Understanding Apex Predator And Pelagic Fish Habitat Utilization In The California Current System By Integrating Animal Tracking With In Situ Oceanographic Observations

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LONG-TERM GOALS

The long term goals of this program are to map the oceanic habitats used by top predators in the California Current System (CCS) and to describe the oceanographic features that define these hotspot regions. This has been done by examining both top down and bottom up processes, and predicting how climate variability impacts the distribution and utilization of oceanic habitats within the CCS. We are also developing methods that are required to integrate animal collected environmental data into existing oceanographic databases. To achieve these goals, we have assembled a team that includes researchers from the University of California Santa Cruz (UCSC) and Stanford's Hopkins Marine Station and oceanographers from the Environmental Research Division (ERD), a branch of National Marine Fisheries Service (NMFS) in Pacific Grove. The integration and analysis of the diverse datasets requires the development of new software which is being developed collaboratively by the NMFS, UCSC, and Stanford as well as researchers from Sea Mammal Research Unit (SMRU) in Scotland.

OBJECTIVES

This study will develop a dynamic, ecosystem-based approach to map and understand habitat utilization by top predators in the CCS. Specifically, our objectives are:

(1) To map critical habitats of predators in the California Current System;

(2) To link the movement patterns of these predators to physical and biological ocean features, in order to:
   a. determine how ocean dynamics act to aggregate diverse organisms;
   b. define the stability and community structure around biological hot spots;
   c. define the persistence of hot spots in space and time;
   d. examine the relationships among different species in the context of habitat utilization;
   e. identify the influence of top down and bottom up processes and their influence on dynamics of hot spots;

(3) To map habitat distribution of commercially-viable and threatened fish stocks in the CCS, based on predator distribution and behavior from tracking data;
(4) To quantify the seasonal and interannual variability of mesoscale ocean features (potential hot spots) in the CCS, from remotely sensed and *in situ* data;
(5) To contribute a significant quantity of high-resolution *in situ* oceanographic data from animal tags to coastal and global ocean observing programs;
(6) To provide critical advice to fisheries managers on the distribution of commercially-viable fish stocks in relation to oceanographic variability;
(7) To develop and test models that allow for the prediction of animal abundance and distribution based on the physical environment.

APPROACH AND WORK PLAN

Oceanographic data have been obtained from both satellite imagery and the electronic tags deployed on top predators, which record environmental variables such as temperature, depth, light and salinity. Physical data obtained by tagged animals permit comparison to features that are spatially and temporally concurrent with the animals' foraging behavior. For example, temperature and salinity data collected by the tags place the animals' behavior in the context of distinct water masses. Large-scale habitat usage is being modeled based on individual animal utilization. Habitat preference is indicated when an animal uses an area more than would be expected based on relative availability of habitat. Our approach to define habitat usage is focused on modeling the relative accessibility of habitat mechanistically based on distance from a capture site, speed of movement, and the observed distribution of trip durations. These estimates are then used as variables within a Generalized Additive Model (GAM) approach to relate the environmental variables that define habitats and spatial utilization by tagged animals.

One of the critical requirements in ecosystem-based resource management is learning how to define zones of high biological activity, or "biological hot spots". However, methods to characterize behavioral changes within these hot spots, as well as to quantify their temporal variability, stability and long-term viability, are still being developed. Regardless, the first step is to identify where they occur. The Tagging of Pacific Pelagics (TOPP) research program, which is composed of the member groups listed above, is providing new data on spatial and temporal characteristics of hot spots in the CCS as well as new methods to identify them using both remotely sensed oceanographic information and data obtained from the tagged animals.

In the first phase of the NOPP grant, we focused on automating routines that allow more rapid assessment of animal collected data and the habitat utilized by the tagged animals in relation to the surrounding oceanography. We have developed a data base for delivery of tag derived data to a Live Access Server (LAS). This involved development of database code and data delivery in a seamless fashion from multiple archival tag sources, to NOAA-ERD. Secondly, data visualization software has been developed for both fish and marine mammal derived datasets. The fish research team intends to combine visualization and data analysis software developed from independent laboratories (e.g. Block lab) into one software package that can be integrated with ongoing TOPP funded efforts in the marine mammal area (Costa and Fedak labs). To accomplish this, the development of a programming code specific to the complexities of air-breathing mammals as well as diving fish with gills (who rarely surface), is required.

