

## **Project Title: NOPP: Accelerating Electronic Tag Development for Tracking Free-Ranging Marine Animals at Sea**

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ONR Award No: N00014-02-1-1012/N00014-03-1-0325

Organization Award No: 26306 (Stanford #)

Reporting Period: October 1, 2003 – September 30, 2004

Award Period: December 30, 2002 - August 30, 2006

<http://www.toppcensus.org>

### **LONG-TERM GOALS**

The Tagging of Pacific Pelagics (TOPP) program is pioneering the application of bio-logging science to study pelagic habitat use by marine vertebrates in the North Pacific. The program has four primary goals. First, develop methods and equipment necessary to implement large-scale, multi-institutional, multi-species electronic tagging programs. Second, improve basic knowledge of marine vertebrate predators and key processes linking them to their ocean environs. These data will ultimately be used to model the distributions of marine vertebrates and their habitats; information critical for management. Third, integrate environmental data collected by the tagged animals into global oceanographic databases for use in ocean observation, and model development. Fourth, build an education and outreach program to educate the public about the marine environment and its conservation.

### **OBJECTIVES**

The objectives of this proposal are to complete the development and testing of archival and satellite tags necessary for TOPP to reach its long-term goals of multi-species tagging in the North Pacific. Efforts center on both the improvement and testing of existing electronic tag technologies and on the development of new tools that will allow us to address more complex questions about the animals and their environment. Electronic tags are used both to describe the movements and behaviors of marine vertebrates and to collect oceanographic data for inclusion into the growing global databases. To maximize the value of the oceanographic data collected by the tags we are working to test and improve the quality of existing temperature, pressure, light sensors standard on most instruments. In addition,

we are developing new tags including improved geolocation tags using the Global Positioning System (GPS) and tags that measure of salinity and chlorophyll *a*. The overriding objective is that the data collected is of equal precision and quality of that obtained from standard oceanographic sensors. TOPP is also developing data management techniques, and computational code for near-real time tracking.

## **APPROACH AND WORK PLAN**

For new tag technologies, we are working with engineers to identify the best sensors for incorporation into existing tag platforms. After calibration in the lab, these tags are deployed for short durations in the field. Seals are captured at a local rookery, equipped with electronic tags, and then released at sea. As a seal is released, a SEABIRD CTD (conductivity, temperature and depth) cast is made. After 2-5 days, seals return to the rookery where the tags are recovered. Upon recovery, the tags are recalibrated to examine drift and data are compared to that collected by the SEABIRD CTD. Once the tags have been proven on short-term deployments they are deployed for months to years on a range of species to test their long-term durability. At each stage in the process, we consult directly with engineers to fix any problems.

To advance tag technology, TOPP scientists are working closely with engineers at Wildlife Computers, (USA), Lotek Technology (Canada), and the Sea Mammal Research Unit (SMRU, UK). Wildlife Computers produces archival (MK9) and satellite tags (PAT and SPOT). Lotek produces the LTD 2300 and 2400 series archival tags. SMRU is the developer and manufacturer of the Satellite Relay Data Logger (SRDL) selected for the CTD tags currently being tested in the field. Tags currently produced by these manufacturers are being tested on a range of marine mammal, reptile and fish species for long-term durability, sensor accuracy and the ability to obtain biological and oceanographic data. These tags include the Single Position Only Tag (SPOT), the pop-up satellite archival (PAT) tag, archival tags (the MK9 and LTD 2300 and 2400 series), and the SRDL. All sensors must meet the precision and accuracy of standard oceanographic sensors.

