PFRP

Pelagic Fisheries Research Program

university of hawai'i at mānoa

Volume 14, Number 1 2009

Predation, Cannibalism, and the Dynamics of Tuna Populations

Tim Essington, Mary Hunsicker, Robert J. Olson, Mark Maunder, and Jim Kitchell

Introduction

The unmistakable trend toward ecosystem approaches to fisheries management is documented in a wide range of official declarations, national and international guidelines, and national-level legislation. The central motivation for this movement is the view that a more holistic ecological perspective on fisheries can lead to more robust management strategies.

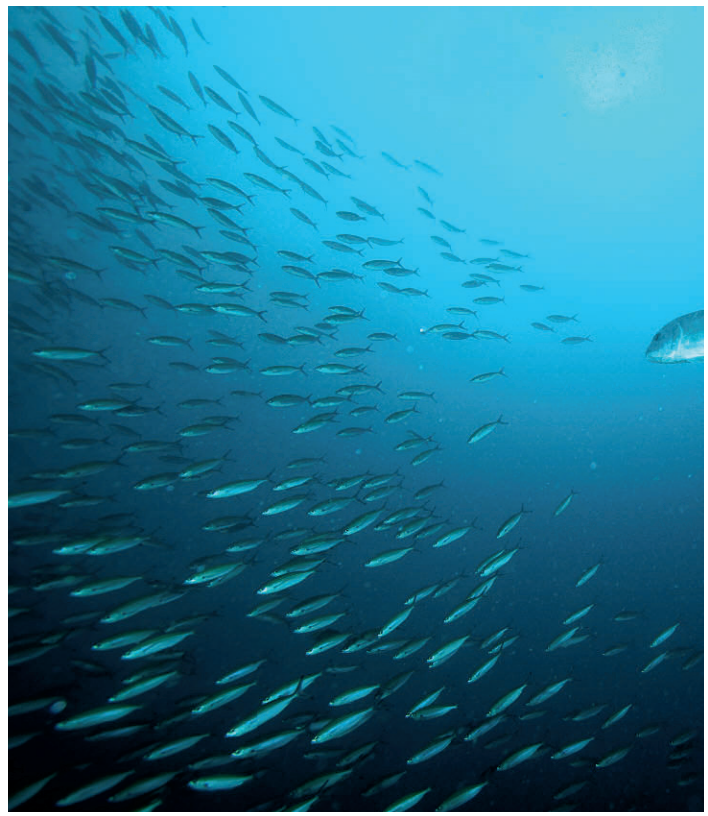
Ecosystem-based fisheries management includes consideration of the impacts of ecosystem processes *on* fisheries and the unintended alteration of ecosystems *by* fisheries. The latter interest has been fueled by the rapidly accumulating evidence that selective removal of marine life can induce profound restructuring of marine food webs. This weight of evidence is remarkable considering that until very recently strong trophic interactions were thought to be rare in marine ecosystems. The challenge for fisheries scientists is to be able to identify and predict these strong species interactions and to consider their management implications.

Pelagic longline fisheries for tunas, sharks, and marlins are unique compared to other fisheries in the world in that they catch a relatively narrow component of the food web. While these piscivorous fishes constitute the apex predators in these ecosystems, many of these species also prey upon members of their own guild. Might these same types of food-web interactions be occurring among species targeted in the high-seas pelagic fisheries? These high-seas pelagic fisheries target tuna species that are dominant components of the predator guild in pelagic ecosystems but also capture high-trophic-level marlins and sharks.

Given the restricted range of the food web that is captured, one might reasonably anticipate little in the way of trophic interactions that could potentially corrupt conventional single-species management approaches. However a closer examination of the trophic linkages within the apex-predator guild reveals the potential for complex interactions among and within species in the form of intra-guild predation and cannibalism.

Large-bodied marlins commonly consume skipjack and yellowfin tuna; pelagic sharks are widely viewed as opportunistic top predators; and skipjack, yellowfin, and bigeye tunas all cannibalize juveniles with some regularity. Consequently even species considered

(continued on page 2)



School of baitfish (Photo: Kevin C. Weng)

CONTENTS

Table 1. Location of capture, sampling time period, and type of data sources available for major predators in the pelagic predators food-habits database. ETP, eastern tropical Pacific; CTP, central tropical Pacific; and WTP, western tropical Pacific. H, historical period (1950–1979); and C, contemporary period (1980–2005)

Common Name	Species name	ETP	CTP	WTP	Summarized	Primary
Bigeye thresher shark	*Alopias superciliosus*	x			C	
Blacktip shark	*Carcharhinus limbatus*	x				C
Blue shark	*Prionace glauca*	x				C
Bull shark	*Carcharhinus leucas*	x				C
Galapagos shark	*Carcharhinus galapagensis*		x		H	
Oceanic whitetip	*Carcharhinus longimanus*	x	x		H	C
Pelagic thresher shark	*Alopias pelagicus*					C
Scalloped shark	*Sphyrna lewini*	x			C	C
Shortfin mako shark	*Isurus oxyrinchus*	x	x		C,H	C
Silky shark	*Carcharhinus falciformis*	x			C	C
Smooth hammerhead shark	*Sphyrna zygaena*	x			C	C
Tiger shark	*Galeocerdo cuvier*		x		H	
Whitenose shark	*Nasolamia velox*	x				C
Billfish (nei)	*Istiophoridae, Xiphiidae*			x	H	
Black marlin	*Makaira indica*			x	H	C
Blue marlin	*Makaira nigricans*	x	x	x	C,H	C
Indo-Pacific sailfish	*Istiophorus platypterus*	x			C	C
Shortbill spearfish	*Tetrapturus angustirostris*	x				C
Striped marlin	*Tetrapturus audax*	x	x	x	C,H	C
Swordfish	*Xiphias gladius*	x			C	C
Albacore tuna	*Thunnus alalunga*	x	x	x	C,H	C
Bigeye tuna	*Thunnus obesus*	x	x	x	H	C
Frigate and bullet tunas	*Auxis sp.*	x				
Pacific bluefin tuna	*Thunnus orientalis*	x			H	C
Skipjack tuna	*Katsuwonus pelamis*	x	x		C,H	C
Tunas (nei)	*Thunnini*			x	H	
Yellowfin tuna	*Thunnus albacares*	x	x	x	C,H	C,H
Coastal spotted dolphin	*Stenella attenuata*	x			H	C
Eastern spinner dolphin	*Stenella longirostris*	x			H	C
Common dolphinfish	*Coryphaena hippurus*		x	x	C,H	C
Dolphinfishes	Coryphaenidae	x				C
Almaco jack	*Seriola rivoliana*	x				C
Eastern Pacific bonito	*Sarda chiliensis*	x			C	
Rainbow runner	*Elagatis bipinnulata*	x				C
Wahoo	*Acanthocybium solandri*	x				C

nei = not elsewhere included

apex predators suffer predation mortality from conspecifics and other members of the same trophic guild. We sought to evaluate the potential role of predation as a regulating process for commercially valuable tuna populations and intended this work to be an initial step towards considering potential roles of changing predation mortality.

Research Synthesis

We immediately recognized that the best way to tackle this problem was via research synthesis. That is, rather than create an entirely new sampling program that considered all potential predators and all locations and times, we instead relied on the considerable body of work already conducted. Accordingly we compiled all available data on the food habits of these predators into a common database. This approach has multiple benefits. The first is the reduced costs (both time and monetary) that come from avoiding redundant sampling effort. The second is that it permits us to consider both contemporary and historical (i.e., mid-twentieth-century) conditions. Third, by compiling these data into a common database we can make these synthesized data available to other researchers seeking to address other aspects of the trophic ecology of large pelagic fishes. And lastly, compiling these data in a systematic fashion will help identify any significant gaps in the available data and thereby inform priorities for future research.

The Pelagic Predators Food-Habits Database

We used three primary methods to gather historical and contemporary data for the database. The first was to compile published records of food habits, either from reports or journal articles. These (n = 37) tended to provide summarized accounts of food habits of various predators. This was useful for generating broad comparisons across time, space, and species. The second was to broadly appeal to scientists in the field to gain access to primary data (i.e., data that comprised the summary tables appearing in publications) to permit formal statistical analysis. The third was to directly acquire and digitize primary data from archived data sheets.

In total the database now includes summarized data on nearly 25 predator groups and primary data on approximately 65 predator groups (Table 1). The spatial extent of the summarized data spans much of the range of the tropical tuna species while the primary data are restricted to an area south of the Hawaiian Islands and a large portion of the eastern Pacific Ocean. The temporal extent of the data sources spans more than a 50-year period (1950–2005). Both data sources contain information on the time periods and ocean regions sampled, the range of body sizes sampled, and the proportional contribution of each species to predator diets.

The primary data include additional detailed information on individual samples including: predator and prey body lengths, the spatial coordinates and sea-surface temperature at the location of capture, and the date/time of collection. These attributes are available for much of the contemporary data collected by observers aboard fishing vessels. The historical data, however, reflect predator diets sampled at canneries and do not contain the same degree of detail.

Applications

Here we describe two applications of these data that are actively being pursued:

Characterizing predation on skipjack and yellowfin tuna—Skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) tuna comprise the majority of commercial tuna landings in the Pacific Ocean and worldwide. We sought to identify which predators consistently prey upon these tuna species and the size ranges that are vulnerable to predation. Both of these are important factors in identifying predators that might regulate populations: high rates of predation on life-history stages subject to density dependence or that have low reproductive value would be expected, on average, to have diminished impact on intrinsic rates of growth, unfished biomass, and, ultimately, on fisheries reference points. Our intent is to use this approach as a rapid-screening protocol to identify potentially important predators. That is, we define potentially key predators as those species that consistently consume substantial numbers of individual skipjack and yellowfin tunas that have relatively high reproductive value.

