JIMAR – PFRP ANNUAL REPORT FOR FY 2007

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Collaborator: Brian Fry
Graduate Student: Brittany Graham

Project Proposal Title: **Trophic structure and tuna movement in the cold tongue-warm pool pelagic ecosystem of the equatorial Pacific.**
PROJECT # 659559.

Funding Agency: NOAA

NOAA Goal:

- ☒ To protect, restore, and manage the use of coastal and ocean resources through ecosystem-based management
- ☒ To understand climate variability and change to enhance society's ability to plan and respond
- ☐ To serve society's needs for weather and water information
- ☐ To support the nation's commerce with information for safe, efficient, and environmentally sound transportation

1. Purpose of the project:

Previous modeling suggests that tuna productivity in the western and central Pacific Ocean is tied to upwelling along the equator in the central and eastern Pacific. This project proposes to test this hypothesis by combining diet analysis, stable isotopic analyses, and food-web modeling to study trophic-level variation and tuna movements in the equatorial Pacific. Our hypothesis predicts that tunas that reside near equatorial upwelling regions feed at relatively low trophic levels. Opposite trends are expected in equatorial regions with little upwelling, such as the warm pool of the western Pacific, where tunas are expected to feed at higher trophic levels and move extensively, searching for less-abundant prey. The main objectives of the project are to define the trophic structure, establish an isotope-derived biogeography, and characterize large-scale tuna movements in the pelagic western, central, and eastern tropical Pacific. Results of this study should help define ecosystem linkages leading to tuna production and the effect of climate variability on the systems. This information is important for both fisheries production and ecosystem modeling of the equatorial Pacific Ocean.

2. Progress during FY 2007:

2.1 Sampling and stomach content analysis

In the western and central Pacific, since the beginning of the project, 96 sampling trips on tuna fishing vessels have been completed. Of the 4132 stomachs collected so far from about 67 species, 3158 have been examined in the laboratory.

In the eastern Pacific, fauna from 272 sets made during 64 trips on tuna purse-seine fishing vessels have been sampled since the beginning of the project. Samples of stomachs, muscle, and liver tissues have been collected from more than 10,700

specimens of about 47 taxa. The majority of the stomach samples have been processed in the laboratory, and the stomach contents identified. The diet data from 53 trips have been analyzed by two students at CICIMAR, Mexico, and for 11 trips by students in Manta, Ecuador (all supervised by F. Galván, co-PI of this project).

2.2 Stable isotope and mercury analyses

Since the beginning of the project, ~2800 predator, prey, and POM samples have been isotopically analyzed and all the bulk stable isotope analyses planned for the duration of the project have been completed. Overall, our final isotope dataset for the equatorial Pacific confirms our initial hypothesis that there are spatially-coherent patterns in the $\delta^{15}N$ values of several top predators in the equatorial Pacific Ocean. These spatial patterns will lead to insight into tropical tuna trophic dynamics and movement patterns. Efforts are currently concentrated on writing manuscripts that synthesize these data.

Approximately 30 samples have been analyzed for compound-specific isotope analysis (CSIA) of specific amino acids. Results of CSIA of amino acids from eastern tropical Pacific yellowfin indicated that the ^{15}N enrichment in the north was due to changes in the $\delta^{15}N$ values at the base of the food web (Popp et al. 2007). We used the difference between the $\delta^{15}N$ values of trophic (alanine, aspartic acid and glutamic acid) and source (glycine and phenylalanine) amino acids to estimate the trophic level of ETP yellowfin tuna. Assuming the difference between the $\delta^{15}N$ values of source and trophic amino acids changed by 7‰ per trophic level, we estimated that the trophic level of ETP yellowfin ranges from 4.2 to 4.6. This amino acid-derived estimate matched well the estimate of 4.6 to 4.7 derived from diet analysis (Olson and Watters 2003) and an estimate of 4.1 to 4.9 calculated from a model based on the difference between the $\delta^{15}N$ values of bulk mesozooplankton and yellowfin tuna in the ETP. The implication of our results is that $\delta^{15}N$ analyses of individual amino acids in yellowfin can be used to estimate the $\delta^{15}N$ values at the base of the food web and their trophic level, using a single sample. We propose that differences between the $\delta^{15}N$ values of source and trophic amino acids can be used to examine possible historical changes in the trophic level of archived samples of fish to investigate potential effects of fisheries removal on the trophic dynamics of pelagic ecosystems. During June to August 2006, samples were analyzed with CSIA to investigate a) the processes producing anomalous high and low ^{15}N enrichment in bulk yellowfin tuna white muscle tissue collected from throughout the equatorial Pacific Ocean, b) the major processes involved in the distinct positive shift in the $\delta^{15}N$ of Oahu FAD-associated yellowfin tuna documented by Graham *et al*. (2007), and c) the effects of tissue catabolism during fasting on bulk $\delta^{15}N$ values of Oahu FAD-associated juvenile yellowfin tuna. All three of these objectives have also provided an opportunity to examine the constancy and the mechanisms underlying the 7‰ per trophic level difference between the $\delta^{15}N$ of 'trophic' amino acids and the 'source' amino acids. Current efforts are concentrated on writing manuscripts synthesizing these CSIA data.

