

JIMAR ANNUAL REPORT FOR FY 2005

P.I./SPONSOR NAME: LEHODEY Patrick

PROJECT PROPOSAL TITLE: Mixed-resolution models for investigating individual to population spatial dynamics of large pelagics

FUNDING AGENCY: JIMAR-Pelagic Fisheries and Research Program

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

1. PURPOSE OF THE PROJECT:

This project addresses ways to improve upon two classes of models: Individual Based Models (IBMs) and Advection Diffusion Reaction Models (ADRM) that would help to model from ocean basin to individual scale. Both these types of models have been successfully applied to predicting tuna behaviors; IBMs at the very fine scale and ADRMs at the population level. The two classes of models 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. Mixed resolution models use a stretched grid system with greater resolution at one of multiple locations of the model domain. Therefore, the project proposes mathematical and programming developments in movement and spatial population dynamics models including a post-doctoral grant devoted to the development of an individual-based model (IBM). Though not included in the budget, a second post-doctoral study is closely associated to this project, as it will develop technics of local stretching for a grid generator that will be embedded into the coupled physical-biogeochemical model (ESSIC, Univ Maryland) and the spatial ecosystem model (SEAPODYM, SPC) that will be used for predicting the oceanic environment of tuna and the large scale dynamics of their populations. The ESSIC model (co-P.I. R. Murtugudde, Univ. Maryland) will provide fields of predicted data (currents, temperature, primary production and zooplankton biomass) with several areas of focus at higher resolution. These predicted data will serve as input in SEAPODYM that will provide predicted

distributions of tuna forage (~micronekton) and tuna (skipjack, albacore, yellowfin, bigeye) biomass. The IBM will use the oceanic environment predicted by both ESSIC and SEAPODYM models. Behaviour of tuna or other large pelagics predicted with the IBM will be compared to observed movements of individuals marked with electronic tags in selected study areas, and to spatial patterns generated by ADRMs.

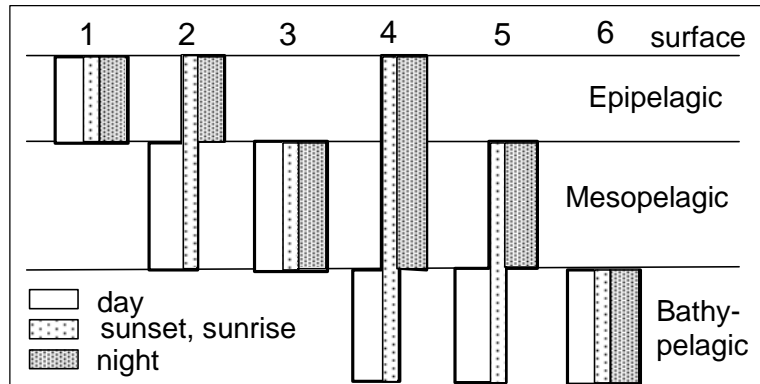
2. PROGRESS DURING FY 2005:

Planned research activities for FY 2005 as listed in FY 2004 report were:

- Simulations at different time and space resolutions based on predicted fields from the coupled physical-biogeochemical model (ESSIC, Univ. Maryland) and the model SEAPODYM (SPC).
- Evaluation of the predicted biomass distribution of the three forage components in SEAPODYM.
- Development of a multi-grid technique to be used in ESSIC and SEAPODYM models.
- Analyses of bigeye tuna habitat predicted from SEAPODYM against observed tuna behaviour from archival tag data
- Development of the IBM model and first simulations using the predicted environment from ESSIC and SEAPODYM.

Dr. R. Murtugudde provided to the PI a second set of predicted fields from the coupled biogeochemical model for the period 1950-2002 at an enhanced spatio-temporal resolution of $\frac{1}{2}$ degree and 10 days. In relation with the new developments in SEAPODYM to more realistically describe the dynamics of intermediate trophic levels, the model requires oceanic variables averaged over three vertical layers: epi-pelagic, meso-pelagic and bathy-pelagic. This is an important evolution to allow comparisons between individual vertical tuna behaviour as observed from archival tagging and model predictions. The classification of the micronekton (forage) components is based on their vertical distributions that control their relationships with (and accessibility to) top predators, with both groups showing daily migrations to the upper layers during the night. A 3-layer, 6-forage component conceptual model was developed on the basis of a literature review. Several parameterizations of energy transfer from primary production to the 6 forage components were tested and the outputs compared to some available observation in the literature.