Analyses of summarized and primary food-habits data suggest that skipjack and yellowfin tuna may represent a substantial component of shark and billfish diets. Skipjack may comprise as much as 23% and 30% (by % frequency of occurrence) of shark and billfish diets, respectively, and yellowfin may contribute to as much as 15% and 10% of their diets, respectively. Closer analysis of the primary data indicate that sailfish (*Istiophorus platypterus*), marlin (*Makaira* sp.), silky sharks (*Carcharhinus falciformis*), and blacktip sharks (*Carcharhinus limbatus*) may be the main predators of skipjack while silky sharks, blacktip sharks, and hammerhead sharks (*Sphyrna* sp.) may be important predators of yellowfin. Further estimates of prey sizes consumed by sharks and marlins show that predation is not restricted to early life stages of skipjack and yellowfin tuna. These predators also consume juvenile and subadult tunas large enough to recruit to the fishery and to contribute to the reproductive potential of tuna populations.

The next steps are to use these findings in a population-modeling framework to explore how the productivity of skipjack and yellowfin tuna populations might respond to various levels of depletion of potential predators. Most important will be the consideration of the range of variation in common biological reference points that can be attributed to depletion of predators on these stocks.

Evaluating changes in food-web structure—One of the principle challenges preventing an evaluation of the indirect effects of fishing apex predators on marine food webs, and the secondary consequences of those responses to fisheries, has been the absence of long-term monitoring of non-target species. This challenge is particularly acute in the high-seas pelagic ecosystems where tunas and other large pelagics reside: sampling programs are expensive, restricted in time and space, and rarely continue for multiple years—let alone the decades needed to identify long-term changes. However, because most apex predators are primarily generalist predators, changes in their feeding habits can be considered reflective of changes in the availability of food, i.e., changes in the food web.

For instance, many have noted that global and regional cephalopod landings have increased markedly over the past

(continued on page 4)

Predation (continued from page 3)

half century, leading some to hypothesize their abundance has increased due to depletion of their predators. Landings data are confounded, however, by changes in targeting practices which themselves are driven by the creation and dissipation of markets for fisheries products. There are few long-term surveys of cephalopod productions that cover the entire ranges of populations. We are using the pelagic-predators-diet data base to consider whether feeding rates on cephalopods, principally squids, have increased from the mid-twentieth century to present. Our initial assessment has revealed substantial increases in the frequency of occurrence of squid in all apex predator diets over the past half century and may provide the first direct empirical evidence for large-scale increase in cephalopod populations.

Future Directions

The aims of research synthesis are often twofold: first, to directly ask and answer a set of scientific questions; and second, to provide consolidated data with which other investigators can address other new and important questions. We therefore view the newly generated database as a dynamic resource that will be further developed and elaborated as more data become available and new scientific questions are posed.

Our intention is to make this database widely available to all interested researchers. Information on the database and updates on access procedures can be found on our internet site http://fish.washington.edu/research/tunapred/.

PFRP

Tim Essington is an Associate Professor and Mary Hunsicker is a graduate student, both at the School of Aquatic and Fishery Sciences, University of Washington, Box 355020, 1122 NE Boat Street, Seattle, Washington, 98195-5020, USA; tel +1 206-616-3698 and +1 206-221-5458, email essing@u.washington.edu and mhunsick@u.washington.edu; website http://fish.washington.edu/people/essington/ and http://students.washington.edu/mhunsick/

Robert J. Olson and Mark Maunder are both Senior Scientists at the Inter-American Tropical Tuna Commission (IATTC), 8604 La Jolla Shores Drive, La Jolla, California, 92037-1508, USA; tel +1 858-546- 7160 and +1 858-546- 7027; email rolson@iattc.org and mmaunder@iattc.org; website http://www.iattc.org/HomeENG.htm and http://www.fisheriesstockassessment.com/TikiWiki/tiki-index.php?page=Mark+Maunder

Jim Kitchell is the Director at the Center for Limnology, University of Wisconsin, 680 North Park Street , Madison, Wisconsin, 53706-1492, USA; tel +1 608-262-3014; email kitchell@wisc.edu; website http://limnology.wisc.edu/index.php?pr=Home_Page

A Graph-Theoretic Approach to Analyzing Food Webs Leading to Top Predators in Three Regions of the Pacific Ocean

Jeffrey M. Dambacher, Jock W. Young, Robert J. Olson, and Valérie Allain

This article summarizes research which has recently been accepted for publication in Progress in Oceanography *(Dambacher et al., in press). We concentrate here on the rationale for the work, its outcomes, and potential for future research.*

Introduction

Fishing pressure and predicted ocean warming are two major challenges facing tunas and billfishes worldwide. Most approaches attempting to understand how these fishes will respond to these challenges require a range of quantitative data and life-history parameters from which scenarios of future change can be assessed. A central component of such analyses is the trophic interactions of the predators and their prey and how they might change if one or the other is removed. Such questions involving pelagic food webs are critical in adopting ecosystem approaches to fisheries management.

In reality, data on predator-prey interactions are rarely complete and require, at some point, subjective interpretation of what the strength of the linkages might be. The approach discussed here—broadly described as qualitative analysis—relies solely on the presence or absence of links made between the species and is purely data driven. The benefit of this approach is that key components of the food-web interactions are quickly identified and very complex systems can be reduced to a manageable size for interpretation. Then, by attributing a positive or negative effect to a given species or species grouping, the impact of that effect can be traced through the system.

We took this approach with a data set of stomach contents from fish predators (mainly tunas and billfishes) taken from longline and purse-seine fisheries in the tropical and subtropical western and eastern Pacific Ocean (Figure 1). Three food webs were constructed—one from the eastern Pacific, one from the western and central Pacific, and one from the southwestern Pacific. These food webs were examined using graph-theoretic methods which included: aggregating species based on food-web relationships, both predators and preys, and identification of potentially influential species. Species aggregations were used to construct simplified qualitative models from each region's food web. Models from each region were then analyzed to make predictions of response to climate change for six commercially important species: dolphinfish (*mahimahi*), skipjack tuna, albacore tuna, yellowfin tuna, bigeye tuna, and swordfish.

Results

For the three diet studies of pelagic predators, a total of 651 taxa (composed of predators and prey) were distinguished in the raw data among the three regions of the Pacific Ocean. Removal of rarely occurring prey taxa and isolates, or those taxa that were not linked to other species, reduced the number of taxa to 248. Of the 248 taxa, there were 180 identified to genus and 133 identified to species. There were 23 taxa that were common to all three data sets, of which 14 were identified to species-level. All of these 14 species were upper-trophic-level pelagic predators and included albacore tuna, bigeye tuna, skipjack tuna, yellowfin tuna, black marlin, blue marlin, shortbill spearfish, striped marlin, shortfin mako shark, silky shark, scalloped hammerhead shark, dolphinfish, snake mackerel, and wahoo (*ono*).

All three food webs were dominated by species with trophic-level designations between 3.5 and 4.5 (Brodeur and Pearcy 1992) (Figure 2). In each food web the maximum trophic level of a species was 4.6 while the mean trophic level was essentially the same in all three regions—3.6 in the south-western region and 3.5 in both the central regions.

The aggregated food web of the south-western Pacific had a network structure composed of three predation levels we defined as "tiers." In contrast the food webs of the central-western and central-eastern regions were four tiered (Figure 3). The lowest predation tier in all regions was composed of groups containing a range of squid, crustacea, and small-sized fishes while the highest predation tiers were generally dominated by sharks and other large predatory fishes.

(continued on page 6)

Pelagic Fisheries Research Program Newsletter
Volume 14, Number 1 **2009**

Editors Henry Bennett and Kevin Weng
Writers Valérie Allain, Jeffrey Dambacher, Tim Essington, Edward Glazier, Mary Hunsicker, David Itano, Jim Kitchell, Mark Maunder, Jeffrey Muir, Robert Olson, Kevin Weng, and Jock Young
Layout May Izumi
Printing Fisher Printing, Honolulu, HI

For more information
Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai‘i at Mānoa
1000 Pope Road, MSB 313
Honolulu, HI 96822
TEL (808) 956-4109 FAX (808) 956-4104
E-MAIL kevin.weng@hawaii.edu
WWW http://www.soest.hawaii.edu/PFRP

UPCOMING EVENTS

2009 California Cooperative Oceanic Fisheries Investigations (CalCOFI) Conference

7–9 December 2009, Pacific Grove, California, USA
Contact: John Heine, Southwest Fisheries Science Center, +1 904-242-7029, calcofi_coordinator@coast.ucsd.edu
http://www.calcofi.org/conference.html

Western and Central Pacific Fisheries Commission, 6th Regular Session

7–11 December 2009, Papeete, Tahiti, French Polynesia
Contact: Andrew Wright, +691 320-1992 or 320-1993, wcpfc@wcpfc.int
http://www.wcpfc.int/meetings/1

International White Shark Symposium

7–10 February 2010, Honolulu, Hawai‘i, USA
Contact: Michael Domeier, Marine Conservation Science Institute,
+1 760-721-1440, ML.Domeier@gmail.com
http://www.whitesharkscience.com/

CLIOTOP Mid-term Workshop—CLimate Impacts on Oceanic TOp Predators

8–11 February 2010, UNESCO, Paris, France
Contact: Olivier Maury, Institut de Recherche pour le Développement (IRD), +33 (0) 499-57-32-28, Olivier.Maury@ird.fr

61st Tuna Conference, Southwest Fisheries Science Center, NOAA/NMFS, and the Inter-American Tropical Tuna Commission

24–27 May 2010, Lake Arrowhead, California, USA
Contact: info@tunaconference.org
http://www.tunaconference.org/

