JIMAR ANNUAL REPORT FOR FY 2008

P.I./SPONSOR NAME: Valerie Allain, Robert Olson, Felipe Galván-Magaña, Brian Popp, John Sibert

COLLABORATOR: Brian Fry.

GRADUATE STUDENT: Brittany Graham

NOAA OFFICE (Of the primary technical contract): PIFSC

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 (Check those that apply):

- ☒ 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

PURPOSE OF THE PROJECT:
Previous modelling suggested that tuna productivity in the western and central Pacific Ocean was tied to upwelling along the equator in the central and eastern Pacific. This project proposed to test this hypothesis by combining diet analysis, stable isotopic analyses, and food-web modelling to study trophic-level variation and tuna movements in the equatorial Pacific. Our hypothesis predicted that tunas that reside near equatorial upwelling regions fed at relatively low trophic levels. Opposite trends were expected in equatorial regions with little upwelling, such as the warm pool of the western Pacific, where tunas were expected to feed at higher trophic levels and move extensively, searching for less-abundant prey. The main objectives of the project were 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 modelling of the equatorial Pacific Ocean.

PROGRESS DURING FY 2008:

Biological analyses (stable isotope analysis and stomach content analysis) in the western, central, and eastern Pacific were terminated as the end of this project approached. A total of 3844 samples of stomach contents from 68 pelagic fish species, and 1809 stable isotope samples (nitrogen and carbon) from predators and prey have been analysed during the project in the western and central Pacific. In the eastern Pacific, a total of 9495 samples of stomach contents from 44 predator species, and 735 stable isotope samples of predators and prey were analysed during the project. Analyses of the data were pursued by the project participants in the different areas of the Pacific to prepare scientific papers for publication and presentations for meetings, as listed below.

Given this is the final annual report for this project, we summarize the major findings below:

a) An ontogenetic diet shift in juvenile yellowfin tuna from nearshore Oahu, determined by stable-isotope and stomach-content analyses, demonstrated that the onset of endothermic capability required for accessing deep-dwelling prey occurred at about 45 cm fork length (Graham, B.S., D. Grubbs, K. Holland and B.N. Popp, 2007: A rapid ontogenetic shift in the diet of juvenile yellowfin tuna from Hawaii. Mar. Biol., 150, 647-658.
b) Results of compound-specific isotope analysis (CSIA) of specific amino acids from yellowfin tuna in the eastern tropical Pacific indicated that ^{15}N enrichment in the north was due to changes in the $\delta^{15}N$ values at the base of the food web. 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 the trophic level of the predator, using a single sample (Popp, B.N., B.S. Graham, R.J. Olson, C.C.S. Hannides, M.J. Lott, G.A. López-Ibarra, F. Galván-Magaña and B. Fry. 2007: Insight into the trophic ecology of yellowfin tuna, *Thunnus albacares*, from compound-specific nitrogen isotope analysis of proteinaceous amino acids. *In*: Stable Isotopes as Indicators of Ecological Change. T.E. Dawson and R.T.W. Siegwolf (eds). San Diego: Elsevier-Academic Press, Terrestrial Ecology Series, pp. 173-190).
c) CSIA also indicated that the trophic level (TL) of small and large size classes of yellowfin from Hawaii did not differ. Instead, the observed rapid ontogenetic shift in the $\delta^{15}N$ values of white muscle tissue reflected a change in the vertical foraging habitat, with juveniles confined to the surface mixed layer and larger individuals foraging over a greater vertical range. Furthermore, bulk and amino acid isotope results for larger yellowfin suggest there were at least two general foraging strategies in the regional Hawaiian "population", with one group foraging at greater depths than the other group. Overall, the compound-specific isotope results revealed that tuna $\delta^{15}N$ values reflect processes that occur at the base of the food web and that CSIA can be applied to examine vertical and horizontal foraging patterns in the pelagic environment.
d) Results from a diet shift conducted on captive yellowfin tuna showed that, of four tissue types, liver had the fastest turnover rate and white muscle the slowest turnover rate, with tissue half lives estimated as 12 and 63 days, respectively. Tissue turnover rates measured in captive and wild yellowfin were similar for liver, but those for muscle were considerably slower in the captive tuna. The difference in muscle

turnover rate may be due primarily to rapid growth and protein turnover in wild tuna, which increases estimates of N turnover. These tissue-turnover rates provide a temporal framework on which to base interpretations of stable isotopic data of tropical tunas (Graham B. S., B. Fry, B. N. Popp, R. J. Olson and K. Holland, 2008: Tissue turnover rates of an endothermic teleost, yellowfin tuna, *Thunnus albacares*, in captivity and in nature. *Journal of Experimental Marine Biology and Ecology* (submitted).