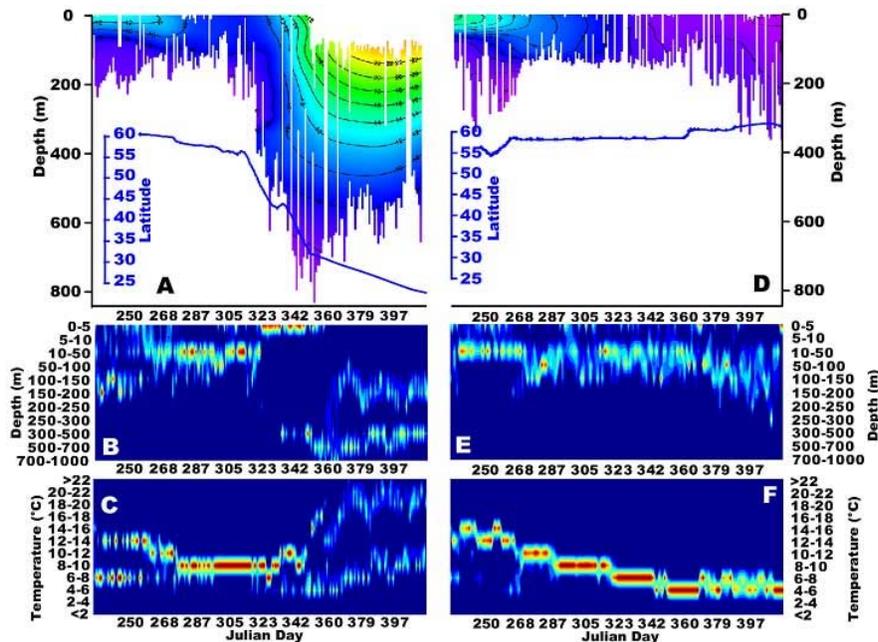
Over the next year, we will complete the testing of recently developed tags on elephant seals, sea lions and fur seals. We will analyze the data obtained from the 19 dual wavelength chlorophyll tags and redeploy 31 of these tags on Northern elephant seals (15), California sea lions (8), and Antarctic fur seals (8). In addition, we will test the capability of chlorophyll *a* tags in the Southern Ocean with 8 deployments on Antarctic fur seals in collaboration with the US Antarctic Marine Living Resources Program. Given the success of the 4 prototype CTD tags deployed in 2004, we will proceed with the deployment of a total 23 CTD tags on California sea lion males (6), Southern elephant seals (7) and northern elephant seals (10). Another 10 SPOT /Mk9 tag with dual wavelength combination will be deployed on female California sea lions. The data from these tags will be provided to the TOPP oceanographers and NODC to further prove the concept of TOPP animals as ocean sensors.

To obtain more precise geolocation estimates we have invested in integrating GPS technology with archival tags. Although the development of the GPS tag has taken longer than anticipated, we expect delivery of the first tags by March 2005. Plans are to conduct test deployments with 3-4 day translocation experiments (described above) followed by a long-term deployments on 7 adult female elephant seals. We will also test a new Wildlife Computers GPS tag using the Fastlock tag technology.

In addition to these test deployments, we will deploy the first archival tags on elephant seals at one of the southern most breeding colonies at San Benitos Islands, Mexico. During June 2005 we will deploy 15 SPOT tags, in combination with Mk9 with the new fast responding thermistors, on female seals and 5 CTD SRDLs on males. It is anticipated that elephant seals from this breeding colony will use different regions of the eastern North Pacific than elephant seals from the more northern rookeries.

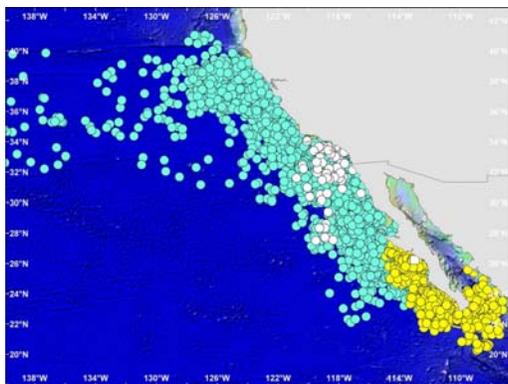
Satellite tags deployments are also planned for other TOPP species. We will deploy 15 SPOT tags on humpback whales and 15 on blue whales this summer. A combination of SPOT and PAT tags

will be deployed on salmon, mako, thresher, white and blue sharks as well as swordfish and the ocean sunfish in the summer and fall in the California Current. The new SRDL, modified for mounting on the dorsal fin, will be tested on salmon sharks in Alaska as well as the PAT and SPOT tags. Deploying tags on a range of species provides a more robust test of the technology and allows for oceanographic sampling over a broad spectrum of habitats. With the new fast responding thermistor in the PAT tags the profiles obtained from sharks and fish meet oceanographic standards (Figure 1).



**Figure 1.** Salmon shark profiles obtained using PAT tag technology with a fast thermistor. Panel A shows the depth temperature profiles for a shark that was tagged in Prince William Sound Alaska and traveled to Hawaii. Depth (B) and temperature (C) preferences through out the tracks are also shown. Panels D-F show similar data for a salmon shark that over wintered in the Gulf of Alaska.