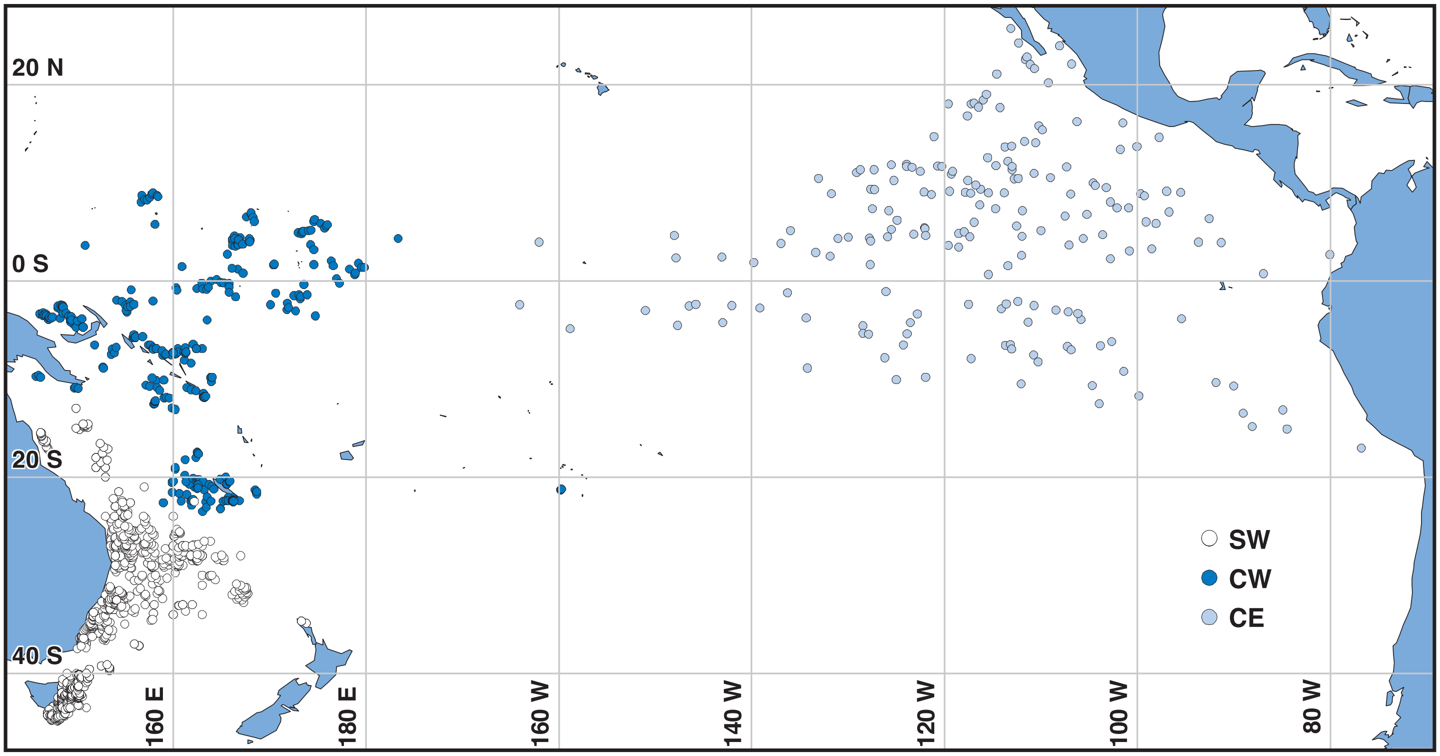


Figure 1. Collection locations for diet studies in the south-western (SW) Pacific Ocean and two equatorial regions that are identified as the central-western (CW) and central-eastern (CE) regions.

The aggregated food web of the south-western Pacific (Figure 3) had a single group at its highest tier (group 2) which contained shortfin mako and hammerhead sharks. The second predation tier was composed of a suite of mid-sized predators. The food web of the central-western Pacific was topped by three groups, which generally included large predators, such as billfish, swordfish, and sharks but also included mid-sized predators such as wahoo, dolphinfish, and the great barracuda. The second predation tier had four groups that contained tunas, opah, and longnose lancetfish. In tier 3 were a mix of sharks and medium-size fishes that included pomfrets and skipjack tuna.

The aggregated food web of the central-eastern region was visibly more complex than those of the other two regions (Figure 3). It also had three groups at the highest predation tier, two of which fed at tiers 2, 3, and 4. The groups in the first tier were generally composed of billfishes and sharks. The next predation tier had three groups that contained various mid-sized predators and included dolphinfish and yellowfin tuna. Tier 3 included bullet, frigate, bigeye, and skipjack tunas and a range of other medium-sized predators.

Qualitative predictions—We selected yellowfin tuna to perturb in the qualitative models because it was identified as a key player (Table 1) in two of the three regions and is projected to increase its range or abundance via ocean-warming. We used this increase as a perturbation scenario. This perturbation produced varied responses in the abundance of commercially important fishes for each model system (Table 2). An increase in yellowfin tuna in the south-western region and the central-eastern region was predicted to lead to a decrease in the abundance of commercial species that were not within the same group as yellowfin tuna (i.e., in the south-western region, decreases were predicted for dolphinfish, albacore tuna, bigeye tuna, and swordfish; in the central-eastern region decreases were predicted for skipjack, albacore, and bigeye tunas). Within the central-western region, however, commercial species not sharing group membership with yellowfin tuna were predicted to increase for two species (dolphinfish and swordfish) and decrease for two others (skipjack and albacore tunas).

Discussion

This study was the first of its kind to examine the trophic structure of oceanic ecosystems. As such, there was no previous study with which we could compare our results. However an earlier quantitative analysis (Kitchell et al. 2002) completed for the central Pacific Ocean provided a useful comparison.

Sharks, which have been considered as keystone predators in some studies, do not appear to play a key role in the present study, a finding also demonstrated by Kitchell et al. (2002). In their study of the pelagic food webs of the Central Pacific, Kitchell and his colleagues (using a compartment-flow type model) could not identify any keystone species. Complementary to our key-player results for the central-eastern region, they singled out yellowfin and skipjack tunas as the most important components of the system in terms

Table 1. Key players in the pelagic food webs of three regions in the Pacific Ocean. Key players were identified by their role in fragmenting the food web if removed or by how many other species can be reached through them in a specified number of links.

	Food web		
Key-player species	**South-western**	**Central-western**	**Central-eastern**
Longnose lancetfish	+	+	
Dophinfish			+
Opah		+	
Triple tail			+
Skipjack tuna			+
Albacore tuna		+	
Yellowfin tuna	+		+
Swordfish	+		a
Unidentified teleosts	+	+	+
Unidentified cephalopods	+	+	

a = no data

Table 2. Qualitative change in abundances of commercially important species resulting from a positive perturbation to yellowfin tuna, as predicted by models of pelagic ecosystems for three regions of the Pacific Ocean (SW, southwestern Pacific; CW, central western Pacific; CE, central eastern Pacific).

	Predicted direction of change in abundance of commercial species following perturbation				
Region	**Dolphinfish**	**Skipjack**	**Albacore**	**Bigeye**	**Swordfish**
SW	-	+	-	-	-
CW	+	-	-	+	+
CE	+	-	-	-	a

a = no data

of diet diversity as well as in terms of biomass and rapid rates of turnover.

The food web of the south-western region had only three predation tiers topped by a group with only mako and hammerhead sharks. In contrast, the other two regions had four tiers in which mako and hammerhead sharks occupied either the first or the third predation tier. Examination of the database revealed that in the south-western Pacific their diets were dominated by tuna species whereas in the other regions their diets were dominated by lower trophic-level species such as ommastrephiid squid. Stable-isotope analysis of predator white-muscle tissues in the south-western region supports the lack of distinction between top- and mid-order predators. The qualitative predictions from the three models generally illustrate the point that the response that a species might have to a change in ocean conditions depends on the structure of their food web. Given the high likelihood of ocean warming (Intergovernmental Panel of Climate Change 2007), detailed knowledge of food-web structure will be central to understanding and predicting how top pelagic predators, and the ecosystems in which they are embedded, will respond.

This work was purely data-driven, in that we only considered species and predator-prey interactions represented by the data directly available from the catches of the tuna and billfish fisheries in the three regions and thus we did not, as is commonly done, include supplementary information from other studies and other regions. Moreover our aggregations of species into groups were based purely on food-web structure and so we have avoided a priori classifications based on size or functional attributes such as whether a species inhabits the epi- or meso-pelagic. Also we have strictly adhered to constructing qualitative models from an aggregation algorithm based only on the structure of food-web graphs. By limiting ourselves to a qualitative assessment of the diet data we have sought a general understanding of how the pelagic ecosystems of these three regions are structured and to develop

(continued on page 8)