e) Stable isotope analysis of three tropical tunas (yellowfin, skipjack, and bigeye) and of wahoo and dolphinfish suggest limited movement behavior throughout the equatorial Pacific. In the eastern Pacific, yellowfin tuna appear to be largely resident at the same scale as zooplankton (Figure 1).

f) The trophic level occupied by yellowfin tuna shows little significant variation across the Pacific, as judged by amino acid $\delta^{15}N$ values, although a study in the eastern Pacific shows that there may be an onshore/offshore increasing gradient in TL, especially if little seasonality occurs in basal $\delta^{15}N$ values.

g) An Ecopath with Ecosim (EwE) model developed for the western and central Pacific, based on diet studies, revealed a different trophic structure than that described for the eastern Pacific based on a previous EwE model. A small scombrid, *Auxis spp.*, has a very important role in the food web in the eastern Pacific, while it is absent in the western Pacific, where skipjack may have a similar trophic role. Sensitivity analyses revealed an important impact of changes in cephalopod biomass in both systems (Allain V**.**, Nicol S., Essington T., Okey T. Olson R.J. & Kirby D. 2007. An Ecopath with Ecosim model of the Western and Central Pacific Ocean warm pool pelagic ecosystem. Third regular session of the Scientific Committee of the Western and Central Pacific Fisheries Commission. 13-24 Aug. 2007. Honolulu, USA. WCPFC-*SC3* – EB SWG/IP-8: 1-42).

h) Stable isotope spatial patterns of mesopelagic myctophid fishes are distinct from those of epipelagic zooplankton species and yellowfin tuna in the eastern tropical Pacific. Mesopelagic myctophids might reflect the $\delta^{15}N$ value of the N at depth, and this $\delta^{15}N$ value is enriched in ^{15}N relative to that in the euphoic zone. Mesopelagic, vertically-migrating squid showed spatial patterns of the epipelagic type, despite published stomach-contents studies showing a diet dominated by myctophid fishes.

i) Stable isotope analysis provided the first broad-scale depiction of trophic relations among the pelagic copepod community in the eastern Pacific Ocean. Several copepod species were reclassified as either herbivores, omnivores, or carnivores.

j) Analyses of diet data of fishes associated with the purse-seine fishery in the eastern Pacific Ocean showed a direct trophic relationship among floating objects and small "intranadant" fishes, which feed on algae and invertebrates that inhabit the objects. Large apex predators, such as sharks, billfishes, and wahoo preyed on the intranadant fishes, and therefore showed an indirect trophic relationship with floating objects. The tunas showed no trophic relationship with floating objects.

k) Co-occurring yellowfin and skipjack tunas, caught in purse-seine sets on tunas associated with dolphins and in unassociated schools, did not appear to share prey resources in the eastern Pacific, suggesting that the function of these inter-specific aggregations may be predator avoidance.

PLANS FOR THE NEXT FISCAL YEAR:
The project finished on December 31, 2007.
A number of submitted papers will require revision according to reviewer's comments before publication. Other papers (5) are currently under preparation. We acquired a large dataset during this project and though the project terminated in Dec. 2007, further data analysis will be conducted in 2008 to extract and publish more information.

LIST OF PAPERS PUBLISHED IN REFERRED JOURNALS DURING FY 2008
None during this reporting period

PAPERS SUBMITTED TO REFERRED JOURNALS

Dambacher, J.M., J.W. Young, R.J. Olson, V. Allain, M.J. Lansdell, and S.P. Cooper, 2008: Analyzing pelagic food webs leading to top predators in the Pacific Ocean: a graph-theoretic approach. *Progress in Oceanography*, CLIOTOP special issue (submitted).

Graham B. S., B. Fry, B. N. Popp, R. J. Olson and K. Holland, 2008: Tissue turnover rates of an endothermic teleost, yellowfin tuna, *Thunnus albacares*, in captivity and in nature. *Journal of Experimental Marine Biology and Ecology* (submitted).

Hannides C. C. S., B. N. Popp, M. R. Landry and B. S. Graham, 2008: Quantitative determination of zooplankton trophic position using amino acid-specific stable nitrogen isotope analysis. *Limnology and Oceanography* (submitted).