WORK COMPLETED

Cumulatively, the TOPP program has deployed 3,647 tags on 2,771 individual animals from 23 different species since 2002. Nearly half of these species visit the California Current region for weeks to months or longer, indicative of the ecological significance of the region. In fact, our data indicate that the CCS is one of the most significant hotspots within the entire northeast Pacific Ocean. We base this observation on the number of species and the abundance of tagged individuals that utilize this region. We have defined at least three hotspots within the CCS: 1) the Monterey Bay and Gulf of the Farallones Marine Sanctuaries, 2) the Southern California Bight, and 3) the Baja Peninsula hot spots. We are now working closely with our colleagues at ERD to correlate the animal distributions with the oceanographic factors that define these hotspots, and we are beginning to construct models that explain the observed distributions for some species. These regions become primary areas for future protection or ocean zoning to mitigate interaction with humans. Analyses to understand the seasonal development and species utilization of these hot spots are now fully underway and we expect to provide substantial insight in the next annual review. Nevertheless, some detailed results are provided below. We have also published 12 papers in top-tier journals (2006-2007) that were directly or indirectly supported by this award (see publications listed at the end).

RESULTS

Marine Mammals and Seabirds
Crictical to our understanding of habitat use is the development of analytical tools that characterize animal movement patterns in time and space. Over this past year, several efforts were conducted using data collected from tagged marine mammals and birds. The first was the creation of a new method to identify Area Restricted Search (ARS) behavior using the fractal landscape method (Tremblay et al. 2007). This method is robust (>80% correct) at identifying the location of ARS events in animal tracks, which is critical for correlating feeding events and oceanographic variables (e.g. eddies or upwelling zones) that can be identified through remote sensing. Utlimately, the strength of the relationships between environmental variables and animal distribution should enhance our predictive power to define critical habitat. Another effort has involved the creation of program codes to evaluate Utilization Distributions (UD) of tracked animals based on an adaptive kernel density. The UD weights each grid cell and thus kernel, based on the number of individuals contributing to the total number of observations within a grid cell. The method 'normalizes' kernel density so a low number of individuals with a high number of locations within a grid do not over represent the UD. Another significant step has been the creation of program codes to define animal paths (i.e. tracks) with greater precision and better quantification of location errors. Currently, our team has developed a routine based on a combination of a 'biased' random walk model and boostrapping to recreate an animal path with the highest likelihood. The model was validated using conventional Argos-derived and GPS-derived location data from tagged elephant seals. Athough testing and refinement of the model is ongoing, the preliminary results are outstanding. Again, these tools will be critical in our assessment of critical habitat use by tagged animals within the California Current System.

Fish

To date 1,000 archival tags have been deployed on 3 species of tunas (bluefin, yellowfin and albacore) and over 400 tags have been recovered. The data sets provide over 60,000 observation days of data of tuna movements in the California Current with 1.4 million temperature and depth observations. Analyses of seasonal movements off California indicated four distinct regions that are occupied primarily by tunas. For example, bluefin tuna were found farthest south in the spring when they were located off southern Baja California, Mexico and farthest north in the fall when fish were found predominately off central and northern California, USA (Fig. 1 below). The bluefin show latitudinal movement patterns that were correlated with peaks in primary productivity (Boustany, 2006, Kitigawa et al. 2007). Interannual variation in the locality of these productivity peaks was linked with a corresponding movement in the distribution of tagged fish. Bluefin occurred within a relatively small range of sea surface temperatures from 14-20^{o}C (Fig. 1). Overall geographical area occupied by tagged bluefin varied with primary productivity, with fish being more tightly clustered when in areas of high productivity and more dispersed when in regions of low productivity. In the spring through fall, bluefin tuna were located in areas with the highest levels of primary productivity available. However, in the winter months tagged bluefin tuna were found in areas with lower productivity compared to other regions along the coast at that time of year.

Currently we are focusing on the physical forcing and environmental data sets on a weekly basis to discern what aspects of the water column most influence the movement of the bluefin away from a hot spot. We are analyzing temperature and depth preferences, and plan to look closely into diving and feeding behavior. In future work, we plan to compare the oceanography (temperature, chlorophyll-a, and mixed layer depth) both between these areas and within each area before, during, and after the time of occupation. We hope to determine what is attracting the fish to these areas and what is driving them to move on to other areas.

Oceanographic Exploration of Hot Spots

Several ongoing studies are focusing on the physical forcing and characteristics of hot spots within the California Current and greater northeast Pacific (Palacios et al., 2006; Yen et al., 2006; Wilson et al., 2007; Bailey et al., 2007; Palacios et al., 2007; Shillinger et al., 2007). Switching state-space models are being applied to satellite positions of several tracked species, including leatherback sea turtles and salmon sharks, providing an objective differentiation between foraging and non-foraging habitat. The oceanographic characteristics of these foraging regions are then assessed using both the tag data and a suite of remote sensing platforms. Information on the physical characteristics and time-space variability of hot spots is subsequently being used in the development of species-specific habitat models.

