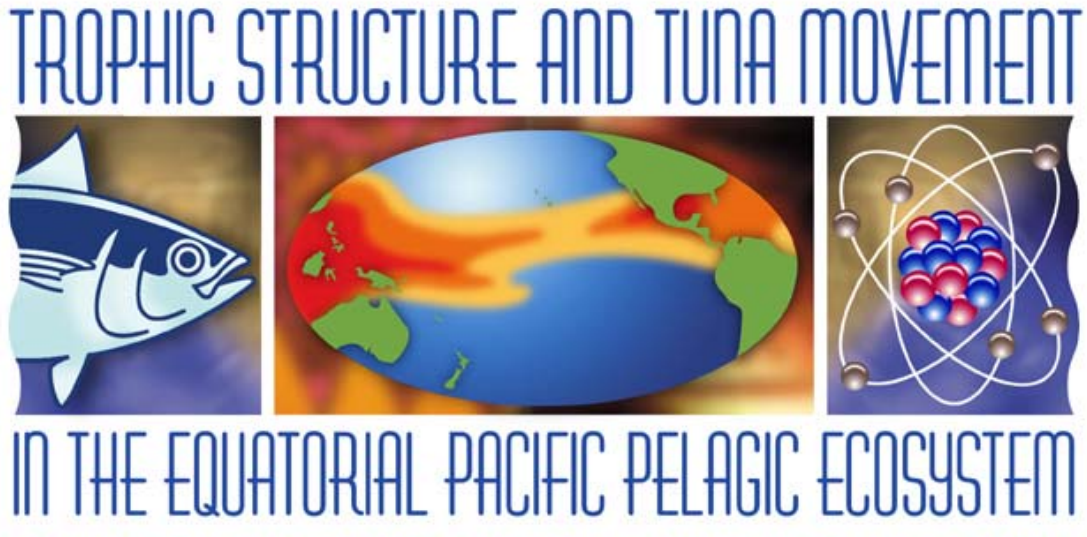

JIMAR, PFRP ANNUAL PROGRESS REPORT FOR FY 2003-2004
PROJECT # 659559

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Project Proposal Title: Trophic structure and tuna movement in the cold tongue-warm pool pelagic ecosystem of the equatorial pacific

Funding Agency: PFRP

1. Purpose of the project and indicative results.

Recent 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. The project proposes to test this hypothesis by combining diet analysis, stable isotopic compositions, food-web modeling, and stable isotope markers to trace tuna movements and trophic-level variation in the equatorial Pacific. The hypothesis predicts that tunas that reside near equatorial upwelling fronts 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 study are:
1. to define the trophic structure of the pelagic ecosystems in the western, central and eastern parts of the tropical Pacific Ocean,
2. to establish an isotope-derived (upwelling-related) biogeography of the pelagic tropical Pacific ecosystems, and
3. to characterize large-scale tuna movements related to upwelling regions along the equator.

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.

Progress during FY 2003-2004.

2.1. Meetings

The second project PI meeting, funded by the project, took place in Noumea, New Caledonia, from 28 April to 2 May 2003. The four PIs, a collaborator Brian Fry and a Ph.D. student Brittany Graham attended this meeting. The first part of the meeting was dedicated to presentations made by the PIs and by colleagues from SPC; in the rest of the meeting a wide range of subjects about the project were discussed and a list of priorities was established.
The third project PI meeting of the project took place in Honolulu, Hawaii in December 2003 after the PFRP PI meeting. Three of the PIs attended (Felipe Galván-Magaña was absent) as well as Brian Fry and Brittany Graham; progress, future work and priorities were discussed.

2.2. Funding Problems

Bank transfer and exchange rates were higher than expected. There were some delays in receiving of funds but project personnel were able to continue with research work with minimal problems.

2.3. Sampling on tuna fishing vessels

2.3.1 Western and central Pacific

In the western and central Pacific, observers of the National Observer Programs of the area collected samples. Sampling kits were distributed to Papua New Guinea (5 kits), Federated States of Micronesia (4), Solomon Islands (6), Marshall Islands (5), Tonga (1), Vanuatu (1), French Polynesia (6) and New Caledonia. One freezer was bought for storage of the samples in the Federated States of Micronesia and one in the Solomon Islands. Observers on longline and purse-seine vessels are collecting muscle and liver samples from 2 specimens of each species (tuna, shark, billfish and other bycatch species) per set. Predator sampling is widespread from Papua New Guinea to French Polynesia from west to east, and from the Federated States of Micronesia to New Caledonia from north to south. Since April 2003, 13 sampling trips have been completed: 1 longline trip in New Caledonia, 3 longline trips in French Polynesia, 1 purse seine trip in Papua New Guinea, and 8 longline trips in Solomon Islands.