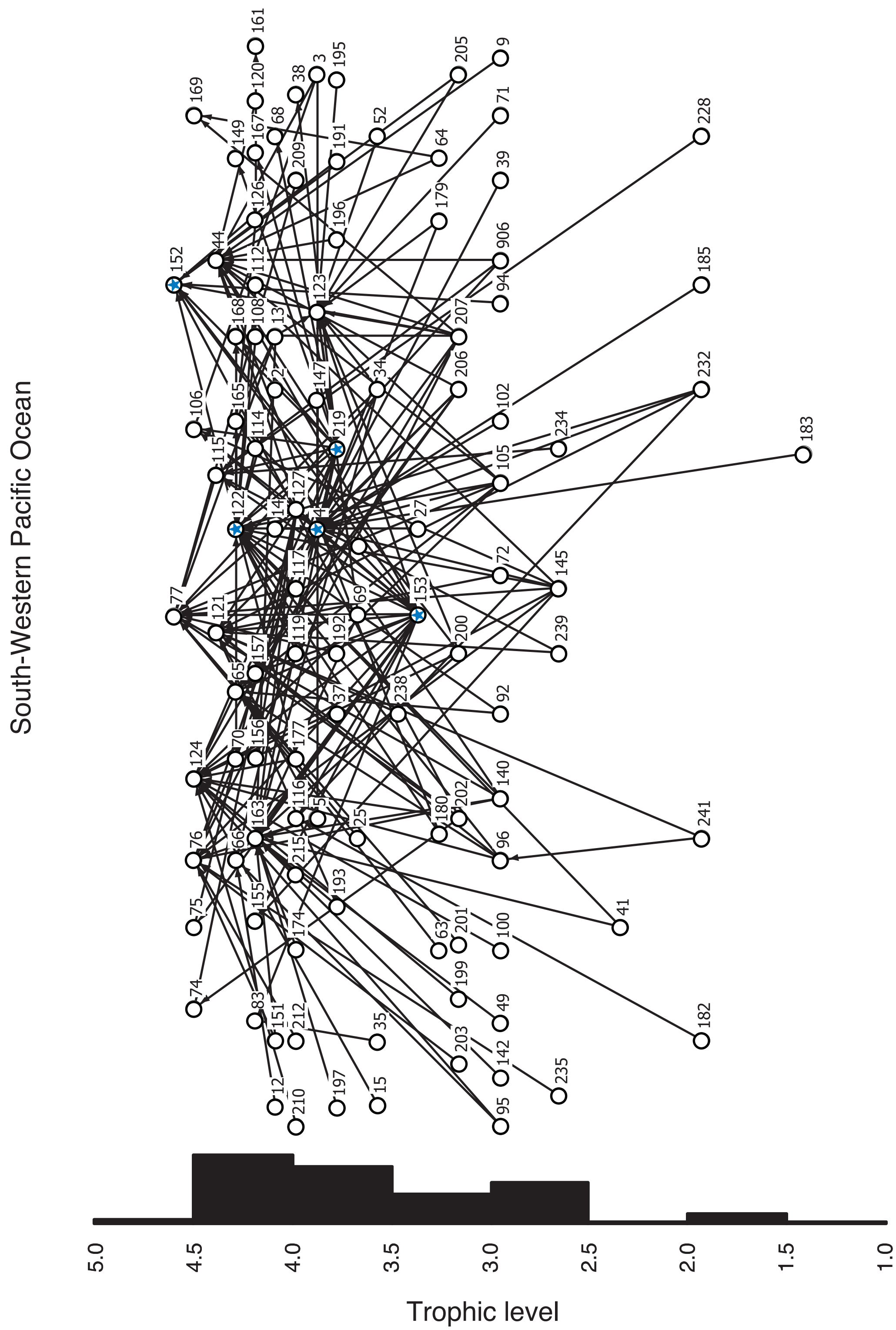


Figure 2. Pelagic food webs leading to top predators in three regions of the Pacific Ocean (Figure 1). Arrows lead from prey to predators and represent a level of consumption that is ≥1% wet weight for a given predator. Histograms denote relative frequency and position of trophic levels in food web. Numbers refer to sequence number of taxa listed in Appendix 1 (refer to Dambacher et al. in press). Graph nodes with a star (★) are taxa identified as key players.

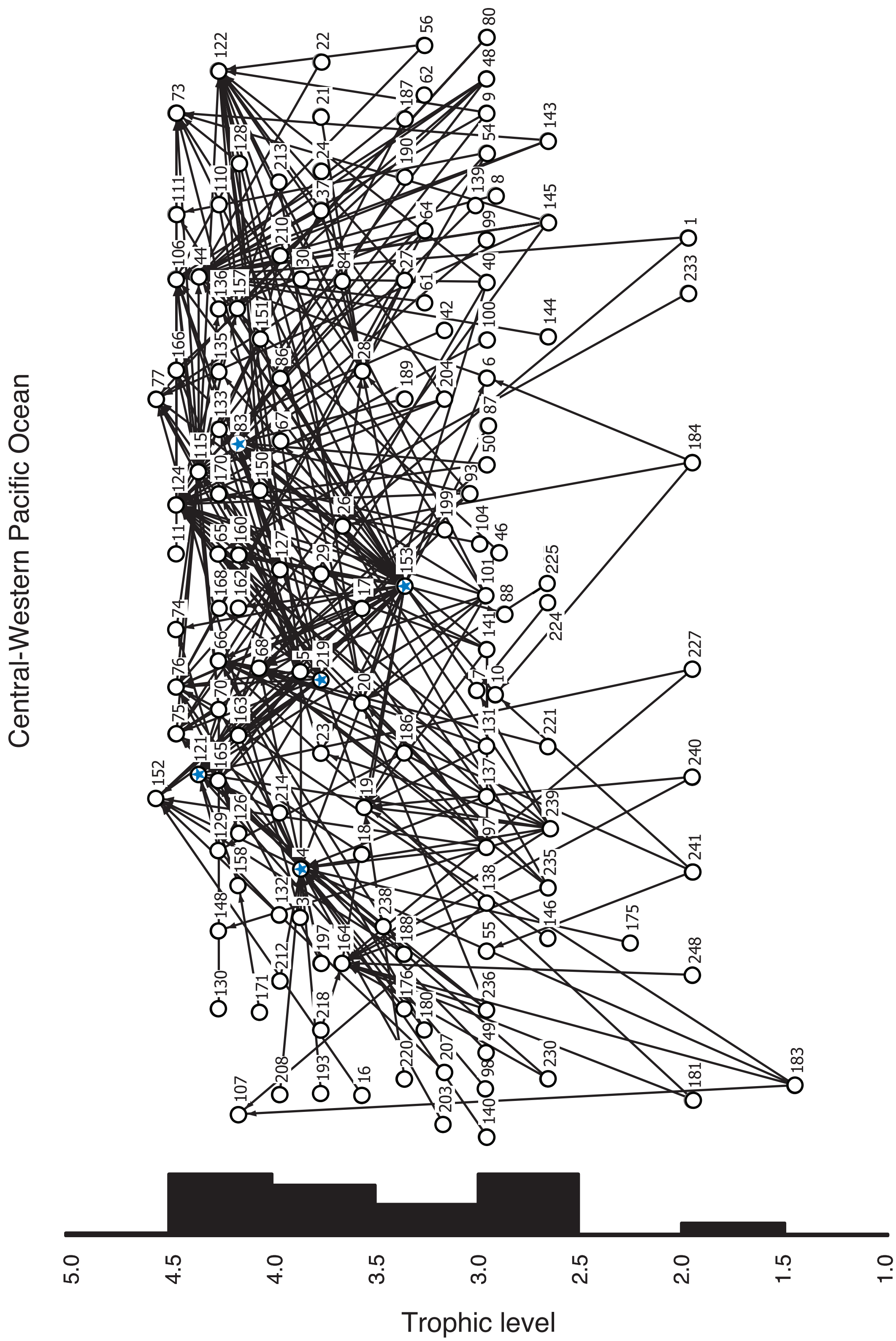


Figure 2. (continued)

(continued on page 10)

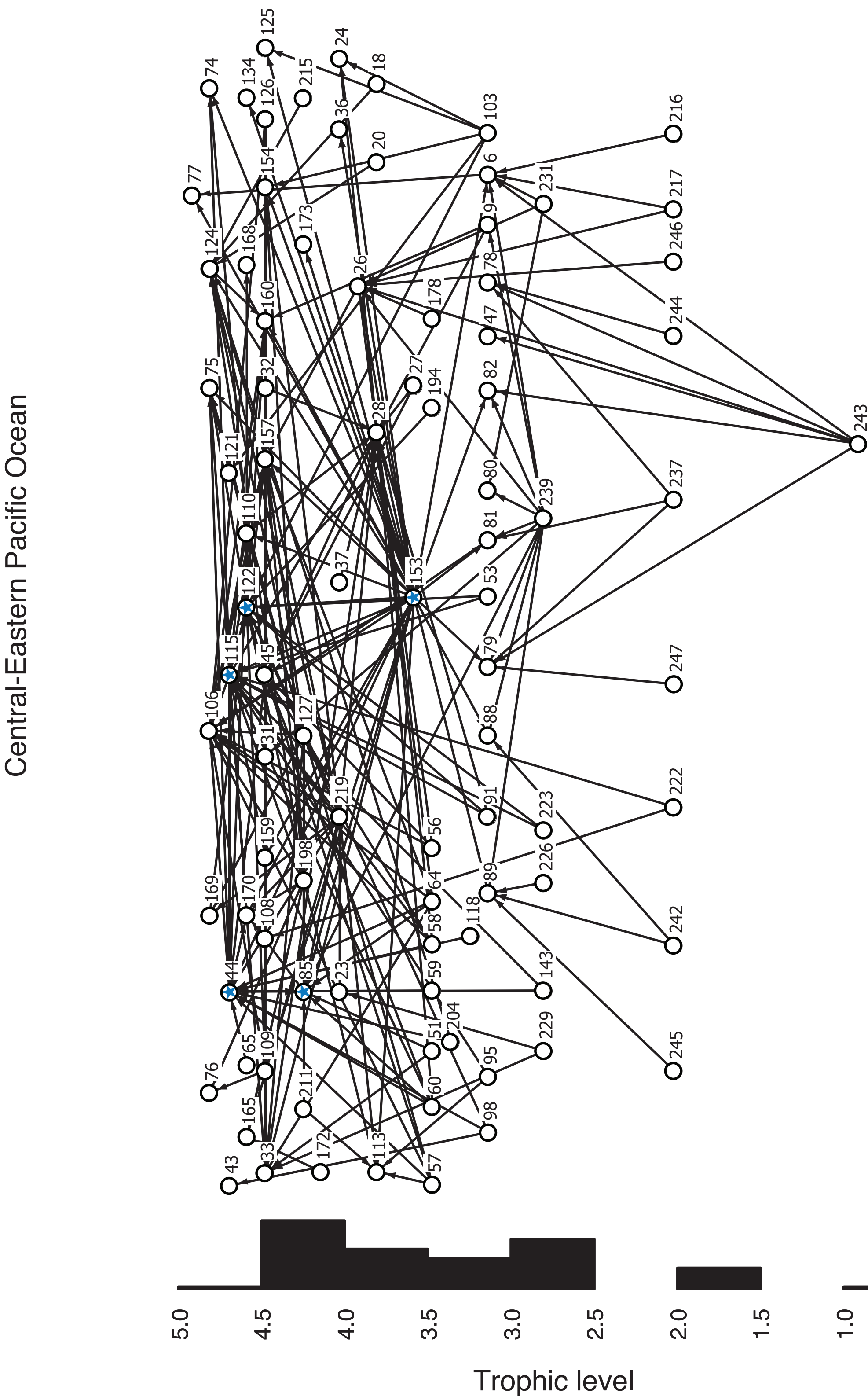


Figure 2. (continued)

