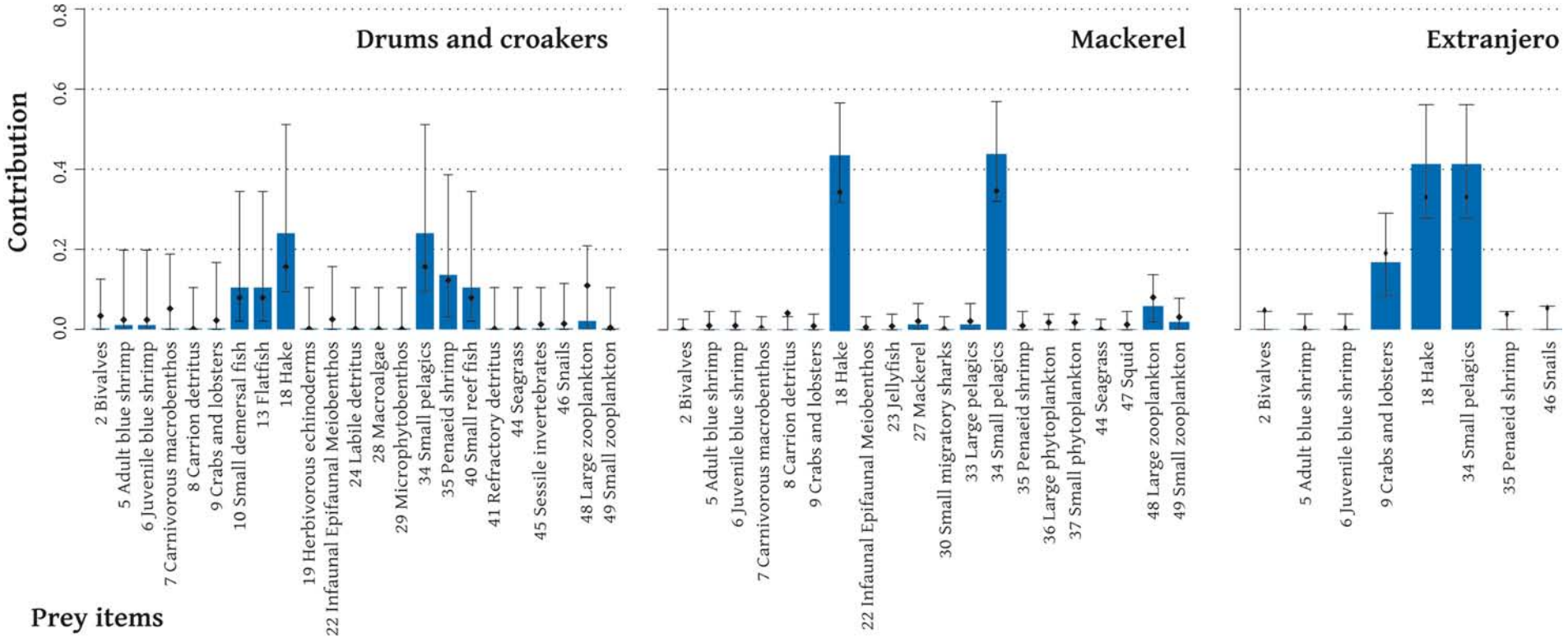
Diets were based on:
Large reef fish - *Balistes polylepis, Semicossyphus pulcher, Thalassoma lutescens, Thalassoma purpureum* and *Trichiurus lepturus*. Drums and croakers, Small pelagics, and Benthopelagics were used to bait these predators, thus their contribution to the diet may be overestimated.
Herbivorous fish - *Girella nigricans, Hermosilla azurea, Mugil cephalus, Mugil curema* and *Scarus ghobban*.
Flatfish - *Ancylopsetta dendritica, Paralichthys* spp. and Pleuronectidae.