The enhanced resolution with the large basin-scale simulation allows prediction of realistic mesoscale patterns in the equatorial region but seems to have difficulties to reproducing mesoscale dynamics in the higher latitudes, especially in the Kuroshio extension. To have realistic oceanic input in the model, it may be necessary to combine several simulation outputs from different model configurations. This could be an evolution of the “grid and mask builder” (GMB) software developed in parallel to this project for designing the spatial grid of the model and interpolating input fields along the selected grid.



The different daily vertical distribution patterns of the micronekton in the tropical pelagic ecosystem used to model the intermediate trophic levels in SEAPODYM. 1, epipelagic; 2, migrant mesopelagic; 3, non-migrant mesopelagic; 4, highly-migrant bathypelagic; 5, migrant bathypelagic; 6, non-migrant bathypelagic.

Dr Inna Senina, who has been recruited at the PFRP for developing the ‘multi-grid’ numerical scheme has now included the stretching techniques in both GMB software and SEAPODYM. Non-regularity of the grid is circumscribed by analytical functions, which transfer either two-dimensionally stretched (see Fig.1, upper graph) or one-dimensionally stretched coordinates (Fig.1, lower graph) into constant step grid coordinates. It allows us to introduce variable resolution into numerical scheme by using only derivatives of stretching functions. Within this approach the number of nodes as well as the cost for numerical computations remains the same. The GMB software is developed accordingly to allow the use to create different types of variable resolution grids, build mask according to topography maps (2 minute resolution elevation data) and to interpolate SEAPODYM data onto constructed grids.

While a reference version of the SEAPODYM code was placed on a server accessible through the internet by authorized members, the new version is developed separately and will become the new reference once fully tested. Code management software (SVN) is used to manage access to the code, and to document all changes. This is particularly useful when several persons are working on the same code. The mixed-resolution with SEAPODYM is working and I. Senina is now running the test phase.

In relation with the changes in the forage modelling in SEAPODYM, it was also necessary to reconsider the approach to link the dynamics of the predators (tuna) to these different prey populations. Several other changes have been introduced; in particular, the possibility to have seasonal behaviour for the reproduction. The dynamics of the tuna species is constrained by the definition of two habitat indices. The adult habitat that constrains the movement is based on accessibility coefficients to each forage component, depending on the temperature and oxygen affinities of the species (and age). The spawning habitat constrains the tuna recruitment to environmental conditions (temperature, food and predators). Spawning seasonality is introduced by shifting the conditions of the adult habitat toward those of the spawning habitat in

relation to the seasonal cycle of day-length (with a peak at maximum gradient). Indeed, results of the archival tagging data analysis by G. Allain could confirm this approach.

Gwenhael Allain started his post-doc at SPC, Noumea, New Caledonia, on 15 May 2004. The objective of his work is to investigate the influence of the environment on bigeye tuna movements in order to develop a rule-based IBM where fish will be able to 'swim through' environmental data for the simulation of spatial dynamics from individual to population scale. Two types of data were available: archival tag records and ocean model outputs, including space-time forage biomass estimations from SEAPODYM. First, G. Allain is *investigating the relationships between tagging and model data* on a common scale. The results of this exploratory analysis will be used to develop a rule-based IBM, in order to validate the parameterisation of fish behaviour in relation to environmental variability used in SEAPODYM and to validate theoretical mechanistic IBMs for tuna behaviour including more physiology.

Horizontal movements. Since October 1999, more than 180 archival tags have been deployed on bigeye tuna in the Coral Sea under a joint CSIRO/SPC project; so far 17 have been recovered. Light records were processed by CSIRO using Wildlife Computers 'Global Position Estimator' software to estimate longitude and latitude. Most probable horizontal movements were then estimated from the geolocation data using Kalman filter analysis (Kftrack R Package by J. Sibert and A. Nielsen). Two individual tag records clearly exhibit eastward migration to New Caledonian waters at the same period of the year (Oct–Apr). The monthly evolution of predicted sea surface temperature and forage biomass from Jan 1999 to Dec 2002 in the area delimited by the supposed migration route (148°E–165°E, 16°S–22°S) suggest that this is a time of seasonal warming and peak biomass of epipelagic and migrant mesopelagic forage.