During FY 2007, we have been exploring the use of generalized linear models (GLMs) and generalized additive models (GAMs) to assess the importance of several environmental variables and sample location in explaining the spatial variation in $\delta^{15}N$ of mesozooplankton (a proxy for the base of the food web) in the ETP. Samples of zooplankton were collected by bongo net on board the R/V *David Starr Jordan* and R/V *McArthur II*, of the National Oceanic and Atmospheric Administration (NOAA), in the

ETP from 5 August to 5 December 2003. This sampling was a component of the *Stenella* Abundance Research (STAR) Project conducted by the Southwest Fisheries Science Center, La Jolla, California, USA. In the laboratory, CICIMAR graduate student Gladis Lopéz-Ibarra sorted the zooplankton samples for copepods, amphipods, euphausiids, and chaetognaths, and bulk carbon and nitrogen isotopic values of these samples were determined. Simultaneous with the zooplankton sampling and from the same ships, oceanographic variables were measured with conductivity-temperature-depth (CTD) instruments. In addition, SeaWiFS turbidity data, bathymetry, altimetry, wind speed and direction, and chlorophyll A concentration were compiled. The mesozooplankton $\delta^{15}N$ values showed strong non-linear dependence on thermocline depth, SST, and bivariate latitude and longitude, and a weaker linear relationship with SeaWiFS turbidity data. We used a GAM to predict the $\delta^{15}N$ of the mesozooplankton guild, using the thermocline depth, SST, turbidity, latitude, and longitude at the purse-seine set locations where yellowfin tuna were sampled. The trophic status of the yellowfin tuna was calculated at each sample position based on the GAM-predicted $\delta^{15}N$ of mesozooplankton, the measured $\delta^{15}N$ of yellowfin, the trophic fractionation factor between the consumer and its diet, and an independent estimate of the trophic status of mesozooplankton in the ETP, based on previous work. Spatial variation in yellowfin trophic status is being examined using the stomach contents data in conjunction with the model estimates.

36 samples of pelagic predators were submitted to B. Fry for sulfur isotope ($\delta^{34}S$) and total mercury (THg) analyses. Preliminary THg data supports the ontogenic trophic shift observed in juvenile yellowfin tuna collected around Hawaii (Graham *et al.* 2007) and, therefore, could help to distinguish average foraging depth of pelagic predators. On a zonal spatial scale, yellowfin tuna had the highest THg values in the ETP compared to Hawaii or the western tropical Pacific. These spatial variations in THg concentrations could provide a valuable tool to further "source" tuna to specific regions with the equatorial Pacific Ocean. There were no significant differences in the $\delta^{34}S$ values of these same fish, which indicates that sulfur isotope analysis might have limitations in resolving trophic ecology and movement patterns of top predators in the open ocean.

2.3 Modeling and diet analyses

The diet data for skipjack, yellowfin, bigeye tunas and other large predators from the warm pool (equatorial western Pacific) have been partially analyzed. This information has been compiled and included in an Ecopath model of the warm pool pelagic ecosystem. Based on this field work, on other model estimates (biomass and production of forage taxa from SEAPODYM and of the tunas from MULTIFAN-CL; tuna consumption estimates from a bioenergetics model), and on literature information, the model has been developed in collaboration with 6 other scientists experienced in ecosystem modeling during a workshop in Noumea, New Caledonia, 5-9 March 2007. A balanced model describing the ecosystem has been produced, and preliminary Ecosim scenarios were tested. Important facts about the system and the modeling process were highlighted:

- Over-aggregation of species groups, particularly forage, along with diet loops (*i.e.* species 1 eats species 2 which eats species 1) is a major problem that prevents balancing the model. Moreover Ecopath does not manage well high percentages of

cannibalism. Consequently despite good quality information from field work (diet data), modifications sometimes very different from field data had to be made to balance the model. Obtaining a balanced model required compromises between simplification and reality.