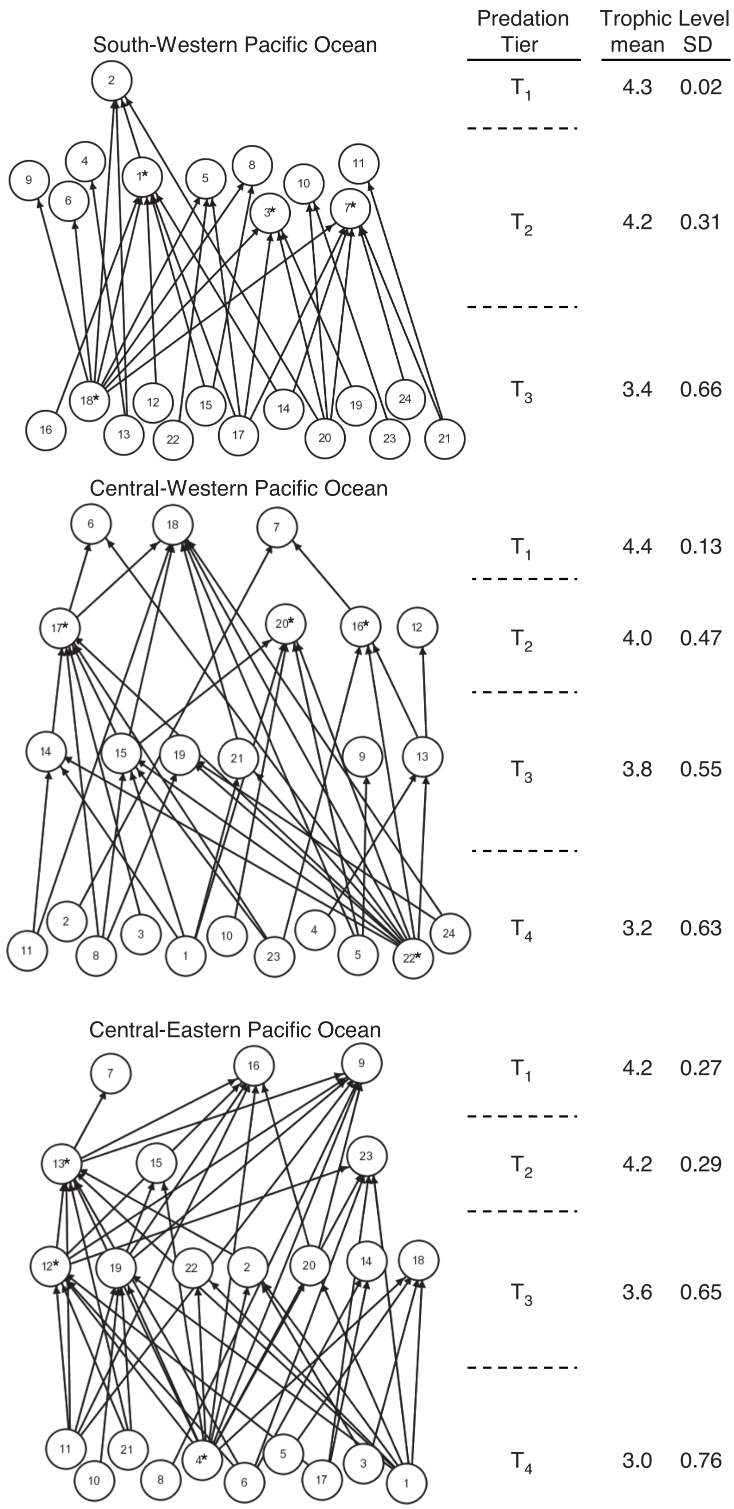


Figure 3. Aggregated food webs of three regions of the Pacific Ocean. Nodes represent groups of taxa with similar predator-prey relationships (Figure 2) and are arranged in predation tiers (T_n) such that a group at level *n* is predator of at least one group at level *n*+1 and a group at the lowest level is not predator of any other group in the system. Groups with asterisks contain key players. Shown for each tier are mean and standard deviation (SD) of trophic levels of taxa in each group. These network structures were used to create qualitative models of each pelagic ecosystem which were then used for the perturbation analyses detailed in Table 2.

(continued on page 12)

hypotheses that can be explored and tested in quantitative models and other studies of these systems.

Future Research—The broad scope of this study has rarely before been attempted in comparative studies of marine ecosystems. A significant challenge in this study was incorporating data from different fisheries with different sampling regimes. This has the potential to bias the representation of the predator and prey species in a food web. Nevertheless our results suggest potentially important differences between three pelagic ecosystems of the Equatorial and South Pacific Oceans and these results can be used to inform the construction of quantitative ecosystem models for the three regions.

The scenario of an increase in yellowfin tuna applied here was based on a projected change in their distribution due to ocean warming. Yellowfin tuna is generally considered to be a tropical species limited by cooler temperate waters. The south-western region of the Pacific Ocean is generally considered to be near the southern limit of yellowfin tuna. Ocean warming would presumably be beneficial for this species by extending its range such that its competitive advantage could increase. Our modeling results for the south-western region suggest that an increase in yellowfin tuna could conceivably lead to a decline in the abundance of dolphinfish, albacore and bigeye tunas, and swordfish, and that these effects would be mediated indirectly through resource competition.

Finally, a conspicuous omission from all three food webs was fisheries exploitation, which has been considered as the keystone predator for at least the central Pacific. Incorporating fisheries exploitation into these qualitative analyses requires consideration of the main feedbacks that drive and regulate the fishing fleet, the market, and the ecosystem.

Acknowledgement

This project was co-funded by the Pelagic Fisheries Research Program and the CSIRO Wealth from Oceans Flagship.

References

Brodeur, R.D., and W.G. Pearcy. 1992. Effects of environmental variability on trophic interactions and food web structure in a pelagic upwelling ecosystem. *Marine Ecology Progress Series* 84, 101–19.

Dambacher, J.M., J.W. Young, R.J. Olson, V. Allain, F. Galván-Magaña, M. Lansdell, N. Bocanegra-Castillo, V. Alatorre-Ramírez, S.P. Cooper, and L.M. Duffy. In press. Analyzing pelagic food webs leading to top predators in the Pacific Ocean: A graph-theoretic approach. *Progress in Oceanography*.

Intergovernmental Panel of Climate Change. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II, and III to the *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. R.K. Pachauri and A. Reisinger, ed. Geneva, Switzerland: Intergovernmental Panel of Climate Change.

Kitchell, J.F., T.E. Essington, C.H. Boggs, D.E. Schindler, and C.J. Walters. 2002. The role of sharks and long-line fisheries in a pelagic ecosystem of the Central Pacific. *Ecosystems* 5:202–216.

PFRP

Jeffrey M. Dambacher is a Senior Research Scientist at CSIRO Mathematical and Information Science, GPO Box 1538, Hobart, TAS 7001, Australia; tel +61 3-6232-5096; email Jeffrey.Dambacher@csiro.au; website http://www.csiro.au/people/Jeffrey.Dambacher.html

Jock W. Young is Deputy Program Leader (Marine Ecological Predictions and Processes, CSIRO Wealth from Oceans Flagship), CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia; tel +61 3-6232-5360; email Jock.Young@csiro.au

Robert J. Olson is a Senior Scientist at the Inter-American Tropical Tuna Commission (IATTC), 8604 La Jolla Shores Drive, La Jolla, California, 92037-1508, USA; tel +1 858-546-7160; email rolson@iattc.org; website http://www.iattc.org/HomeENG.htm

Valérie Allain is a Fisheries Scientist at the Oceanic Fisheries Programme, Secretariat of the Pacific Community, BP D5, 98848 Noumea, New Caledonia; tel +687-262000; email valeriea@spc.int; website http://www.spc.int/oceanfish/html/Staff/StaffList.htm#val

Supply, Demand, and Distribution of Pelagic Seafood on O'ahu: Select Results from the PFRP Seafood-Distribution Project

Edward W. Glazier

Introduction

The true complexities involved in the conduct of distinct marine fisheries are often condensed and obscured by summary statements deriving from broadly-scaled fisheries research.

For instance the phrase "global fisheries in crisis" was recently used by Mora et al. (2009) to summarize the status of the world's fisheries. Taken literally, this usage implies the existence of globe-spanning marine fisheries. In reality there are no globally-conducted fisheries but only many thousands of geographically distinct fisheries (as the Mora et al. article later indicates), each of which can be characterized in terms of efficiency of management, productivity, and sustainability.

Taken at face value, headlines such as "dying marine ecosystems" (Agardy 2009) and the "pandemic failure of fisheries management" (Pontecorvo and Schrank 2009) obscure the complex realities of marine fisheries and the varying environmental conditions and human factors that condition them.

The basic principles of supply and demand, central to the study of marine fisheries and to marine-policy decisions, are also frequently used in a way that condenses the variety and complexity of human behavior. For example the Food and Agriculture Organization of the United Nations reports (2004) that worldwide demand for seafood products will likely exceed supply between 2010 and 2015—with a total deficit of 10.9 million tons by 2015. While this statement does indicate the potential scale of the diminishing availability of wild-caught seafood, at the same time it obscures the many varied and complex processes that determine the (unequally distributed) supply of and demand for such food.

This is because generalized "supply and demand" calculations, like summary statements from other fisheries research, tend to capture the behaviors and interests of humans only in aggregate and only in the abstract. On the supply side the labor, knowledge, and skill of individuals in the harvest and distribution sectors are converted simply to available pounds of end product. On the demand side the varied and wide-ranging needs and interests of consumers are similarly only expressed in total pounds of seafood desired or consumed.

The project addressed in this article is intended to describe two examples of distinct market and non-market supplies of and demand for pelagic seafood products. The research examines localized behaviors and experiences of two geographically specified samples of fishermen and consumers—behaviors and experiences that are often lost in sweeping statements regarding trends in fisheries and marine ecosystems around the world.

Overview of Fish Flow: the PFRP Seafood-Distribution Project

In reality, supply and demand calculations involve a variety of human dimensions that are of direct relevance to any fisheries-management strategy designed to enable sustainable local use of marine resources. Supply and demand functions can be considered not only in classical economic terms but also in psychological terms. In such considerations the values and choices of suppliers and prospective consumers assume significance in the outcome of market transactions and the status of specific fisheries.

