JIMAR – PFRP ANNUAL REPORT FOR FY 2006

P.I./Sponsor Name: Patrick LEHODEY, John SIBERT

Project Proposal Title: Mixed-resolution models for investigating individual to population spatial dynamics of large pelagics

Funding Agency: NOAA

NOAA Goal (Check those that apply):

- ☒ To protect, restore, and manage the use of coastal and ocean resources through ecosystem-base 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 (one paragraph)

This project addresses ways to improve upon two classes of models: Individual Based Models (IBMs) and Advection Diffusion Reaction Models (ADRMs) that can provide complimentary approaches to investigating the problems of scale integration when going from individual to the population level and from individual movements to advection-diffusion patterns. However, the approach needs a unifying framework combining large and small spatio-temporal scales i.e., the mixed resolutions in a same model domain. Therefore, the project proposes mathematical and programming developments in movement and spatial population dynamics models. The ESSIC model (co-P.I. R. Murtugudde, Univ. Maryland) will provide fields of predicted data (currents, temperature, primary production and zooplankton biomass). These predicted data will serve as input in the spatial ecosystem model (SEAPODYM) that will predict the oceanic environment of tuna (prey fields) and the large scale dynamics of their populations. Observed movements of individual tuna marked with electronic tags in selected study areas will be used to evaluate the models, and analyzed to enhance the mechanisms of both IBMs and ADRMs.

2. Progress during FY 2006 (One-two paragraphs, including a comparison of the actual accomplishments to the objectives established for the period, and the reasons for slippage if established objectives were not met):

Activities conducted in FY 2006 corresponding to those planned in last year report are listed below:

1- Thanks to mathematical and code development by Dr Inna Senina, at the PFRP, the model SEAPODYM is fully operational in a mixed-grid mode. The associated software GMB developed to define the grid and mask has been enhanced, allowing to interpolate SEAPODYM input data (environmental and fishing data) onto constructed grids.

2- Parameters of mid-trophic (forage) components of the SEAPODYM model have been scaled against available information. Simulation at ½ deg x 10 day resolution for 1948-2004 is available. Further evaluations will be conducted opportunistically as new observation will become available (in particular acoustic survey in Coral Sea and Hawaiian waters).

3- The SEAPODYM web site is implemented www.seapodym.org

4- Archival tag records represent a promising source of observations for the parameterisation of modelled fish movement. The analysis conducted last year was fully revised using new forage outputs (6 components instead of 3), enhanced resolution (1/2 deg x 10 days) and additional tag data (all together, 17 archival tags (AT) released in the Coral Sea and 7 Pop-up Satellite Archival Tags (PSAT) deployed on bigeye tuna by SPC in the waters surrounding Papua New Guinea, New Caledonia and Tonga).

   Horizontal movements. Most probable horizontal movements of tagged fish were recalculated using Kalman filter analysis and latitude was corrected so as to minimize the discrepancies between predicted surface temperature and temperatures recorded by archival tags in the upper 20 meters. There was a large amount of variability in dispersion, from apparent residency (17 nm in 109 days for one tuna tagged near New Caledonia) to quick movement (208 nm in 13 days for another one). Eastward migration towards New Caledonian waters at the same period of the year (Oct–Apr) by two individuals and cyclical movement over the year with a similar migration route in 2 consecutive years by one individual were confirmed. Outputs from SEAPODYM suggest that this migration corresponds to a period of seasonal warming and peak biomass of epipelagic and migrant mesopelagic forage.

   Vertical movements. Bigeye tunas exhibited two main types of vertical behaviour: the 'classic' W-shaped type with typical depths of 300-500 m during the day and 0-200 m during the night (74 % of total time), and the 'mixed' type with only short dives under 200 m during the day (24 % of total time). The analyses using GAMs show that average depth during the day was positively related to estimated forage biomass in the deep layer (>400m) and negatively related to estimated forage biomass in the 'intermediate' layer (100-400m). This suggests rather logically that bigeye tunas, classically swimming at depths 100-400 m during the day, would dive deeper as bathypelagic forage biomass increases and mesopelagic biomass decreases. The new PSAT archival tag records from New Caledonia and Tonga areas confirm the seasonal trend previously observed in the vertical behaviour during the day. A higher proportion of daytime was spent in surface waters during Aug-Nov by nearly all bigeye tuna tagged in the Coral Sea. This shift in vertical behaviour would correspond to the period of maximum increase in day length, warming of the surface layer, drop in primary production after a peak in July, and peak in forage biomass in the surface

layer. These results are coherent with some observations, e.g. aggregations of bigeye tunas observed in surface waters of this area during the spring months in association with spawning concentrations of 'mesopelagic migrant' lantern fish *Diaphus sp*. It is however difficult to distinguish the roles of feeding and reproduction in the seasonal shift in vertical behaviour during the day and the night.