Of the 1466 stomachs collected since July 2002 from 50 species of predatory fishes, 1169 have been examined in the laboratory. The most numerous predatory fish species are yellowfin tuna (176 specimens), bigeye tuna (111), skipjack tuna (257), albacore (79), blue marlin (21), sailfish (10), striped marlin (17), swordfish (18), blue shark (28), silky shark (13), short-finned mako shark (10), pelagic sting-ray (12), wahoo (62), lancetfish (65), dolphinfish (71), moonfish (36), escolar (19), rainbow runner (40), great barracuda (14), and frigate tuna (10). Data have been partially analyzed for three species: dolphinfish, lancetfish and wahoo.

Trophic level of the predators will be estimated using the stomach contents as well as stable isotope analysis of the muscle and liver samples. From the 1423 muscle and 1042 liver samples collected since July 2002, 700 and 696 samples, respectively, were freeze-dried for isotopic analysis since April 2003. A total of 172 samples of muscles and livers of different species of predators and prey have been isotopically analyzed.

In Hawaian waters, under the primary objectives of the PFRP project # 757282, we have continued collecting a suite of samples from Hawaiian FADs and the Cross Seamount. Samples collected include prey items (i.e. stomachs contents) and tissue samples for isotope analysis from bigeye and yellowfin tuna ranging in forklength.

2.3.2 Eastern Pacific

In contrast to the western Pacific, sampling by observers onboard tuna vessels in the eastern Pacific Ocean (EPO) was not in force prior to initiation of this project. During the April 2003–March 2004 period, preparations for sampling were completed and samples were collected on purse-seine vessels. Preparations included a field manual for the observers, observer training, and purchasing and transporting sampling equipment and supplies to Mexico and Ecuador.

Samples from 19 purse-seine trips were collected during the period covered by this report. These included 12 trips from Ecuadorian ports and 7 trips from Mexican ports. Samples and data are in hand for 39 sets associated with floating objects and 16 sets associated with dolphins during 14 of the 19 trips. The other 5 trips are still at sea. Set locations were widely distributed, from 25º N to 12º S and from 146 º W to 91 º W. The observers collected stomach, white muscle, and liver samples from the tunas and bycatch species. For several small non-target fishes that associate with floating objects, whole specimens were collected by the observers at sea. Sampling criteria are to collect 15 specimens per set for the tunas and all specimens available for the associated fishes, up to 15 specimens each per set.

The following numbers of species were collected during the period covered by this report: 555 yellowfin tuna, 412 skipjack tuna, 237 bigeye tuna, 5 black skipjack tuna, 16 frigate tuna, 231 wahoo, 203 dolphinfish (mahi mahi), 221 rainbow runner, 1 spinner dolphin, 131 silky sharks, 2 oceanic whitetip sharks, 1 thresher shark, 14 blue marlin, 1 shortbill spearfish, 392 triggerfishes and filefishes, 172 jacks, and 252 kyphosids and lobotids (small fishes that associate with floating objects).

2.4 Sampling on research vessels

2.4.1 Western and central Pacific

A sampling trip was undertaken onboard the Shoyo-Maru, a Japanese research boat, during a scientific cruise of the Fishery Agency of Japan in the western and central equatorial area. During this cruise, 29 samples of particulate organic matter, 12 zooplankton samples, and 45 forage specimens (fish, shrimps, squids), were collected, which will allow characterizing the low trophic levels.

2.4.2 Eastern Pacific

Samples were collected for this project by personnel of the U.S. National Marine Fisheries Service onboard two research ships in the eastern Pacific under the direction of the *Stenella* Abundance Research Project (STAR). STAR is a multi-year study designed to assess the status of dolphin stocks that have been taken as incidental catch by the tuna purse-seine fishery in the eastern Pacific Ocean. Both NOAA ships, *David Starr Jordan* and *McArthur II*, simultaneously surveyed a large portion of the eastern and central Pacific from July 29 to December 10, 2003 (for cruise track please see http://swfsc.nmfs.noaa.gov/prd/star/default.htm). Oceanographic data were also collected to characterize habitat and its variation over time.

Samples of zooplankton were collected every evening (weather permitting) by bongo net, and the contents of one side of the paired net were frozen for stable isotope analysis (n=156). Samples of particulate organic matter were collected and frozen almost daily by filtering seawater on to 25-mm glass fiber filters (n=199). Dipnetting for surface fauna was conducted every evening (weather permitting), and numerous specimens were shared with us for isotope analysis. These

included flyingfishes (n not yet determined), mesopelagic myctophid fishes (n=400), cephalopods, and other miscellaneous fauna. Also, predator fishes were caught using trolling gear on an opportunistic basis when conditions permitted. The stomachs, liver, and muscle samples of some of these fishes were also collected.