Because groups of people organize themselves in ways that facilitate efficient catch and distribution of seafood for the benefit of suppliers and consumers, supply and demand can also be considered in sociological terms. Finally, supply and demand can be envisioned in cultural terms wherein the capture, distribution, and consumption of fish and other seafood products are considered critical aspects of local or traditional ways of life.

This article summarizes a study involving detailed description and analysis of the commercial and non-commercial transfer ("flow") of pelagic seafood in the Hawaiian Islands. The intent of the study is to enhance understanding of the supply and demand sides of the marine fisheries equation through analysis of distinct processes of harvest, distribution, and consumption of pelagic fish within and across specific fishing fleets on O'ahu. The results will be useful for fishery managers and others interested in the sources, quantities, distribution channels, end uses, and cultural values of pelagic seafood in communities throughout the populated Hawaiian Islands and in other island settings around the Western Pacific.

Research Methods

The PFRP Seafood-Distribution Project involved extensive archival research, in-depth interviewing, and participant observation among small-boat commercial, recreational, and consumption-oriented captains operating from two popular small-boat harbors on O'ahu: Wai'anae, on the Leeward Coast, and Hale'iwa, on the North Shore. Central to the project methodology was a systematic identification of networks of captains known to cooperate or interact extensively at sea. Field staff worked to develop close rapport with such fishermen and to further identify the most highly respected captains in the study area. Knowledge of pelagic fishing and pelagic resources were the principal criteria for identifying the research participants.

The purpose of the project was not statistical representation of seafood distribution across all fishing operations in the study harbors. It was rather to generate a thorough understanding of the social and cultural context of fishing from these small harbors and typical patterns of seafood distribution within, across, and beyond the communities of interest. The project involved focused research emphases on: a) typical patterns of distribution of fish sold in local markets, consumed directly by the fishermen and his family, and/or

(continued on page 14)

Supply, Demand (continued from page 13)

shared and consumed within and across the various *'ohana* (extended families) involved in the study, b) the underlying logic and socio-cultural context within which seafood-distribution decisions are typically made, and c) the implications of identified patterns of seafood distribution for resource managers and others seeking to define and better understand island "fishing communities" and supply of and demand for pelagic fish in the Hawaiian Islands.

Select Findings

Here we report select findings from the project. The principal finding is the clear and overarching importance attributed to fishermen and to locally-caught pelagic seafood in these small community settings. The local social and cultural significance of pursuing, catching, distributing, and consuming marlin (*a'u*), dolphin fish (*mahimahi*), wahoo (*ono*), and especially tuna (*'ahi*) cannot be overstated. These species are consumed directly and extensively by the fishing family. They are also are widely shared, used as trade items, sold at market, and consumed at various community celebrations. As will be described in detail in a forthcoming technical report, individual decisions about how pelagic fish are to be distributed vary extensively based on local social, economic, and cultural context.

From a methodological perspective, the social-network sampling process was very effective in identifying highly knowledgeable and seasoned fishermen. This was particularly true of persons who fish on a commercial and part-time commercial basis. That is, there was strong local agreement about the identities of the most knowledgeable, experienced, and productive fishermen. This was validated through observational work in the communities and through discussions with long-time observers of local fishing activities such as harbormasters and elderly but still attentive fishermen. The sampled networks thus include high-status individuals with strong local reputations as productive fishermen.

While one objective of the network-based sampling process was to identify distinct networks of cooperating commercial, recreational, and consumption-oriented fishermen, it is notable that these distinctions were often somewhat blurred in reality. That is, most persons identified as central actors in the cooperation networks tended to be involved in a mix of commercial, recreational, and consumption-oriented fishing activities. For analytical purposes some such fishermen were "forced" into one or another of the defined study categories, selecting the category that best reflected the majority of the fishing efforts of that individual, so as to enable basic comparison of general operational tendencies.

Fishermen involved in full-time commercial and charter fishing activities naturally tend to sell the vast majority of fish landed during each successful trip. Some degree of sharing and personal consumption was noted among such fishermen but the operational focus obviously was clearly on selling fish for profit and/or to pay for fishing-related expenses. As indicated in this study, such persons also tend to be at the center of at-sea networks of all cooperating fishermen and the most highly respected individuals in terms of relative degree of knowledge about fishing and pelagic resources.

Fishermen in general look to certain commercially-oriented operators for advice and inspiration. Significantly, such persons are also a consistent source of fish for various *'ohana* and community functions. This situation speaks to the importance of highly experienced and highly productive fishermen in local communities around the state, the social status that can be attained by being a knowledgeable and seasoned fisherman in the islands, and the universal importance of sharing at least some portion of the catch within localized community settings.

Some notable differences in the characteristics of local fishing fleets and patterns of seafood distribution were detected between Hale'iwa and Wai'anae (Figure 1). The social network of cooperating fishermen based in Hale'iwa was made up of twenty-eight persons: seven of whom were characterized as consumption/recreation-oriented; fourteen of whom were part-time commercial operators; four of whom were full-time commercial fishermen; and three of whom were charter operators. Hale'iwa-based charter fishermen reported selling 93 percent of pelagic fish landed during trips taken the previous year and consuming and/or sharing 7 percent. The full-time commercial fishing contingent reported selling 86 percent of all pelagic fish, sharing 9 percent, and eating 5 percent. The part-time commercial group reported selling 67 percent, sharing 27 percent, and eating 6 percent. Finally, the consumption/recreation-oriented group reported selling no fish, sharing 56 percent, and eating 44 percent. Of note, Hale'iwa-based fishermen who distributed fish to others typically did so across a relatively extensive geographic range (Figure 2) that included numerous locations on the opposite side of O'ahu.

The overall situation was quite different among the Wai'anae-based network of cooperating fishermen. In sum, there was relatively less overall sale of pelagic fish among the Wai'anae sample, a significantly higher overall percentage of sharing, and a more restricted geographic range of distribution (Figure 3).

The Wai'anae network was made up of twenty-four core fishermen: thirteen of whom were characterized as consumption/recreation-oriented; five of whom were part-time commercial operators; five of whom were full-time commercial fishermen; and one of whom was a charter operator. The sole charter operator had adopted the policy of giving fish to his clients and most of the pelagic fish he retained were shared with his *'ohana*. Full-time commercial operators at Wai'anae reported selling some 69 percent of pelagic fish landed the previous year, sharing 18 percent, and consuming 13 percent. Local part-time commercial fishermen reported selling 38 percent, sharing 46 percent, and eating 16 percent. The consumption/recreation-oriented group reported selling no fish, sharing 67 percent, and eating 33 percent.

Differences between the two networks of fishermen (Figures 2 and 3) relate to two principal factors, summarized here. First, Hale'iwa has become an important tourist destination with many opportunities for fishermen to sell their products to local restaurateurs. Numerous Hale'iwa—based fishermen also transport their

(continued on page 16)