5- Development of the bigeye IBM has been cancelled due to unexpected time consuming tasks in the tag analyses.

6- Tag records were used for the parameterisation of the relation between optimal mean temperature and age in SEAPODYM. Individual tracks were compared to maps of predicted habitat and to vectorial fields of predicted horizontal movements in SEAPODYM. On a monthly scale, a general coherence was observed: NW Coral Sea appeared as a favourable habitat almost all year round and the eastward migration route observed in the individual tracks matched in space and time with a 'corridor' of favourable habitat developing seasonally in the waters between Australia and New Caledonia.

7- Idem 5

8- Several papers are in final phase of preparation. They describe the changes in the model SEAPODYM and the results from the tagging data analysis.

Allain, G. (in prep.) The influence of environment on horizontal and vertical bigeye tuna movements investigated by analysis of archival tag records and ecosystem model outputs.

Lehodey P., Murtuggude R., Senina I., (in prep). A Spatial Ecosystem And Populations Dynamics Model (SEAPODYM): Lower and mid-trophic levels

Lehodey P., Senina I., Murtuggude R., (in prep). A Spatial Ecosystem And Populations Dynamics Model (SEAPODYM): top predators and fisheries

Additional activities associated to this project. The code of SEAPODYM was modified to simplify the prey-predator coupling, to improve the description of movement, to increase the speed of computation and to record the time spent in each layer according to the species, age group (juvenile, young adult), date and region, allowing comparison between prediction and observation from archival tagging or fishing data.

A new key activity is the development of a version of the model with a statistical optimization approach, hereinafter called Seapodym-APE (Adjoint-based Parameter Estimation). Optimal parameterization was tested with an application to skipjack tuna. Derivation of adjoint code was accomplished with help of AUTODIF library (automatic differentiation) functions, although finally it was encoded explicitly in order to avoid huge memory capacity required by automatic functions. Currently, Seapodym_APE includes forward and adjoint code for top predator model only, without coupling between tuna and its forage. Instead forage is being used as input data only. Parameter estimation procedure in Seapodym_APE is based on maximal likelihood technique. Likelihood components are based on catch or CPUE estimated as well as relative length frequencies data. Different types of likelihood functions can be considered depending on data distributions such as log-normal, Poisson, negative binomial, or zero-inflated negative binomial. Experiments on parameter estimation showed that predictions can be significantly improved. However, there are still low correlations between EPO fisheries observed and predicted data. The possible reasons are static vertical structure of environmental data, uncoupled dynamics of forage populations (variability in tuna

population dynamics doesn't influence mid-trophic level), many zeros in EPO fishing data.

3. Plans for the next fiscal year (one paragraph):

The project is almost completed. There is no additional fund required other than those already planned in FY2006 and not yet used (e.g. publication).

Tasks of the following months will be essentially devoted to publication in peer reviewed scientific journals. In addition to the papers describing changes in the model SEAPODYM and the results from the tagging data analysis (see above), there are room for potentially three other articles:

- one describing the version Seapodym_APE and an application to skipjack
- one describing the mixed grid technique and the changes due to different resolution, i.e. effect of integrating meso-scale in simulations (depending however of high resolution input data availability)
- one providing simulation results for 3 tuna species (skipjack, yellowfin and bigeye) over the last 50 years and discriminating between fishing and environmental/climate effects). This will require multiple simulations to obtain the best possible set of parameters.

The PI of the project will attend the PFRP PI meeting in November 2006 to present the conclusion of the project.