Olson, R.J., B.S. Graham, G.A. López-Ibarra, F. Galván-Magaña, C.E. Lennert-Cody, B.N. Popp, N. Bocanegra-Castillo, V. Alatorre-Ramírez, L.T. Ballance, and B.D. Fry, 2008: Food web inferences of stable isotope spatial patterns in copepods and yellowfin tuna in the pelagic eastern Pacific Ocean. *Progress in Oceanography*, CLIOTOP special issue (submitted)

PAPERS IN PREPARATION FOR REFERRED JOURNALS

Allain V. *et al.,* (*In preparation*): 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., R. Olson, V. Allain, F. Galvan, B. Popp and B. Fry, (*In preparation*): Bulk $\delta^{15}N$ biogeography: a novel approach to estimating net movements of tropical tunas in the equatorial Pacific Ocean.

Graham, B., B. Popp, B. Fry, and C. Hannides, (*In preparation*): Linking the base to the top in pelagic food webs: N_2 fixation and fish.

Graham, B., B. Popp, B. Fry, R. Olson, V. Allain, F. Galvan, and A. Lorrain, (*In preparation*): Trophic dynamics of yellowfin tuna in the tropical Pacific Ocean inferred from bulk tissue and compound-specific nitrogen stable isotope analysis.

Olson, R.J., *et al.,* (*In preparation*): Mesopelagic versus epipelagic energy acquisition in ommastrephid squids: evidence from stable isotopes.

OTHER PAPERS, TECHNICAL REPORTS, ETC.:

Allain V**.**, S. Nicol, T. Essington, T. Okey, R.J. Olson and D.S. Kirby, 2007: An Ecopath with Ecosim model of the Western and Central Pacific Ocean warm pool

pelagic ecosystem. *Third regular session of the Scientific Committee of the Western and Central Pacific Fisheries Commission. 13-24 Aug. 2007. Honolulu, USA.* WCPFC-*SC3* – EB SWG/IP-8: 1-42.

MEETING PRESENTATIONS:

Graham, B.S., 2008: Invited talk:. Les Conférences de I'IUEM. Institut Universitaire Européen de la Mer. Trophic dynamics and movements of tuna in the equatorial Pacific.

Graham, B.S., B. Fry, B. Popp, R.J. Olson, V. Allain and F. Galvan, 2008: Invited talk: Pelagic marine isoscapes: determining residency and net movements of top predators in the equatorial Pacific Ocean using bulk and compound-specific stable isotope analysis. *Isoscapes 2008. Santa Barbara (USA) April 7-10, 2008.*

Graham B.S., R.J. Olson, V. Allain, B. Popp, F. Galván-Magaña and B.D. Fry, 2007: Applying stable isotope techniques to determine residency and net movements of tropical tunas in the equatorial Pacific Ocean. *1st GLOBEC CLIOTOP Symposium. La Paz (Mexico). December 3-7, 2007.*

Olson, R.J., B. Graham, C. Lennert-Cody, B. Popp, G. López-Ibarra, F. Galván-Magaña, N. Bocanegra-Castillo, V. Alatorre-Ramírez, L. Duffy, J. Redfern, and B. Fry, 2007: Stable isotope ecology of the pelagic food web in the eastern Pacific Ocean. *1st GLOBEC CLIOTOP Symposium, La Paz, Mexico, 3-7 December 2007.*

GRADUATES:

Brittany Graham, Ph.D. – defended on Friday, Sept 14, 2007. Dissertation title: "Trophic Dynamics and Movements of Tuna in the Equatorial Pacific Ocean Inferred from Stable Isotope Analyses." Official UH Graduation term: Spring 2008.

Noemi Bocanegra-Castillo, Doctora en Ciencias Marinas – Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, México, defended on September 28, 2007. Thesis title: "Relaciones tróficas de los peces pelágicos asociados a la pesquería del atún en el Océano Pacífico oriental."

Gladis A. López-Ibarra, Doctora en Ciencias Marinas – Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, México, defended on June 6, 2008. Thesis title: "Estructura trófica de los copépodos pelágicos en el Océano Pacífico oriental tropical."

Vanessa G. Alatorre-Ramírez, Maestra en Ciencias en Manejo de Recursos Marinos (MS) – Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, México, defended on December 10, 2007. Thesis title: "Hábitos alimenticios del atún aleta amarilla *Thunnus albacares* y barrilete *Katsuwonus pelamis* en cardúmenes mixtos del Océano Pacífico oriental tropical."