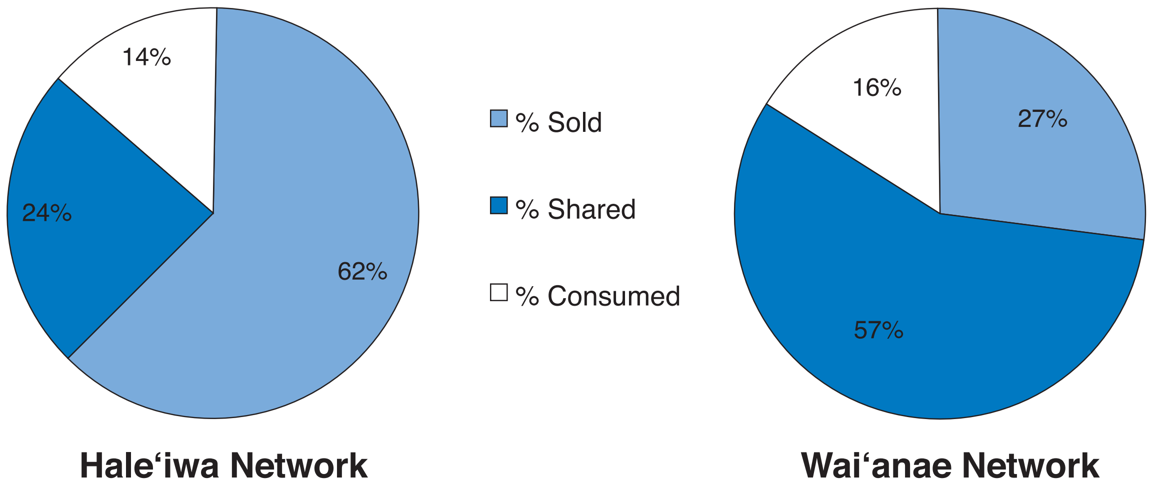


Figure 1. Typical use of pelagic seafood over the past year

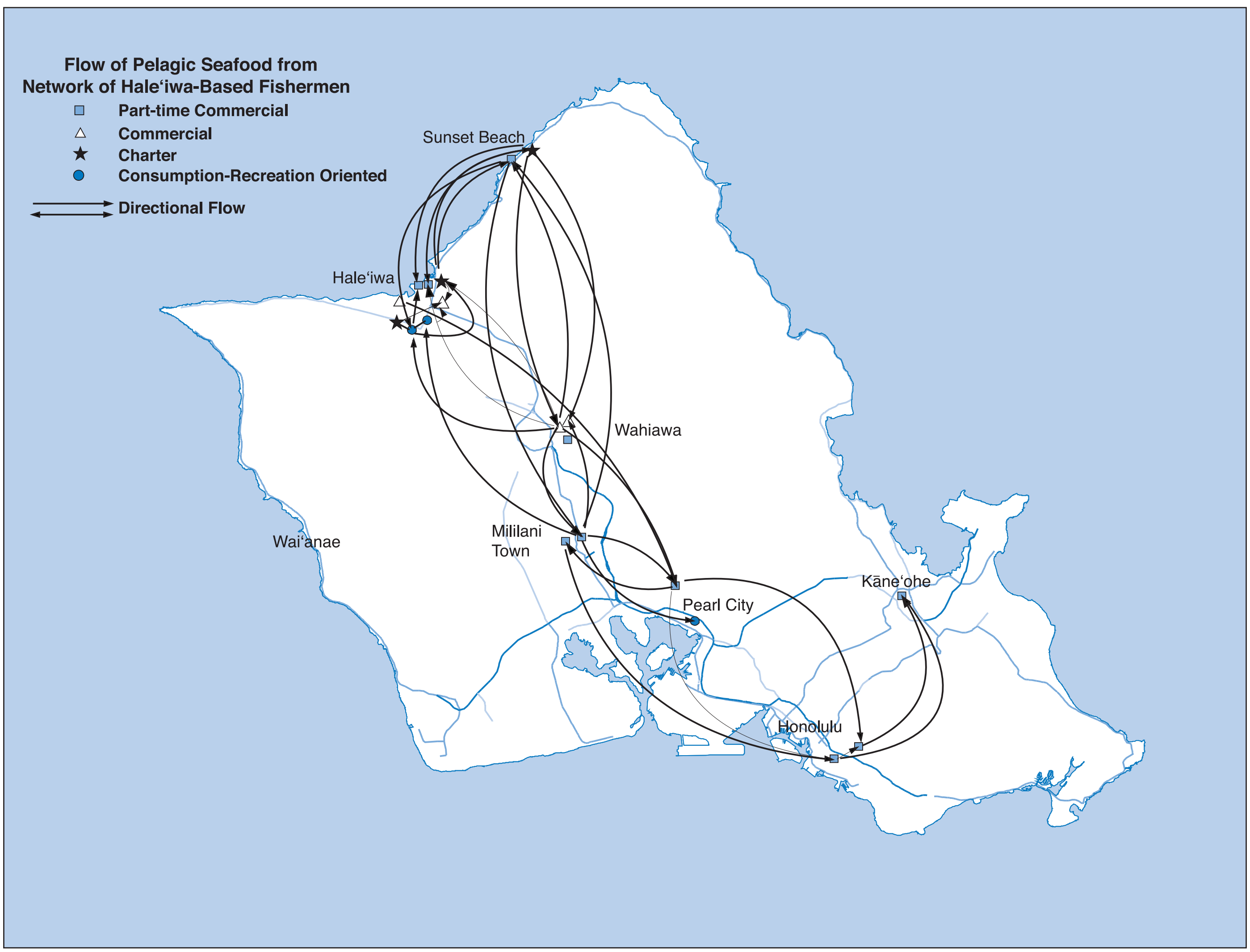


Figure 2. Spatial distribution of seafood landed by Hale‘iwa–based fishing network

Supply, Demand (continued from page 15)

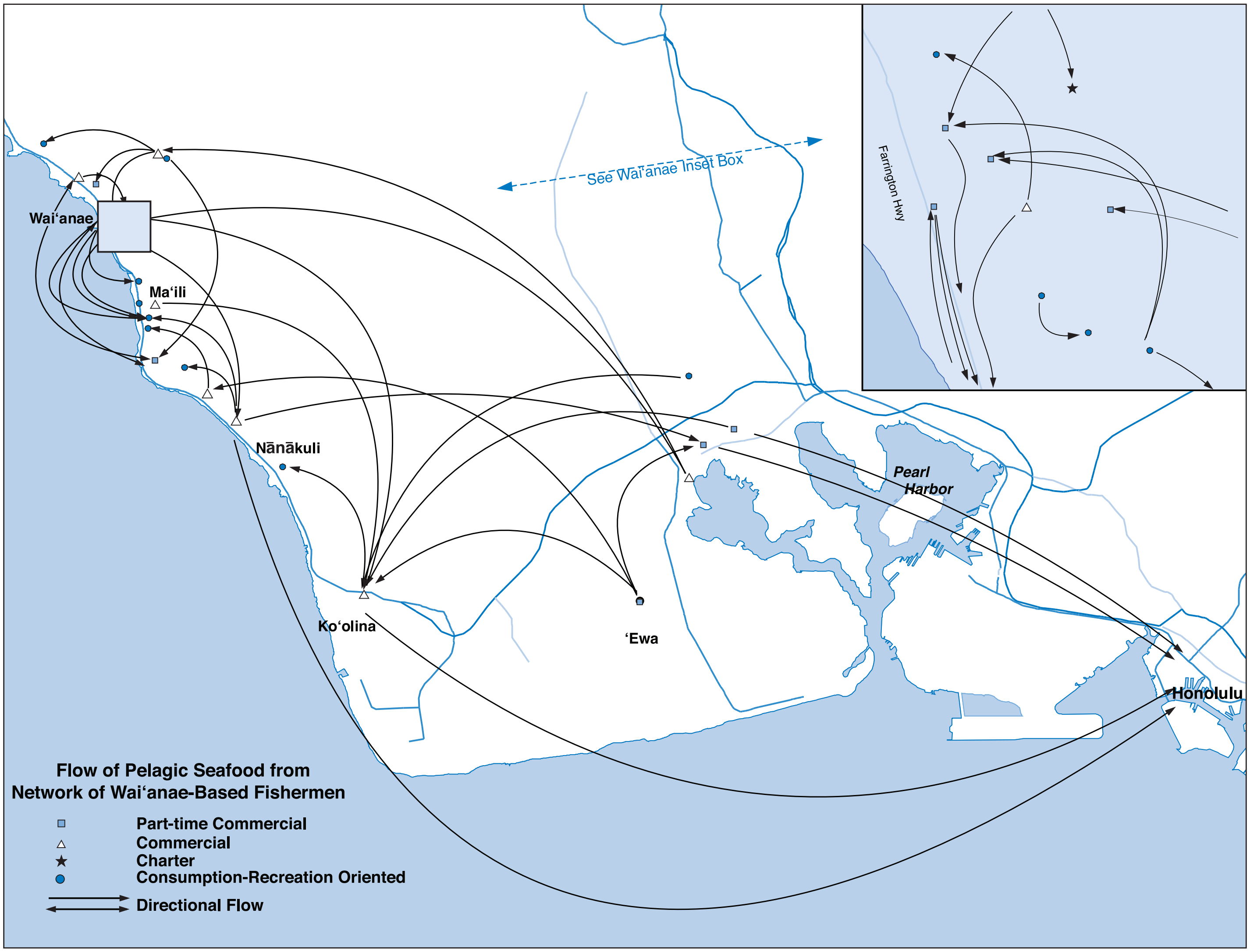


Figure 3. Spatial distribution of seafood landed by Wai'anae–based fishing network

fish to the public auction in Honolulu. In contrast, local opportunities for sale are less common in Waiʻanae and fishermen in the Waiʻanae network report carrying their fish to the auction block relatively infrequently.

Second, while economic conditions are challenging in both communities, and fishermen in both networks meet this challenge in part through reciprocal exchange of seafood and fishing-related labor, this mode of adaptation is particularly common in and around Waiʻanae.

This relates to differences in community context. Many Native Hawaiians live in the Waiʻanae area and there is a well-developed capacity among this group to maintain traditional ways of life amidst the social and economic pressures of modern capitalism. Although people from around Oʻahu trailer their boats to fish along the Leeward Coast, locally-based Waiʻanae fishermen are often part of a distinct local culture and informal economy. This is true to a lesser extent in Haleʻiwa, where there is greater admixture of economic activities and cultural tendencies.

Differences aside, there are important similarities in the socio-cultural context associated with fishing and the distribution of pelagic seafood in both study locations. For example, a strong local norm of giving respect to avid and experienced fishermen is common in both communities and locally-caught seafood is very typically sought in both locations for use at baby *luʻau* (celebrations), graduations, weddings, funerals, and state and national holidays. In fact a great deal of the social activity observed in each of the communities was and is in many ways rooted in the act of fishing, in activities that support local fishermen and fishing fleets, and in the everyday and celebratory consumption of pelagic seafood.

Summary Conclusions

This article provides key findings from the PFRP Seafood-Distribution Project. These findings make it clear that supply and demand is not simply domestic harvest minus exports and per capita consumption multiplied by population. Rather, the supply of pelagic seafood is mediated through real persons and complex societies and the end product is often highly valued in localized market and non-market settings. This has or should have significant implications for managers who seek to understand and accommodate the needs of those who avidly pursue, distribute, and consume pelagic seafood in such settings, and who seek to address the social complexity that drives the need for fishery management in the first place.

On the (broadly-conceived) demand side, fish and other marine resources are distributed and used in a variety of culturally meaningful ways that do not lend themselves to expression solely in terms of the market economy. Sale of seafood is important for select participants but such persons also tend to play important leadership roles among fishermen who are involved in fishing activities and channels of distribution that emphasize traditional and customary values rather than profit.

Modes of distribution and uses of seafood in the study communities and larger island region can vary extensively, typically involving some combination of following: a) direct consumption in the *'ohana* setting; b) distribution and/or consumption in association with community celebrations or rituals; c) reciprocal sharing; d) barter or customary trade; e) selling, where the proceeds of the sale are often put back into the fishing operation, and f) purely altruistic gifting of seafood products.

The reality of the supply and demand equation in this island setting has been demonstrated to be highly complex and one that cannot be adequately expressed through a simple bi-variate relationship. While encompassing relationship measures can help us conceptualize broadly distributed human behavior they can also diminish our understanding of the ways in which human behavior varies in localized settings.

In this case the experiences and behaviors in question relate to activities and products that are particularly meaningful to local residents of O'ahu and other islands in the Hawaiian chain. Ideally future discussions about management of pelagic resources in the Western Pacific will focus strongly on the local and regional details of human maritime experience rather than on the highly condensed and overly generalized versions that now wield such influence on public opinion and in marine-policy settings around the world.