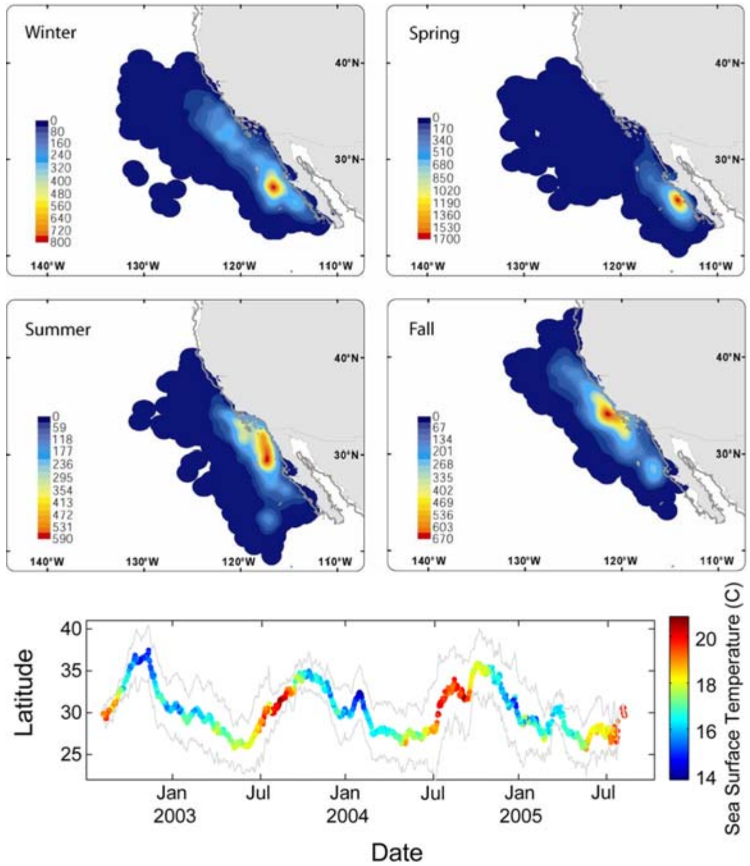

Figure 1. Seasonal movements and temperature preferences of bluefin tuna [graph: 4 panels showing the seasonal changes in the core habitat utilized by bluefin tuna. A 5th panel shows latitudinal distribution (left y-axis) and sea surface temperature preference (right y-axis) of bluefin tuna in the California Current]

IMPACT/APPLICATIONS

Quality of Life

Our ability to identify oceanic hotspots used by marine predators has significant implications for fisheries management and conservation. For example, areas that are deemed "sensitive" or critical to the proliferation of a given species could be protected or managed. However, because the oceans are so dynamic, it is important to identify key features or consistent phenomena (e.g. coastal upwelling or other physical forcing) that affect ocean productivity and the aggregation of predators and prey. This project is making significant progress towards understanding a highly dynamic region of the North Pacific Ocean and the top predators that occur there.

Science Education and Communication

The NOPP award has directly supported 4 postdoctoral researchers, 6 Ph.D. student theses, and several technicians. The results of this research are communicated to the public on the award winning TOPP web page, http://www.topp.org, which has undergone extensive revision with new flash mutlimedia content and blogging by the scientists. Web traffic has increased substantially.

TRANSITIONS

Economic Development

In addition to our contribution to biologging science in general, our research program (i.e. TOPP) has been at the forefront of tag development. Many new generation tags have been developed through collaborative efforts between TOPP researchers and industrial engineers. This includes the development of GPS and CTD tags that are now commercially available. We are also starting a new collaboration with Lotek Wireless, who produces light-based archival tags that we deploy on a variety of species. The main effort will be to test new algrorithms that will improve the location quality (i.e. reduce error) of archival tags and the future development of Application Specific Integrated Circuits (ASIC) based tags with the hope that these tags can be used to track salmon along the California Coast. Another transitional effort will be the development of predictive models that we will test with data from new tag deployments. The thrust of this effort will create a model based on environmental variables that predicts animal distributions within the CCS. The model will be tested by conducting new tag deployments and determining if the newly tagged animals distribute themselves according to the predictions of our model. This will be a significant step because the models developed could be used by wildlife managers to more effectively manage protected resources. This model should be a defining legacy of the TOPP program and this grant.

RELATED PROJECTS

All of the Principal Investigators of this award are part of the Tagging of Pacific Pelagics program (TOPP) which is seeks to understand large predator behavior across the entire North Pacific. All the electronic tagging data for this project are being obtained from animals deployed as a part of the TOPP program. TOPP is pioneering the application of biologging science to study pelagic habitat use by marine vertebrates and large squid in the North Pacific. The program has four primary long-term goals. First, develop methods and equipment necessary to implement large-scale, multi-institutional, multi-species electronic tagging programs. Second, improve basic knowledge of oceans, species and key processes linking apex predators to their ocean environs. Third, integrate environmental data collected by the tagged animals into global oceanographic databases for use in ocean observation, model testing and development. Fourth, build an education and outreach program that will educate the public about the marine environment and associated conservation issues. This NOPP award is provided the support that is allowing the synthesis and integration of data collected within the TOPP program and is thus supporting the CoML.

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