Diet contributions



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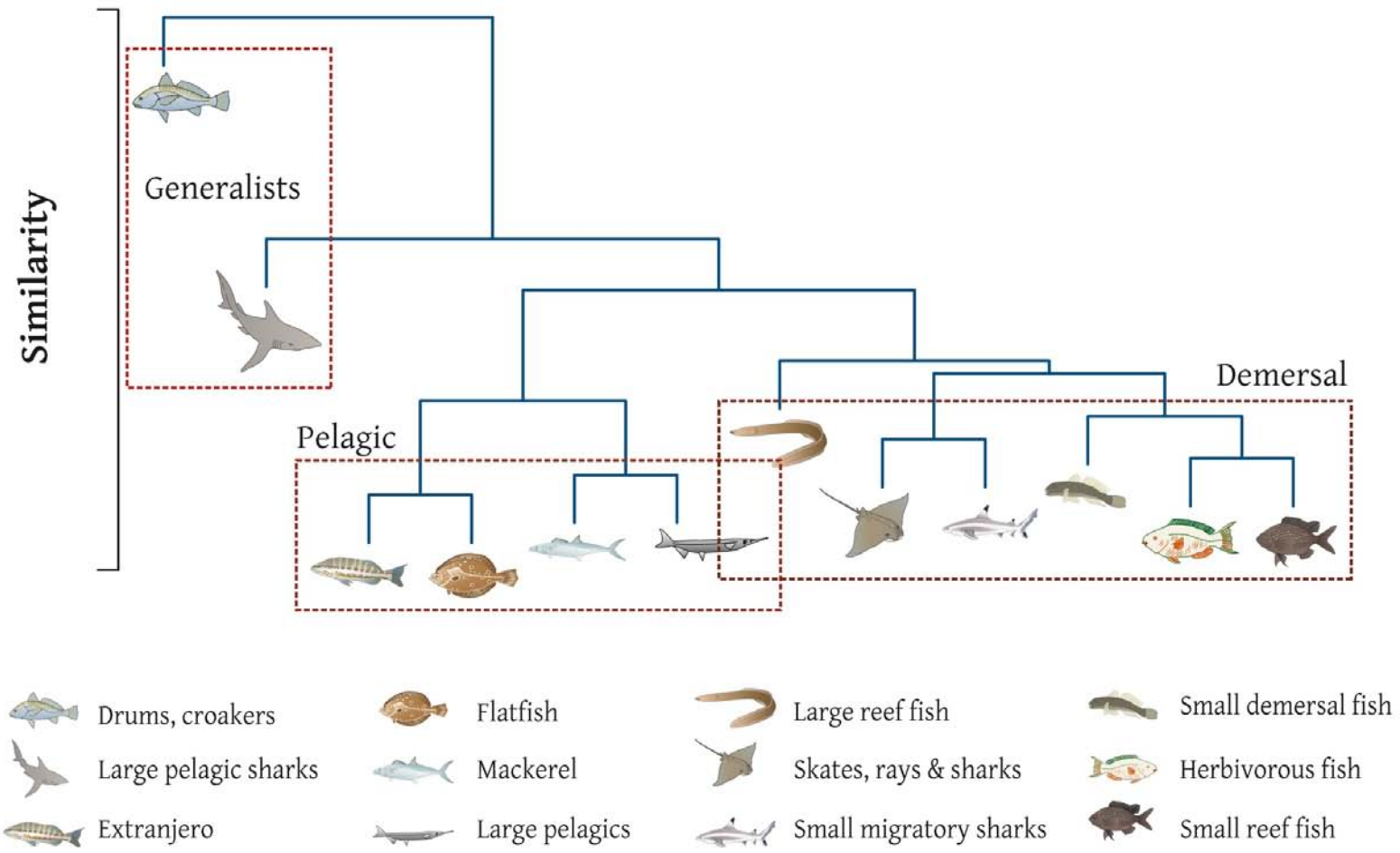
Diets were based on:
Drums and croakers - *Atractoscion nobilis, Cynoscion spp., Cynoscion xanthulus, Larimus pacificus* and *Micropogonias megalops*. Small reef fish and small demersal fish were used to bait these predators, thus their contribution to the diet may be overestimated.
Mackerel - *Scomber japonicus, Scomberomorus sierra* and *Trachurus symmetricus.*
Extranjero - *Paralabrax maculatofasciatus* and *Paralabrax* spp. Small pelagics are used to bait these species, thus their contribution to the diet may be overestimated.