4. List of papers published in refereed journals during FY 2006.

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

Technical reports:

Allain, G., Lehodey, P. and Kirby, D.S. (2005) The influence of environment on horizontal and vertical bigeye tuna movements investigated by analysis of archival tag records and ecosystem model outputs. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **BI WP-3**: 13 pp. http://www.spc.int/oceanfish/Html/WCPFC/sc1/pdf/SC1_BI_WP_3.pdf

Lehodey P., 2005a. Reference manual for the Spatial Ecosystem And Populations Dynamics Model SEAPODYM. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME IP–1:** 54 pp. http://www.spc.int/OceanFish/Html/WCPFC/SC1/pdf/SC1_ME_IP_1.pdf

Lehodey P., 2005b. Application of SEAPODYM to the Pacific Pelagic Ecosystem. Recent results and perspectives First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **EB WP–8**: 29pp. http://www.spc.int/OceanFish/Html/WCPFC/SC1/pdf/SC1_EB_WP_8.pdf

Lehodey P., 2005c. First application of SEAPODYM to Pacific bigeye tuna. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME-WP-1:** 11pp
http://www.spc.int/OceanFish/Html/WCPFC/SC1/pdf/SC1_ME_WP_1.pdf

Lehodey P., 2006. Reference manual for the Spatial Ecosystem and Populations Dynamics Model SEAPODYM (updated Dec 2005). www.seapodym.org: 58 pp.

Senina I.N., Sibert J.R., Lehodey P. (2005). SEAPODYM on a mixed-resolution spatial scale. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005. **ME-WP-2:** 22 pp.
http://www.spc.int/OceanFish/Html/WCPFC/SC1/pdf/SC1_ME_WP_2.pdf

Conferences/Meetings:

Allain, G., Lehodey, P. and Kirby, D.S. (2006) The influence of environment on horizontal and vertical bigeye tuna movements investigated by analysis of archival tag records and ecosystem model outputs. 57th Annual Tuna Conference, Lake Arrowhead, California, May 2006.

Lehodey P., 2005a. Application of SEAPODYM to the Pacific Pelagic Ecosystem. Recent results and perspectives First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005.

Lehodey P., 2005b. First application of SEAPODYM to Pacific bigeye tuna. First meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission WCPFC-SC1, Noumea, New Caledonia, 8-19 August 2005.

Lehodey P., 2005c. SEAPODYM and the mixed-resolution project; recent achievements and perspectives. PFRP Principal Investigators Workshop. November 14 -15, 2005, University of Hawaii,USA

Senina I. and J. Sibert (2005). Progress in parameter estimation for Spatial Population and Ecosystem Dynamics Model (SEAPODYM) applied to Pacific skipjack. PFRP PI meeting. Honolulu. November 15, 2005.

Senina I., J. Sibert and P. Lehodey (2006). Parameter estimation procedure in the model of pelagic ecosystem spatial dynamics with application to Pacific skipjack. 57th Tuna Conference. Lake Arrowhead. May 22-25, 2006.

6. Graduates (Names of students graduating with MS or PhD degrees during FY 2006. Provide titles of their thesis or dissertation):

7. Awards (List awards given to JIMAR employees or to the project itself during the period):

8. Publication Count (Total count of publications for the reporting period and previous periods categorized by NOAA lead author and Institute (or subgrantee) lead author and whether it was peer-reviewed or non peer-reviewed (not including presentations):

	JL Lead Author			NOAA Lead Author			Other Lead Author		
	FY04	FY05	FY06	FY04	FY05	FY06	FY04	FY05	FY06
Peer-reviewed									
Non-peer reviewed						1	3	1	5

9. Students and Post-docs (Number of students and post-docs that were associated with NOAA funded research. Please indicate if they received any NOAA funding. For institutes that award subcontracts, please include information from your subgrantees):

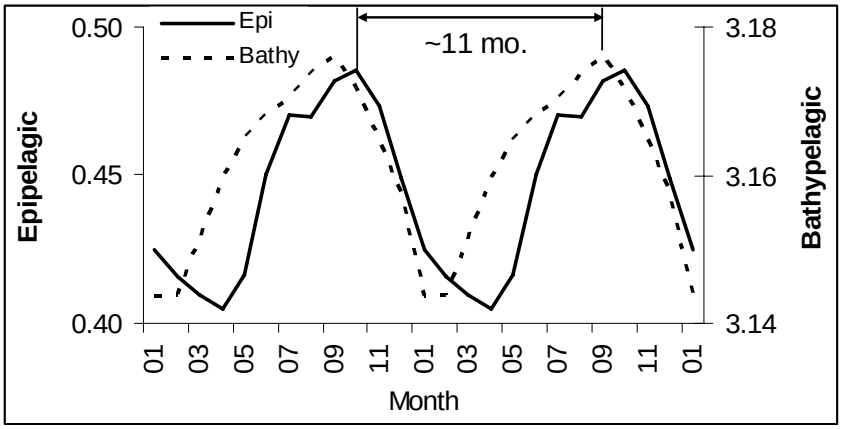
One post-doc position was funded with this project by the PFRP. The selected candidate (Dr Gwenael Allain) started his work at SPC, Noumea, New Caledonia, on 15 May 2004. The position has been funded until May 2006.