- Because of its high biomass, production, consumption and cannibalism skipjack occupies a central position in the system. It exerts a very high predation pressure on lower trophic levels and it constitute a major food source, particularly the juvenile stages, for all the top predators. Ecosim scenarios of top-down control showed very strong resilience of this species.
- The Ecopath model challenged the pre-existing models already in use. During the balancing procedure of our Ecopath model, discrepancy between the forage estimates provided by SEAPODYM and the tuna biomass estimates from the stock assessment model MULTIFAN-CL became apparent. We considered stock assessment estimates more reliable and modified the forage estimates to balance the model.

Some Ecosim scenarios were conducted to examine top-down impacts on the ecosystem. Modifications in the fishing pressure do not cascade down to the forage level, while yellowfin and bigeye respond strongly to any modification.

The diet data for 34 species of tunas and associated fauna from the cold tongue (equatorial eastern Pacific) have been analyzed by CICIMAR graduate student, Noemí Bocanegra-Castillo. The majority of the study was focused on pelagic fishes that associate with floating objects. The study represents an important contribution to understanding the nature of the association between pelagic fishes and floating objects in the open ocean, which is an important subject given that the majority of the catches of tunas world-wide originate from purse-seine sets on fish associated with floating objects. Recent studies have found no evidence that large pelagic predators associate with floating objects for feeding. The current study is the first that shows that several small fishes use floating objects as a feeding substrate, feeding on algae, crustaceans, and other invertebrates that live on the objects. Large pelagic fishes, such as sharks, marlins, wahoo, and barracuda, obtain a portion of their diet by eating the small, closely-associated fishes and juvenile tunas, while the tunas do not feed on animals associated with the floating objects. This work is unique in showing that several pelagic fishes have an indirect trophic connection to floating objects.

The Ecopath models from the warm pool and the eastern Pacific were briefly compared. They are structured differently, particularly the forage component, making comparison difficult; however sensitivity analysis reveal an important impact of changes in cephalopod biomass in both system. On the other hand, while a small scombrid *Auxis sp.* has a very important role in the food chain in the eastern Pacific, it is absent from the western Pacific, where skipjack may have a similar role.

3. Plans for the next fiscal year:

The project has been extended until December 31, 2007. Sampling efforts have been terminated. The project extension will be dedicated to processing the remaining samples in the laboratory, data analysis, modeling, and publication of the results.

In the western and central Pacific, thanks to additional funding for the project extension, two lab assistants will examine the remaining stomach samples. Diets of the main predators from this region will be analyzed and compared to the results from the

eastern Pacific. The Ecopath model developed for the western and central Pacific will be improved. The diet data from the eastern Pacific will be synthesized into peer-reviewed publications, and eventually incorporated into a new Ecopath model for the pelagic eastern Pacific.

Several papers for the different regions and comparative papers on diet and isotopes for the entire equatorial Pacific will be submitted for publication. Final results of the project will be presented during the Hawaii PFRP-PI meeting in November 2007 and the 1st CLIOTOP symposium in La Paz, Mexico, during December 2007.

4. Papers published in refereed journals during FY 2007:

Graham B. S., Grubbs D., Holland K. and Popp B. N. 2007. An ontogenic dietary shift in juvenile yellowfin tuna from Hawaii. Marine Biology 150: 647-658.

Popp B. N., Graham B. S., Olson R. J., Hannides C. C. S., Lott M. J., Lopez-Ibarra G. A., Galván-Magaña F. and Fry B. 2007. Insight into the trophic ecology of yellowfin tuna, *Thunnus albacares*, from compound-specific nitrogen isotope analysis of proteinaceous amino acids. In Dawson T. and Siegwolf R. (eds) Isotopes as Tracers of Ecological Change, Elsevier Academic Press. pp. 167-184.

Papers in preparation for refereed journals:

Allain V. *et al. In Prep.* Gear effect (Longline vs. Purse seine) on the diet description of tropical tuna in the western Pacific incorporating stomach content examination and stable isotope mixing model.

Graham, B. S., B. Fry, B. N. Popp, R. J. Olson, and K. N. Holland. *To be submitted to Journal of Experimental Biology July 2007.* Tissue turnover rates in captive and wild populations of an endothermic teleost, yellowfin tuna, *Thunnus albacares*: implications for estimating movements of pelagic predators.

Graham, B. S. et al. *In Prep.* Bulk $\delta^{15}N$ biogeography: a novel approach to examining movements of tropical tunas in the equatorial Pacific Ocean.