This grant also funded considerable testing of archival tagging on three species of tunas (bluefin, yellowfin and albacore). To date we have had extraordinarily success in archival tag recovery for bluefin and yellowfin tunas and efforts have just begun with the albacore tunas in the past year. Together the three species of tunas have provided over 30,000 days of data in the California Current (Figure 2) including high quality data on behavior and environmental preferences, and *in situ* measurements of the temperature profile of the water column. We expect to recover and deploy additional archival tags on bluefin, yellowfin and albacore tuna, deploying 100 LTD 2310 on each species in 2005. These tags will be programmed to sample at 4 to 32s intervals to obtain more detailed oceanographic data. Deploying tags on these three species of tuna not only provides for valuable inter-specific comparisons and niche separation, but allows for focused oceanographic sampling in the California Current. The data recovered will be added to our growing oceanographic database and enhance oceanographic models working closely with Yi Chao at the Jet Propulsion Laboratory (JPL) in Pasadena, CA. All recovered tags will be thoroughly examined for physical wear and overall performance. The performance and durability of archival tags deployed on elephant seals and sea lions will also be examined. The behavioral and habitat difference among the species provides a thorough test of the technology.



**Figure 2.** Daily distributions of 20 archival tagged bluefin tuna (light blue circles), yellowfin tuna (yellow circles) and albacore tuna (white circles) tagged in 2002- and 2003. Position estimates were determined from light based geolocation and SST based latitude as in Teo et al. 2004.

To compare the data collected by the tags with remotely sensed oceanographic data or the SEABIRD CTD data, all tags must be calibrated before and after deployments. We have developed an excellent relationship with the Oceanography Department at the Naval Post Graduate School to test and calibrate the temperature and salinity sensors and additional experiments are planned. Further examinations will be made on the effects of different shielding configurations to eliminate or control near field effects on CTD tags. For the primary productivity tag, we will compare tag estimates of chlorophyll *a* to those obtained using a fluorometer and determine from water samples.

## WORK COMPLETED

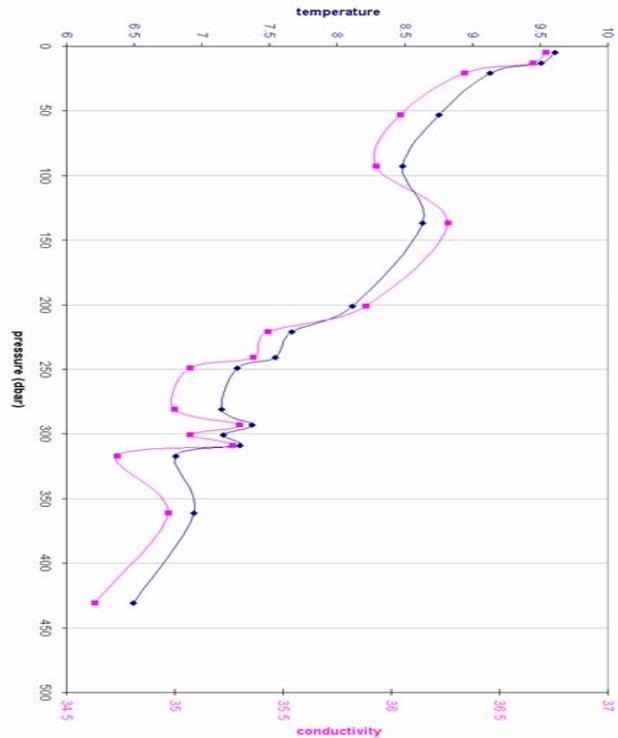
**Table 1.** Summary of tag deployments in the TOPP program in 2004.

Species	Location	Time	Tag types
Leatherback sea turtles	Costa Rica	January	SPOT/SRDL
Salmon sharks	Alaska	July	SPOT/PAT/SRDL
Mako Sharks	California Bight	June, July	SPOT/PAT
Blue Sharks	California Bight	June, July	SPOT/PAT
Thresher Sharks	California Bight	May, July	SPOT/PAT
White Sharks	Central California	August	PAT
Swordfish	California Bight	October	PAT
Elephant Seals	Central California/Mexico	Feb, May, June	SRDL/Archival tags
Sea Lions	Central California	May/September	SRDL
Blue Whales	Central California	July, August	Satellite transmitter
Fin Whales	Central California	August	Satellite transmitter
Humpback Whales	Central California	July-September	Satellite transmitter
Bluefin tuna	Mexico	August	Archival tags
Albacore tuna	Mexico	August	Archival tags
Yellowfin tuna	Mexico	August	Archival tags

Over the 2003-2004 fiscal year, the funding from ONR provided the opportunity to leverage funding from other sources and continue the development and testing of electronic tagging technology. Table 1 summarizes the deployments over the last year that occurred as a part of the TOPP program. In the description of work completed below we focus of the aspects of the project funded by the ONR grant.