Vertical movements. Bigeye tunas exhibited four types of vertical behaviour: the 'classic' or W-shaped one with typical depths of 300-500 m during the day and 0-200 m during the night (74 % of total time), the 'surface' one with depth continuously <100 m during day and night (1 % of total), the 'mixed' one with only short dives under 200 m during the day (24 %) and the 'deep dive' one consisting in short-duration dives <600 m (1 %). The relationships between the type of behaviour and the environment encountered along the tracks were investigated using Generalized Additive Models.

The dependent variable was the average depth during the day during a 10-day archival tag record. The covariates were the 10-day period of the year, temperature in the three layers (0-200 m, 200-500 m, >500 m) during this period, dissolved oxygen concentration in the three layers, primary production over the water column and forage biomass estimated during the day for the three layers. The 'best' model according to these criteria had the three following covariates: 10-day period of the year, 'forage biomass in the deep layer (>500m) during the day' and 'forage biomass in the middle layer (200-500m) during the day'.

The seasonal trend shown by the "10-day period of the year" covariate is common to all individual bigeye tunas tagged. Average depth during the day is closer to the surface

from August to November (Fig. 2). Therefore the data sample was split in two parts (August to November / December to July) that would separate two major seasonal behaviours. GAMs were adjusted to these two sets of data. From August to November, the average depth during the day increase with the increase of forage biomass in the surface layer (0-200 m), *i.e. during this period tunas would prefer to move to surface waters that are poor in forage*. From December to July, the positive relationship with deep forage abundance was predominant and the ‘classic’ behaviour was rather invariant (90 % of time spent in the layer 200-500 m during the day, 98 % of time spent in the layer 0-200 m during the night).

All tagged tuna were supposed to be mature given their sizes at release/recapture and it is tempting to relate this seasonal change in behaviour to a spawning behaviour, when tuna would target waters with low forage abundance (*i.e.*, low predator density of their larvae). The “classical” behaviour would be the feeding behaviour observed most of the time, in which the dive depth during the day would be related to the estimated biomass of bathypelagic and mesopelagic forage.

3. PLANS FOR THE NEXT FISCAL YEAR (One paragraph):

Research activities will include:

- Final test phase of the “mixed-resolution” SEAPODYM version.
- Evaluation of the predicted biomass distribution of the three forage components in SEAPODYM, particularly against acoustic data from Hawaii region.
- Development of a web site for this model with documentation, software executables, and input and output simulations.
- Completion of the bigeye archival tagging data analysis. A similar approach to the one used for vertical movements will also be applied to horizontal movements: the changes in physical parameters and forage biomass estimations between two successive 10-day periods will be investigated in order to understand the motivations of horizontal movements. These results together will constitute the basis for the definition of a rule-based IBM of bigeye tuna movements in relation to their environment. Tag records from Hawaii (archival) and Tonga (PSAT) will be integrated to the analyses as far as possible.
- Preparation of articles.

4. LIST OF PAPERS PUBLISHED IN REFERRED JOURNALS DURING FY 2005:

5. OTHER PAPERS, TECHNICAL REPORTS, ETC.:

One report since August 2004:

Allain G., Lehodey P., Kirby S., 2005. The influence of the environment on horizontal and vertical bigeye tuna movements investigated by analysis of archival tag records and ecosystem model outputs. Working Paper, PFRP project: Mixed-resolution models for investigating individual to population scale spatial dynamics: 9 pp

Several new technical documents will be ready for August 2005, likely leading to articles submission for the end of the year.

6. GRADUATES (Names of students graduating with MS or PhD degrees during FY 2005; 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):

	JI Lead Author			NOAA Lead Author			Other Lead Author		
	FY03	FY04	FY05	FY03	FY04	FY05	FY03	FY04	FY05
Peer-reviewed									
Non-peer-reviewed								3	1