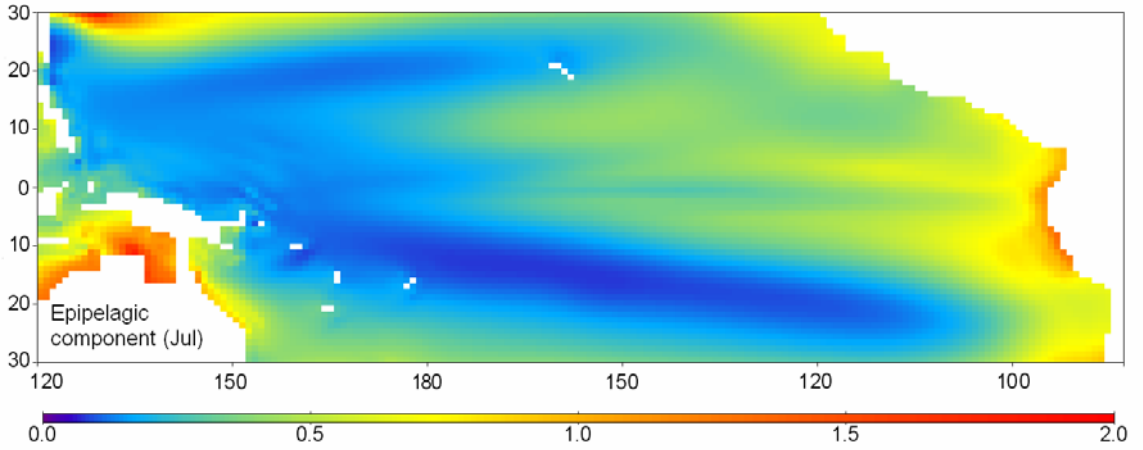
10. Personnel:
    (i) Number of employees by job title and terminal degree that received more than 50% support from NOAA, including visiting scientists (this information is not required from subgrantees):

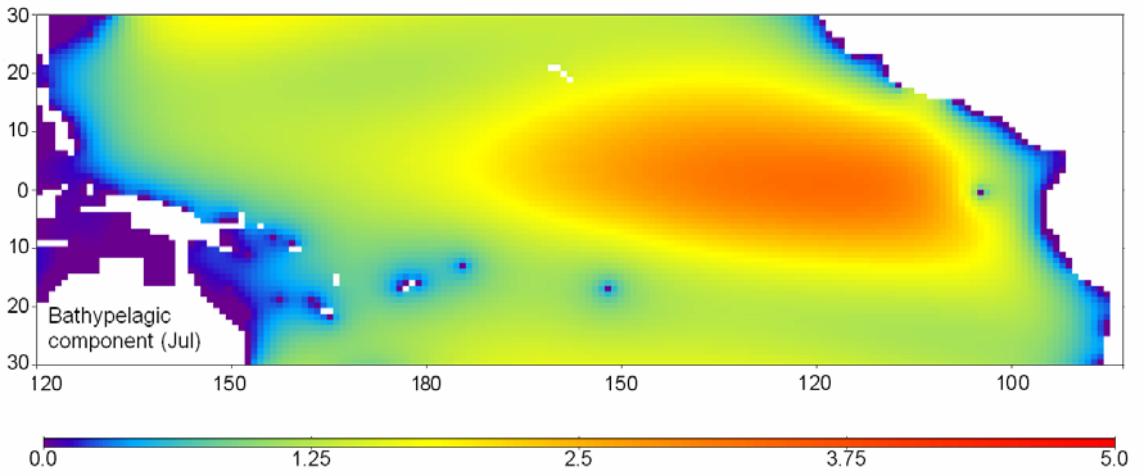
    (ii) Number of employees/students that received 100% of their funding from an OAR laboratory and/or are located within that laboratory.