Considerable effort focused on the development of the CTD tag which is progressing nicely. This spring CTD tags were deployed on 9 elephant seals for the 2-5 day trip across Monterey Bay. After correction for near field effects the data collected was virtually indistinguishable from that

obtained using a Seabird CTD cast at the time of release. Even this small number of deployments provided over 3,000 individual oceanographic profiles for Monterey Bay. To test the tags over much longer periods 4 SMRU/SRD L CTD tags were deployed on elephant seals in June of 2004 for their 8-month post molt migration. These tags transmit the logged data to the lab via satellite (Figure 3) and have already provided a phenomenal amount of data. In December 2004, an additional 3 SRDL CTD tags were deployed on California sea lions. The advantage of deploying these tags on sea lions is that they remain in the California Current, while elephant seals roam over the greater North Eastern Pacific.

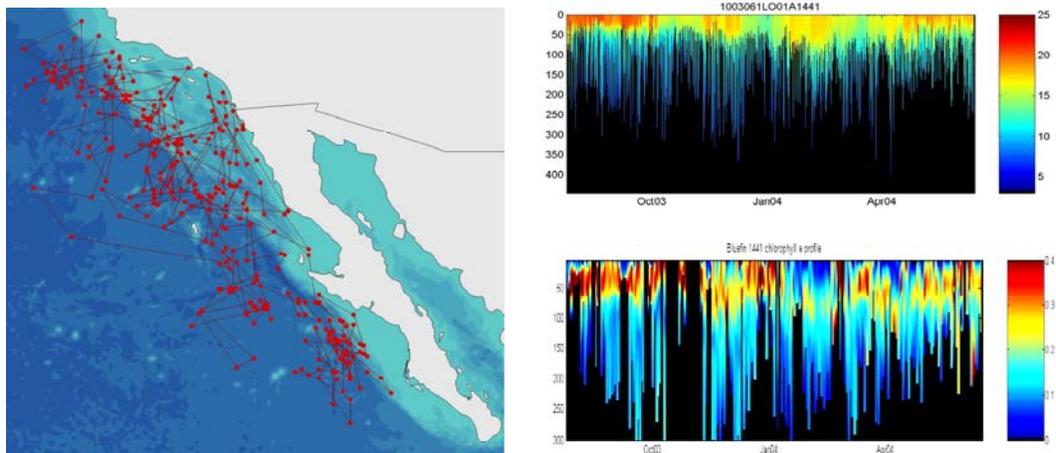


**Figure 3.** SMRU, SRDL CTD tags were secured to female elephant seals prior to their 8-month post molt migration (left). These tags transmitted to satellite temperature and depth profiles from selected dives during the track (right).

Additional efforts focused on the chlorophyll *a* tag. Through our collaborations with Wildlife Computers, using NOPP funds, a dual wavelength archival tag was produced and is now being tested on 19 elephant seals during their 8-month migrations. This second wavelength will allow differentiation of chlorophyll absorbance from the absorbance of particulate matter. Shipboard validation experiments indicate that the single wavelength tag can also be used to successfully calculate chlorophyll *a*. From tags deployed on tunas in 2002 and 2003, we discovered that sampling frequencies were too low to provide continuous high-resolution profiles. To alleviate this problem, archival tags deployed on tunas last year had 4 and 32 second sampling frequencies.

Over the past year 300 archival tags were deployed on yellowfin, bluefin and albacore tuna. From these deployments as well as our prior year deployments on yellowfin and bluefin tuna we have recovered over 140 LDT 2310 archival records. While the data analysis from these tags is in progress, performance with the tags was exceptional. All but 4 tags functioned perfectly, providing a significant amount of behavioral and environmental data. From bluefin tuna alone we currently have over 25,000

days of temperature profiles in the California Current (Figure 4).



**Figure 4. Pacific bluefin tuna movements (left,) depth profiles of temperature (right top) and chlorophyll *a* (right bottom) are shown for one bluefin tuna tracked from 7/25/03 to 6/15/04. This bluefin remained off southern California and Mexico over the duration of the track. The chlorophyll data was obtained by calculating light attenuation with depth from an archival tag with a single wavelength light sensor.**

## RESULTS

Collaborations between academics and industry engineers have expanded the number of electronic tags available for marine vertebrates. While data analysis is in progress it appears that the new CTD tags will meet our objectives. They will provide a platform for the collection of a large volume of subsurface, temperature and salinity data for remote regions in the North Pacific as well as providing insight into preferred habitats of a range of species. While still in the early stages of field tests, results indicate that it will also be possible to obtain sub-surface chlorophyll estimates. This will illuminate links between physical and biological phenomenon and provide the ability to understand the dynamic processes associated with preferred habitats for species at a range of trophic levels. There is currently very little sub-surface salinity and chlorophyll data available and using animals as ocean sensors we have the opportunity to fill large gaps in our understanding of the physical and biological processes in the North Pacific. The methods and technologies developed in TOPP are being transferred to other oceans as well. Additional efforts are needed to validate the chlorophyll *a* measurements in the field as well as to test the new GPS tags.