9. STUDENTS AND POSTDOCS (Number of students and postdocs 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):

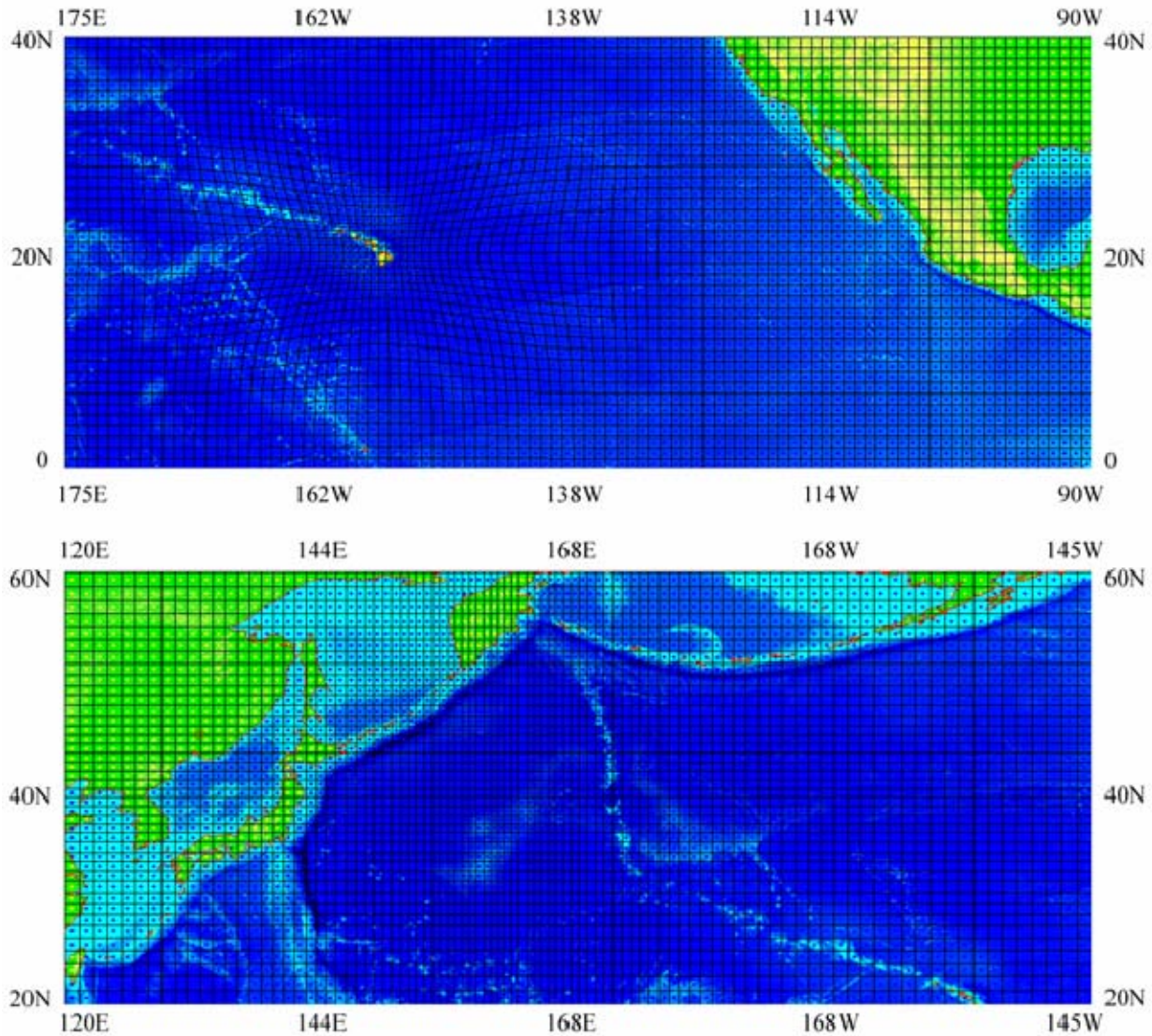
One post-doc position is funded with this project by the PFRP. The selected candidate (Dr Gwenael Allain) started his work at SPC, Noumea, New Caledonia, on 15 May 2004. It is planned that the position will continue to be funded for a second year (until May 2006).

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

- **Caption 1:** Examples of mixed-resolution grid and generated mask (yellow dots – land, blue – ocean). On the upper graph two-dimensional transform of coordinates around Hawaiian islands is shown, below is the twice finer grid in the Kuroshio region, stretched along each direction separately.



Caption 2: Average depth (m) during the day (boxplots, red line) inhabited by tagged bigeye tuna in relation to the month of the year (x-axis) showing a seasonal change in the vertical behaviour with a good match with the seasonal cycle of gradient in day length (here at latitude 25°S).