The zooplankton samples collected on both STAR cruises were prepared for additional analyses by a graduate student from CICIMAR, La Paz, Mexico. M. Sc. Gladis López-Ibarra measured total plankton volumes, fractioned the samples into two equal parts, refroze them, and transported one part to La Paz for use in her Ph. D. research. She will analyze the trophic structure of major taxonomic components of the zooplankton assemblages, especially copepods, using stable isotope analysis. Ms. López's study, not an original component of the project, will be an additional output for this project.

2.5 Stomach content analysis

In the Western and Central Pacific diets of mahi-mahi, wahoo and lancetfish have been partially analyzed. Diets of the three species show different feeding strategies: dolphinfish is a surface piscivorous predator, wahoo also consumes small amounts of mesopelagic prey and if mainly piscivorous, it diversifies its diet eating small quantities of cephalopods and shrimps; lancetfish feeds at the surface and in deeper waters on fish and molluscs but also on small quantities of crustacea and invertebrates.

Stomach content analysis for samples collected in the eastern Pacific is underway at CICIMAR, La Paz, Mexico. To date, 1200 samples have been processed or partially processed. The data have not yet been analyzed.

2.6 Isotope analysis

Stable isotope analysis has advanced on 3 separate fronts: (1) analysis of predators and preys collected from the western and central Pacific, (2) a continuation of analysis of tuna caught around Oahu and the most intense effort has focused on (3) laboratory experiments on captive tuna.

First results of isotope analysis were received for the western and central Pacific: 172 samples of muscle and liver of different pelagic top predators and preys were analyzed for carbon and nitrogen isotopes. Several factors could explain the tendencies observed in the isotope values. Location seems an important factor: fish of the same species but from different locations have different values. Length may be another contributing factor. Nitrogen isotope values of predators also appear related to depth. More samples are needed to try to explain the values observed and are in the process of being analyzed.

Overall, the data collected from Hawaiian waters illustrates a distinct and rapid ontogenic shift in both yellowfin and bigeye tuna. The ontogenic shift, documented in both liver and white muscle tissues, will be modeled to provide estimates of tissue turnover in wild tuna. Currently we are writing up these results for publication. Aptly, these values will be compared to data collected in the diet experiments with captive tuna (Section 2.7).

2.7 Laboratory experiments

A tuna tank was constructed at the HIMB facilities, under the guidance of Dr. Kim Holland (PFRP Project 757282). Effort during the initial weeks after construction was focused on the transport and rearing of captive tuna. Shortly after the construction of the tank was completed, tuna were placed in the tank and serendipitously provided an ideal diet shift experiment to base future work

on. More specifically, the diet fed to the tuna once in the tank (i.e. a mixture of squid and smelt) was isotopically distinct from the wild diet. A more rigorous diet shift experiment began in Feb. 2004 and is nearly complete. Overall, the tissue turnover rates of captive tuna are similar to those recorded f for mammals. These results are now being compiled for publication. Not only is the scientific community interested in the uses of stable isotopes to determine tissue turnover rates, but the results of these experiments will also enable us to better assess tuna migration and are at the foundation of future work.

2.8 Ecosystem modeling

2.8.1 Western and central Pacific

The preliminary model developed during the last quarter of 2002 has been greatly improved by adding several components to the model. Formulation of primary and secondary components (phytoplankton and zooplankton) have been improved, and the piscivorous fish group has been subdivided. The Ecopath model includes 20 functional groups: detritus, phytoplankton, zooplankton, crustacea, cephalopods, epi- and meso-pelagic fish, small top predators and adult top predators. Data inputs for each group are Biomass, Prodution, Consumption, Ecotrophic efficiency, catch and diet matrices. This new model has been compared to the previous one and tests on increasing effort and reaction to ENSO have been conducted. Further work is needed for the improvement of the model. The diet matrix will be improved using data collected in the area by the observer programmes in particular.

2.8.2 Eastern Pacific

A trophically-explicit, spatially-aggregated ecosystem model of the pelagic eastern tropical Pacific, developed previous to this project, using Ecopath with Ecosim, was published during the period covered by this report (Olson, R.J., and G.M. Watters. 2003. A model of the pelagic ecosystem in the eastern tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm., Bull. 22 (3): 133-218). The model will be reformulated based on new data describing trophic connections (diet data) and trophic structuring (stable isotope data) forthcoming from this project. Substantial improvements are expected because the existing model contains a paucity of information about the forage fishes and cephalopods at middle trophic levels, whereas this project will measure trophic positions of these taxa relative to those of the predators, based on stable isotope analysis.