The archival tags and satellite tags are proving an excellent platform for collecting biological and oceanographic data from tuna, sea birds and pinnipeds. In our initial efforts alone we have collected a phenomenal amount of sub-surface temperature, depth and light data in the California Current and North Pacific. The efforts to improve the reliability and data quality of archival and satellite tags will provide the oceanographic community the means to collect high-quality, sub-surface data from remote, un-sampled locations. Steps necessary to further increase the value of electronic tags for both biologists and oceanographers includes developing the methods and software for integrating the oceanographic data into existing databases as well as for examining animal behaviors in relation to regional oceanography.

## **IMPACT AND APPLICATIONS**

### **National Security (Delete this section if there are none)**

New electronic tags have advanced our ability to collect biological data on an ecosystem scale and to observe oceanography on a global scale. The oceanographic data can be used to develop oceanographic models as well as those dealing with ocean-atmospheric coupling and global heat balance.

### **Economic Development (Delete this section if there are none)**

New and improved electronic tags are currently available to the community through the respective manufacturers.

### **Quality of Life (Delete this section if there are none)**

The major output of TOPP will be the ability to examine or model the movements of pelagic predators leading to a greater understanding of the North Pacific ecosystems and improving the ability to develop predictive models of marine predator movements in relation to environmental conditions. This level of understanding is required for dynamic, adaptive fisheries management and provides the information needed to conserve and manage marine resources.

### **Science Education and Communication (Delete this section if there are none)**

Over the last year the Education and Outreach team has been working towards the launch of a redeveloped web site for the TOPP program, which will enable students, teachers, scientists, reporters and the general public to explore the journeys of TOPP animals.

## **TRANSITIONS**

### **National Security (Delete this section if there are none)**

The ability to model animal movement will simplify the planning of naval exercises. Improvements in oceanographic models by JPL and NODC will help the Navy and Coast Guard in their operations.

### **Economic Development (Delete this section if there are none)**

Wildlife Computers licensed the Fastlock technology developed by WildTrack Telemetry.

### **Quality of Life (Delete this section if there are none)**

The data collected will aid NMFS and the IATTC in the development of models allowing for predictions of animal distribution and abundance based on oceanographic features. This facilitates the creation of adaptive management plans and the establishment of dynamic MPA in the open sea.

### **Science Education and Communication (Delete this section if there are none)**

The development of engaging tools to visualize 4-D data has direct application to other projects in the Census of Marine Life and will be of broader interest in the science education community.

## **RELATED PROJECTS**

There are three international efforts, the Eastern Tropical Pacific Sea Scape, Southern Ocean Census of Marine Life (SO-CoML) and Marine Mammal Exploration of the Oceans - Pole to Pole (MEOPP) that have been greatly facilitated by the tag developments carried out under this award.

**PUBLICATIONS (*DELETE THIS SECTION IF THERE ARE NONE*)**

Costa, D.P. and Sinervo, B. 2004. Field physiology: Physiological insights from animals in nature. *Annual Reviews of Physiology* 66, 23.1–23.30

Costa, D.P., Kuhn, C.E., Weise, M.J., Shaffer, S.A. and Arnould, J.P. 2004. When does physiology limit the foraging behaviour of freely diving mammals? *International Congress Series* 1275 (2004) 359– 366.

Shaffer, S.A., Tremblay, Y., Awkerman, J.A., Henry, R.W., Teo, S.L.H., Anderson, D.J., Croll, D.A., Block, B.A., and Costa, D.P. (in review) Comparison of light- and SST-based geolocation with satellite telemetry in free-ranging albatrosses. *Marine Biology*.

Shaffer, S.A. and Costa, D.P. (2005) A Database For The Study Of Marine Mammal Behavior: A Tool To Define Their Behavior And Critical Habitat. *Journal of Oceanography*. *In press*.

Teo, S.L.H., Boustany, A., Blackwell, S., Walli, A., Weng, K.C. & Block, B.A. 2004. Validation of geolocation estimates based on light level and sea surface temperature from electronic tags. *Marine Ecology Progress Series*. 283, 81-98.