References

Agardy, Tundi. 2009. Is Ocean Zoning the Solution to Dying Marine Ecosystems? *Scientific American*. Special Edition June 2009. http://www.scientificamerican.com/article.cfm?id=is-ocean-zoning-the-solution

Food and Agriculture Organization. 2004. *The State of the World Fisheries and Aquaculture.* Rome, Italy: Food and Agriculture Organization of the United Nations Fisheries Department. ftp://ftp.fao.org/docrep/fao/007/y5600e/y5600e00.pdf

Mora, Camilo, Ransom A. Myers, Marta Coll, Simone Libralato, Tony J. Pitcher, Rashid U. Sumaila, Dirk Zeller, Reg Watson, Kevin J. Gaston, and Boris Worm. 2009. Management effectiveness of the world's marine fisheries. *PLoS Biol* 7 (6): e1000131. doi:10.1371/journal.pbio.1000131. http://www.plosbiology.org/article/info%3Adoi%2F10.1371%2Fjournal.pbio.1000131

Pontecorvo, Guilio, and William E. Schrank. 2009. *Fisheries Management: Pandemic Failure, Workable Solutions*. Bingley, U.K.: Emerald Group Publishing.

PFRP

Edward W. Glazier is Research Director of the Pacific Islands Office of Impact Assessment, Inc., 910-A Pueo Street, Honolulu, Hawai'i 96816; tel: +1 910-200-9650 (cell); e-mail: eglazier@ec.rr.com or ImpactAssessment@hawaii.rr.com

Hawai‘i Tuna Tagging Project Two (HTTP2)

David G. Itano, Jeffrey A. Muir, and Kevin C. Weng

Figure 1. PFRP researcher David Itano fastens a listening station to a FAD anchor chain. (Photo: Kevin C. Weng)

Introduction

Tagging programs are widely recognized as important tools for understanding the population dynamics, dispersal patterns, and fisheries interactions of fish populations (e.g., Bills and Sibert 1997). For pelagic species in the Pacific, two large tag-and-recapture projects were carried out by the South Pacific Commission (SPC, now the Secretariat of the Pacific Community) in the 1970s and 80s to begin to develop an understanding of the tuna resources of the western Pacific. The results of those studies became central to fisheries management throughout the region.

In the face of changing fishing pressures and the availability of new tag technologies and improved analytical techniques, the newly established Western and Central Pacific Fisheries Commission (WCPFC) has recognized the need to update these analyses and has initiated what is hoped will become a pan-Pacific Tuna Tagging Program (PTTP). The primary goal of the PTTP is to provide the region- and fishery-specific data necessary to validate and improve stock assessments for tropical tuna harvested throughout the Pacific Basin. The Hawai‘i-based tuna tagging project described herein is a sub-regional component of the broader SPC/WCPFC sponsored PTTP and is using previously defined common methodologies and arrangements for integrated data sharing and analysis.

Previous tagging initiatives in Hawaiian waters have been funded by the Pelagic Fisheries Research Program (PFRP). These studies focused primarily on issues of local importance but produced results that were clearly of broader relevance.

Two priorities were identified for examination by these earlier studies:

1) The role of the Cross Seamount and its associated fishery in the dynamics of tuna fisheries and movement in Hawai‘i; and
2) The impact of anchored Fish Aggregating Devices (FADs) on the exploitation and behavior of yellowfin and bigeye tuna.

In response to these concerns PFRP funded research into FAD effects on fishes, including the initial Hawai‘i Tuna Tagging Project (HTTP), focused primarily on the yellowfin and bigeye populations associated with the Cross Seamount and offshore moored weather buoys targeted by Hawai‘i fishing fleets. The HTTP deployed over fifteen thousand conventional tags on yellowfin and bigeye tuna to address issues of movement between geographical areas and different fishery sectors and to derive life-history parameters. The project was effective in quantifying residence times of yellowfin and bigeye tuna on the seamount, exchange rates between major fishing grounds or fisheries, and providing size-dependent estimates of natural mortality and fishing mortality (Adam et al. 2003; Sibert et al. 2000; Holland et al. 1999). Similarly, PFRP-funded FAD-related research has elucidated important aspects of the biology and behavior of fish aggregations associated with these devices (e.g., Dagorn et al. 2007; Itano and Holland 2000).

Local fisheries have, however, changed significantly in the decade since that initial HTTP ended. The seamount fishery has developed new methods and targets different species and sizes while privately set “bigeye FADs” have proliferated closer to Hawaiian shores. These and other developments in the domestic and expanding international fisheries have created a new set of potential user-group conflicts and management concerns.

To update movement and life-history parameters of tuna in Hawaiian waters and to address current fishery issues in Hawai‘i (and the broader Western Central Pacific Ocean) we initiated the Hawai‘i Tuna Tagging Project Two (HTTP2). In this second major tagging effort more emphasis has been placed on nearshore fisheries (although there remains an important seamount component) and skipjack tuna are included in the tagging program.

Objectives

Three principal objectives have been identified to address management concerns of the Western Pacific Regional Fishery Management Council (WESPAC) and WCPFC:

1) Obtain estimates of growth rates, natural mortality, fishing mortality, and movement (dispersal) parameters for yellowfin, bigeye, and skipjack tuna in Hawaiian waters. This will be the first time that these parameters have been quantified for skipjack tuna in Hawaiian waters.
2) Document the FAD-associated behavior of skipjack tuna. Although skipjack tuna is the most common species found in association with FADs, no previous work in Hawaiian waters has focused on their FAD-associated behavior (either residence patterns or depth distribution).
3) Determine the diurnal vertical behavior of bigeye tuna associated with the Cross Seamount. Seamounts play an extremely important role in the tuna fisheries of the world. In Hawai'i the Cross Seamount plays a key role in local fisheries and has received considerable attention in terms of its physical oceanography and fisheries biology (Holland and Grubbs 2007; Holland et al. 1999).

Methodology

Two general methods are being used throughout the project:

1) Mark-recapture experiments using "spaghetti tags." These tags are recovered by fishermen and reported to the researchers via a dedicated phone number. We hope to tag between ten and fifteen thousand animals over the course of the project.
2) Passive acoustic tracking using ultrasonic pingers implanted in fishes and listening stations deployed in strategic locations. Pingers will be surgically implanted in fishes, allowing them to be detected when they swim near listening stations attached to FAD anchor chains (Figure 1) or others deployed on temporary bottom moorings on the Cross Seamount and on other topographic features.

Because HTTP2 has been designed and implemented as a compatible sub-regional component of the broader-scale Pacific Tuna Tagging Program (PTTP), we have established protocols for data sharing between HTTP2 and PTTP so that maximum use can be made of the data acquired by the two projects. The project is being led by Kim Holland (Principal Investigator), David Itano, Jeff Muir, and Kevin Weng in collaboration with commercial fishermen.

References

Adam, M.S., J. Sibert, D. Itano, and K. Holland. 2003. Dynamics of bigeye (*Thunnus obesus*) and yellowfin (*T. albacares*) tuna in Hawaii's pelagic fisheries: Analysis of tagging data with a bulk transfer model incorporating size-specific attrition. *Fish. Bull.* 101:215–228.

Bills, P.J., and J.R. Sibert. 1997. *Design of tag-recapture experiments for estimating yellowfin tuna stock dynamics, mortality, and fishery interactions.* SOEST Publication 97-05, JIMAR Contribution 97-313, 80 pp.

Dagorn, L., K.N. Holland, and D.G. Itano. 2007. Behavior of yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna in a network of fish aggregating devices (FADs). *Mar. Biol.* DOI 10.1007/s00227-006-0511-1.

Holland, K.N., and R.D. Grubbs. 2007. "Fish visitors to seamounts: Tunas and billfish at seamounts," in *Seamounts: Ecology, Conservation and Management,* pp. 189–201, Pitcher, T.J., T. Morato, P.J.B. Hart, M.R. Clark, N. Haggan, and R.S. Santos, eds. Oxford, UK: Blackwell Publishing Ltd.

Holland, K.N., P. Kleiber, and S.M. Kajiura. 1999. Different residence times of bigeye and yellowfin tuna occurring in mixed aggregations over a seamount. *Fish. Bull.* 97:392–395.

Itano, D.G., and K.N. Holland. 2000. Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) in relation to FADs and natural aggregation points. *Aquatic Living Res.* 13 (4): 213–223.

Sibert, J., K.N. Holland, and D.G. Itano. 2000. Exchange rates of yellowfin and bigeye tunas and fishery interaction between Cross Seamount and near-shore FADs in Hawaii. *Aquatic Living Res.* 13 (4): 225–232

PFRP

David G. Itano is a Biologist for PFRP fish tagging projects, Jeffrey A. Muir is a Research Associate, and Kevin C. Weng is the Interim Program Manager, all at Pelagic Fisheries Research Program, Joint Institute for Marine and Atmospheric Research, University of Hawai'i at Mānoa, 1000 Pope Road, MSB 313, Honolulu, Hawai'i 96822, USA; tel +1 808-956-4108, +1 808-956-7895, and +1 808-956-4109, email dgi@hawaii.edu, jmuir@hawaii.edu, and kweng@hawaii.edu; website http://www.soest.hawaii.edu/pfrp/pfrp1.html

PNAS Publication for Graduate Student

PFRP Staff

C. Anela Choy, a graduate student receiving support from the Pelagic Fisheries Research Program (PFRP), is the first author on a recently published paper in the prestigious *Proceedings of the National Academy of Sciences*. Choy was also this year's recipient of the J. Watumull Merit Scholarship.

Choy's work focuses on identifying trace metals in large pelagic fishes and their prey, helping to better understand the risks and benefits of eating seafood. Natural markers such as trace metals are also promising ecological research tools for determining trophic linkages in pelagic ecosystems.

Choy collaborates with other researchers at the University of Hawai'i and also with industry partners in Honolulu. She is continuing her studies of pelagic food webs in a new PFRP-funded project, "Examining pelagic food webs using multiple chemical tracers."

The *PNAS* paper from Choy and her coauthors is available through the PFRP website: http://www.soest.hawaii.edu/PFRP/reprints/Choy%20et%20al%202009_Hg.pdf.

C. Anela Choy (Photo: C. Anela Choy)

Choy, C.A., B.N. Popp, J.J. Kaneko, and J.C. Drazen. 2009. "The influence of depth on mercury levels in pelagic fishes and their prey." *Proceedings of the National Academy of Sciences of the United States of America* 106:13865–13869

PFRP

PFRP Pelagic Fisheries Research Program

Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawai'i at Mānoa
1000 Pope Road, MSB 313
Honolulu, HI 96822