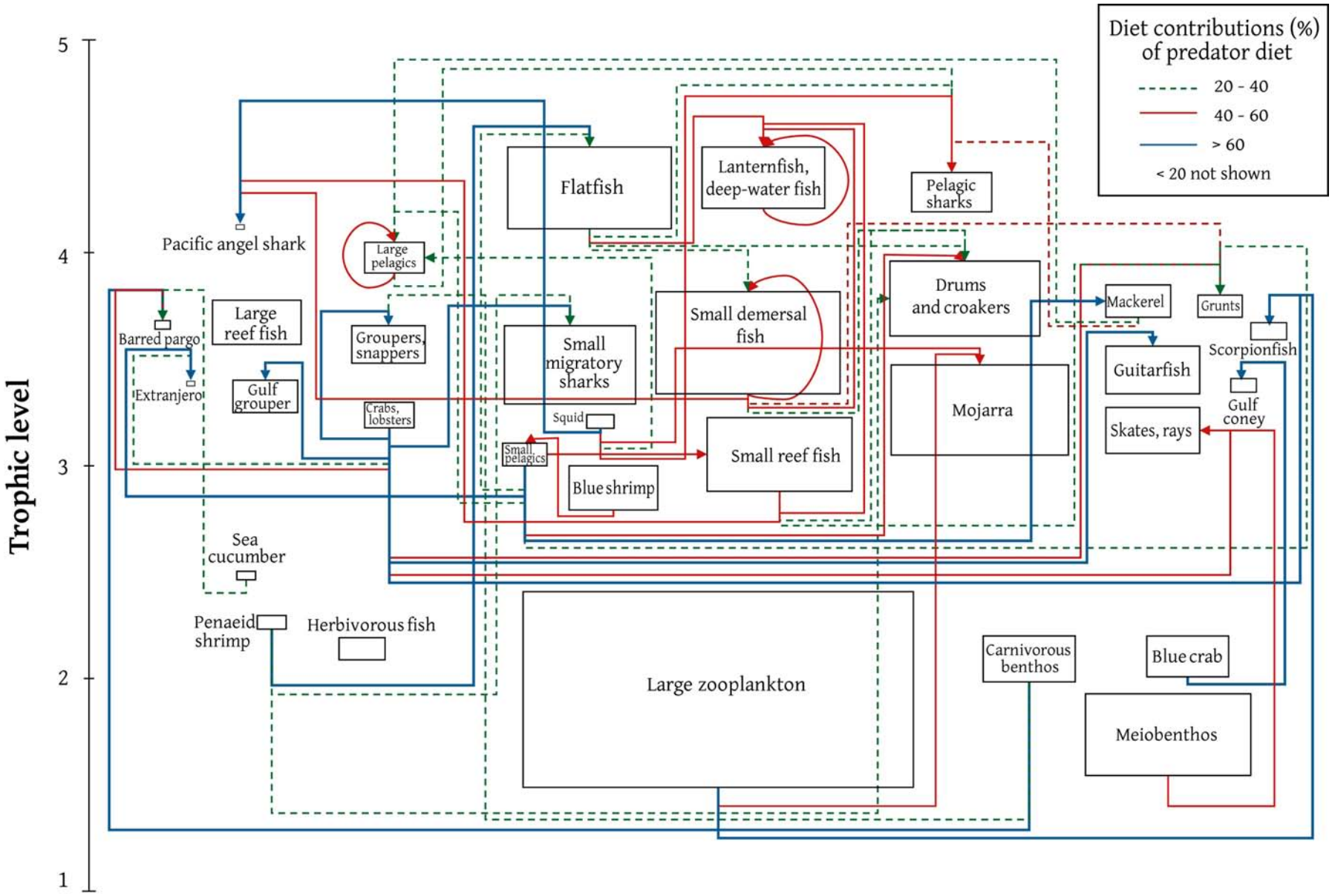


Comparison of the similarity among fishing guilds, derived from the maximum likelihood estimates and calculated using complete linkage clustering. At the level of species resolution used we were able to identify two broad feeding guilds, pelagic and demersal. The pelagic guild consists of benthopelagic and pelagic species, while the demersal guild consists of elasmobranchs that feed primarily on benthic invertebrates, and demersal teleosts that feed on a mix of invertebrates, fish, algae and seagrasses. Identifying these feeding relationships can help us predict ecosystem effects of fisheries and management plans.

Further reading

Arreguín-Sánchez, F., E. Arcos and E. A. Chávez. 2002. Flows of biomass and structure in an exploited benthic ecosystem in the Gulf of California, Mexico. Ecological Modelling 156:167-183.

Fulton, E.A., A. D. M. Smith and D. C. Smith. 2007. Alternative Management Strategies for Southeast Australian Commonwealth Fisheries: Stage 2. Quantitative Management Strategy Evaluation. Australian Fisheries Management Authority. CSIRO, 372 pp. Available at http://atlantis.cmar.csiro.au/



Food web interactions in the Northern Gulf of California based on estimated fish diets. The forage groups most important for the demersal assemblage are the small reef fish and small demersal fish. These prey items are consistently the two most important contributors to diet among demersal predator groups. They are also primary diet items for drums and croakers and flat fish. Pelagic species show a wider variety in the types of prey items consumed, but commonly these prey include small pelagic fish and hake.

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The data here presented are part of the publication: Ainsworth C.H., I.C. Kaplan, P.S. Levin, and M. Mangel. In review. A statistical approach for estimating fish diet compositions from multiple data sources: Gulf of California case study. Ecological Applications. This manuscript can be requested from the author, cameron.ainsworth@noaa.gov

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Symbol in diagrams courtesy of the Integration and Application Network (ian.umces.edu/symbols/), University of Maryland Center for Environmental Science. Type set in Gentium. Cover and back photos: M.A. Medina. Inside photos: R. Loaiza-Villanueva, H. Morzaria-Luna, A. Iris-Maldonado. We would like to acknowledge P. Turk Boyer, A. Sánchez-Cruz, R. Loaiza-Villanueva, S. Pérez-Valencia, V. Castañeda-Fernández de Lara (CEDO) and J. Torre, N. Encinas, M. Rojo and C. Moreno (COBI) for sample collection and analysis, and B. Semmens (NOAA), N. Tolimieri (NOAA) and B. Pflugeisen (Ohio State University) for helpful discussions.

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