Graham, B. S. et al. *In Prep.* Compound-specific $\delta^{15}N$ stable isotope analysis of yellowfin tuna collected from Hawaii: N_2 fixation fueling juvenile tuna production?

Olson, R. J. *et al. In Prep.* Trophic status of yellowfin tuna in the pelagic eastern Pacific Ocean: $\delta^{15}N$, mesozooplankton, and environmental correlates.

5. Other papers, technical reports, meeting presentations, etc:

5.1. Other papers:

Allain V. & Leroy B. 2006. Ecosystem monitoring and analysis: stomach sampling overview of the GEF-SAP project 2000-2005 and stomach sampling strategy of the GEF-OFM project 2005-2010. WCPFC-*SC2* – EB IP-6.

5.2. Technical reports: None

5.3. Meeting presentations:

Fry, B. et al. 2007. Isotopia and the Tides of Global Change. Keynote speaker at the 13th Annual CF-IRMS workshop in New Brunswick, Canada. June 2007.

Graham B., B. Popp, R. Olson, V. Allain, F. Galvan-Magana and B. Fry. 2006. Employing chemical tags to determine trophic dynamics and movement pattersn of migratory predators in the equatorial Pacific Ocean. 5th International Conference on Applications of Stable Isotope Techniques to Ecological Studies (IsoEcol 5) in Belfast, UK. Aug 2006.

Graham B., B. Fry, B. Popp, V. Allain, R. Olson and F. Galvan-Magana. 2006. From Pelagic Predators to Primary Production: Using Isotope Biogeography to Understand Tropical Tuna Foraging Behavior, Migration, and the Nutrient Dynamics of the Equatorial Pacific. PFRP PI Workshop. Hawaii. November 2006.

6. Graduates:

Marie-Laure Coudron obtained her Master degree at the University of Caen in September 2006 presenting her work entitled "1998 regime shift detection by comparing tuna diets in French Polynesia".

7. Awards:

B. Graham received the best student oral presentation at the 5th IsoEcol meeting in Belfast, UK.

8. Publication Count:

	JL Lead Author			NOAA Lead Author			Other Lead Author		
	FY04	FY05	FY06	FY04	FY05	FY06	FY05	FY06	FY07
Peer-reviewed									2
Non-peer reviewed							3	4	1

9. Students and Post-docs:

Brittany Graham. Ph.D. Candidate, Department of Oceanography, University of Hawaii. Ms. Graham has been continously supported by a PFRP graduate assistantship and just began her 5th year of the program. She intends to defend her dissertation work in Aug 2007.

Noemi Bocanegra-Castillo. Ph.D. Candidate, Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S, Mexico has been working with diet data of fishes in the eastern tropical Pacific, with partial support from this project through F. Galván's budget. She is scheduled to defend her dissertation, entitled "Relaciones tróficas de los peces pelágicos asociados a la pesquería del atún en el Océano Pacific oriental," in August 2007.

Gladis López-Ibarra. Ph.D. Candidate, Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S, Mexico has been working on stable isotopes in zooplankton collected by this project, with partial support for isotope analyses provided by this project. She is scheduled to defend her dissertation, entitled "Estructura trófica de los copépodos pelágicos en el Océano Pacific oriental," in December 2007.

Vanessa Alatorre-Ramírez. MS. Candidate, Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S, Mexico has been working on diet data of fishes in the eastern tropical Pacific, with partial support from this project through F. Galván's budget. She is scheduled to defend her MS thesis, entitled "Hábitos alimenticios del atún aleta amarilla *Thunnus albacares* y barrilete *Katsuwonus pelamis* en cardúmenes mixtos del Océano Pacífico Oriental Tropical" in September, 2007.

Jorge Morales and Mónica Loor. BS candidates, Universidad Laica "Eloy Alfaro" de Manabi, Manta, Ecuador have been working on the food habits of yellowfin, bigeye, and skipjack tunas associated with floating objects in the equatorial eastern Pacific Ocean using samples collected under the auspices of this project. They are jointly preparing a BS thesis summarizing their work.

10. Personnel:

(iii) Number of employees/students that were hired by NOAA during the past year:
Secretariat of the Pacific Community: Caroline Sanchez – Lab assistant (6 months), Kim Loeun – Lab assistant (6 months), Marie-Laure Coudron – Student in Master degree (3 months).

11. Images and Captions: Images to be provided upon request.

12. For multi-year projects, provide budget for the next year on a separate page.

The project will end on December 31, 2007.