AWARDS:

None during this reporting period

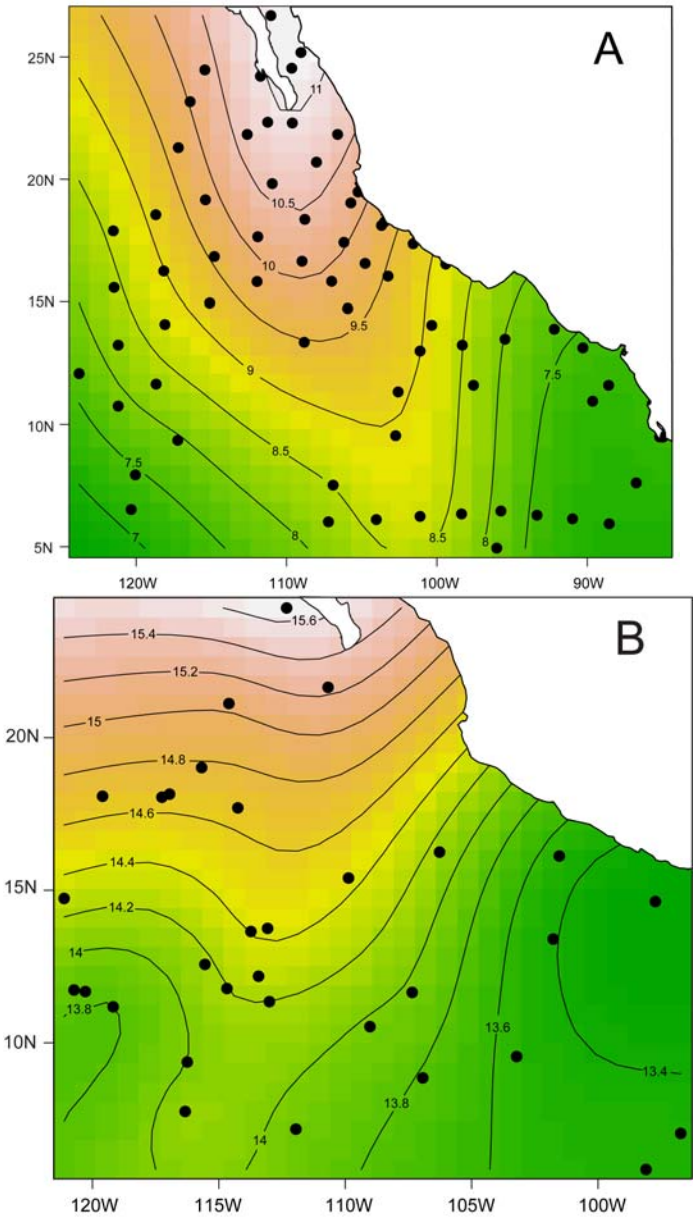
PUBLICATION COUNT:

	JI Lead Author	NOAA Lead Author	Other Lead Author
Peer Reviewed			
Non-Peer Reviewed			1

PERSONNEL:
Secretariat of the Pacific Community: Aude Chenet – Lab assistant (2 months)

IMAGES AND CAPTIONS (We will also be including images for the annual report. Please send two of your best high-resolution, color images (photo, graphic, schematic) as a **JPEG or TIFF (300 dpi)** with a caption for each image. If you do not have an electronic version of the image, a hardcopy version may be dropped off at the JIMAR office located in the Marine Sciences Building, Room 312):

- Caption 1: Figure 1(A). Contour plot of the bivariate latitude-longitude surface for abundance weighted-average $\delta^{15}N$ values (‰) of omnivore copepods estimated from a generalized additive model. The filled circles are 68 sampling stations where the omnivore copepods were sampled by bongo net. There is a strong south-to-north gradient of increasing $\delta^{15}N$ values in the eastern Pacific Ocean.
(B). Contour plot of $\delta^{15}N$ values (‰) from 50 composite samples of up to 6 yellowfin tuna each. The filled circles are the locations where the fish were caught in purse-seine sets. As with the copepods, yellowfin tuna showed a general south-to-north gradient of increasing $\delta^{15}N$ values in the eastern Pacific.



Caption 2: Figure 2(A). $\delta^{15}N$ isoscapes for (A) bigeye (n = 196) and (B). yellowfin (n = 387) tuna. Crosses indicate sample locations. Samples collected in the eastern tropical Pacific represent a composite of ~5 individuals. The $\delta^{15}N$ values for each species were normalized against the average value for that species within the study region. (C). Map of the residuals between the interpolated $\delta^{15}N$ values for the two species (*i.e.*, observable difference between the normalized values). Regions with positive residuals represent areas where the $\delta^{15}N$ values of yellowfin tuna are greater than those of bigeye and negative residuals represent areas where the $\delta^{15}N$ values of bigeye are greater than those of yellowfin.