    (iii) Number of employees/students that were hired by NOAA during the past year:

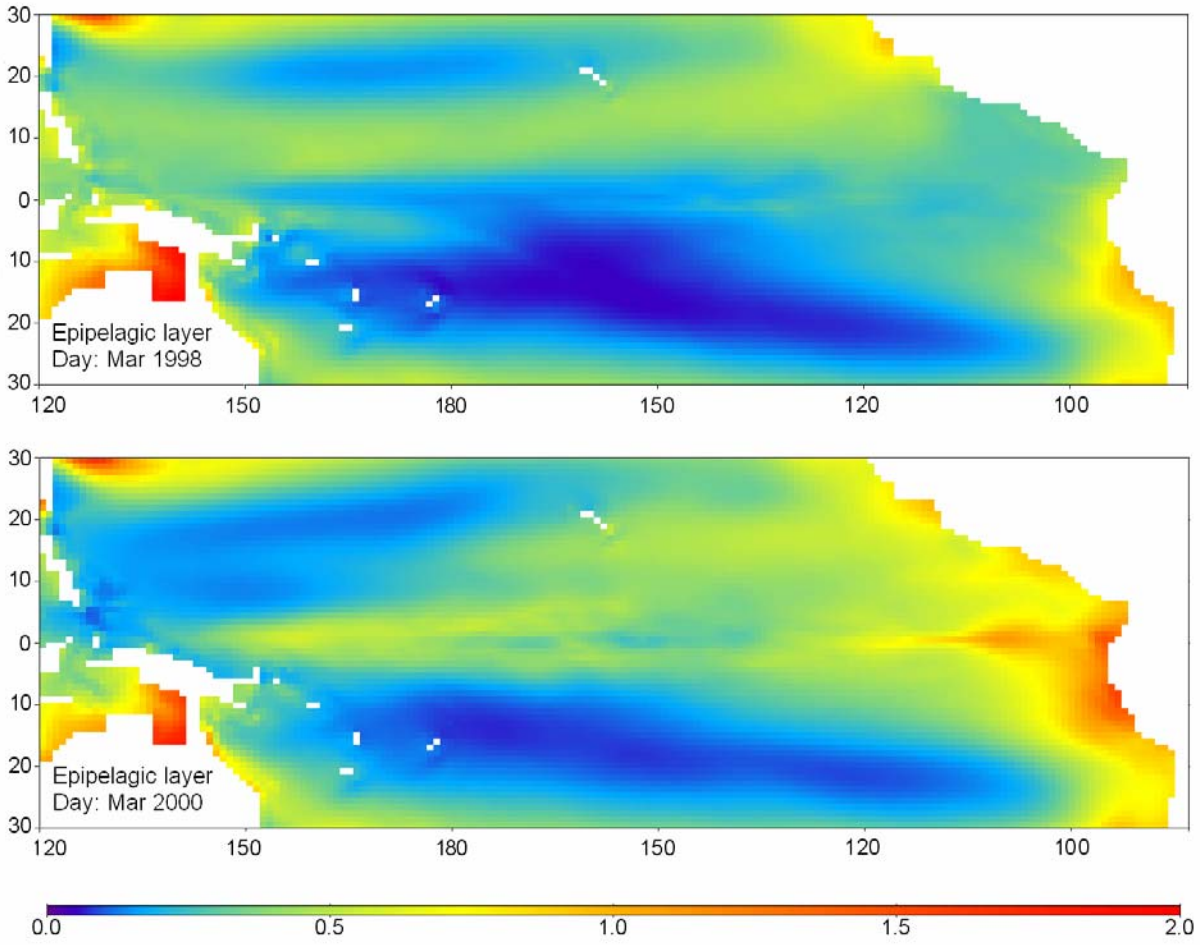
11. Images and Captions. (JIMAR will be including images in the annual report. Please send two of your best high-resolution, color images (photo, graphic, schematic) as a JPEG of TIFF with a caption for each image. Hardcopies of images can be dropped off at the JIMAR office if no electronic versions are available.







Caption 1: Seasonal cycle and spatio-temporal shifts of mid-trophic (forage) components simulated with SEAPODYM. Due to different temperature habitat, turn-over rates of mid-trophic populations are different. The biomass time series of epipelagic and bathypelagic components (average in the box 5N-5S; 120W-100W) indicates a lag of about 11 months between peaks of the two series. This time lag and the different physical forcing (currents) lead to very different spatial distribution as illustrated for a climatological mean in July for these two components (from Lehodey et al., in prep)



Caption 2: Interannual variability of mid-trophic (forage) components simulated with SEAPODYM. The ENSO impact is shown with the distribution of forage biomass in the epipelagic layer during the day in March 1998 in the final stage of the 1997-98 El Niño event and at the end of the following La Niña event in March 2000 (from Lehodey et al., in prep).