3 Plans for the next fiscal year.

We have presented results of this study at the 4th Stable Isotope Ecology Conference in Wellington in April 2004 and at the PFRP PI meeting during the 55th Tuna Conference in Lake Arrowhead in May 2004. A workshop on isotopes, partially funded by GLOBEC, is being organized by the project PIs in La Paz, Mexico, in May-June 2004 with invited scientists working on similar projects in Australia and Atlantic/Indian Oceans. Concomitant to these meetings, but also during a meeting scheduled in March 2005 in Hawaii, PIs and collaborators will meet to discuss progress, problems and future plans and to discuss interpretation of the stomach content and isotope analyses.

3.1. Western/central Pacific

In the western/central Pacific, sampling will be pursued to increase the number of predator stomachs, muscle and liver samples collected. Stomach examination will continue and data will be analyzed for most of the species and included in an Ecopath model of the ecosystems. The number of samples analyzed isotopically will be increased to establish an isotope-derived Pacific map for the most important species of the ecosystem.

Possibilities to join scientific cruises for collection of plankton and prey samples will be explored. We plan to still explore the possibility of requesting samples of sessile primary producers (i.e. barnacles) to be collected on NOAA vessels servicing the TOGA-TAO array in the central Pacific.

3.2. Eastern Pacific

Sampling is being intensified during 2004 due to a budget increase provided by PFRP for year 2, 2004. With the budget increase, we will sample 50 trips during 2004. The additional diet and isotope data obtained from intensified sampling will greatly help parameterize a new ecosystem model for the eastern Pacific. This will provide valuable input for continuing efforts to incorporate ecosystem considerations in fisheries management.

Stomach contents analysis from purse-seine caught predators will continue by CICIMAR personnel. It is unlikely that we will obtain samples of POM, zooplankton, and forage fishes and invertebrates from the lone STAR cruise to be conducted by the U.S. National Marine Fisheries Service during 2004. This is because that cruise is planned to survey the mammal stocks in nearshore areas only. We will attempt to obtain samples from other research cruises on an opportunistic basis.

4 List of papers published in refereed journals during FY 2003-2004.

None.

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

5.1. Other papers

Godinot, O. & V. Allain. BBRG-5. A preliminary Ecopath model of the warm pool pelagic ecosystem. SCTB16. Mooloolaba, Australia. 9-16 July 2003.

Allain, V. BBRG-6. Diet of mahi-mahi, wahoo and lancetfish in the western and central Pacific. SCTB16. Mooloolaba, Australia. 9-16 July 2003.

5.2. Meeting presentations

V. Allain. 2003. A preliminary Ecopath model of the warm pool pelagic ecosystem. SCTB16. Mooloolaba, Australia. 9-16 July 2003.

V. Allain. 2003. Diet of mahi-mahi, wahoo and lancetfish in the western and central Pacific. SCTB16. Mooloolaba, Australia. 9-16 July 2003.

V. Allain, R. Olson, F. Galvan, B. Popp. 2003. Trophic structure and tuna movements in the cold tongue-warm pool pelagic ecosystem of the equatorial Pacific. PFRP PI Workshop. Hawaii. 9-11 December 2003.

V. Allain, B. Graham, R. Olson, B. Popp, F. Galvan-Magana, and B. Fry. 2004. Stable isotopes as tracers of trophic structure and tuna movement in the equatorial Pacific pelagic ecosystem. 4th International Conference on Applications of Stable Isotope Techniques to Ecological Studies. Wellington. April 19-23 2004.

B. Graham, V. Allain, K. Holland, D. Grubbs, B. Fry, R. Olson, F. Galvan, and B. Popp. 2003. Chemical Clues: stable isotopes and tuna. PFRP PI Workshop. Hawaii. December 2003.

B. Graham, K. Holland, D. Grubbs, B. Popp, V. Allain, R. Olson, F. Galvan, B. Fry. 2003. Tuna trophic dynamics in the western, eastern, and central tropical pacific. Tuna conference. Lake Arrowhead. May 2003.

B. Graham, K. Holland, D. Grubbs, B. Popp, and B. Fry. 2004. Tuna trophic dynamics in Hawaiian waters: Are there differences in the $\delta^{15}N$ of mesopelagic and epipelagic food webs? 4th International Conference on Applications of Stable Isotope Techniques to Ecological Studies. Wellington. April 19-23 2004.

R. Olson. 2003. Trophic structure and tuna movements in the cold tongue-warm pool pelagic ecosystem of the equatorial Pacific. *Stenella* Abundance Research 2003–Orientation and Training Workshop. La Jolla, California. 23-25 July 2003.

6 Names of students graduating with MS or Ph.D. degrees during FY 2003-2004.

No students have graduated. Ms. Brittany Graham was accepted in the Ph.D. program by the Department of Oceanography, University of Hawaii in September 2002. Ms. Graham is supported by a PFRP fellowship/graduate assistantship and is working jointly between this project and PFRP project 757282 of Holland et al.

7 Budget for the next year

See attached budget sheets.