Accelerating Electronic Tag Development for tracking Free-Ranging Marine Animals At Sea

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Award Numbers: N00014-03-1-0325 & N00014-02-1-1012
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LONG-TERM GOALS

Refine and develop electronic tagging technologies for Tagging of Pacific Pelagics (TOPP), a pilot program of the Census of Marine Life (CoML). The tags under development will enable the project to address more complex questions about marine predators and their environment and collect high quality environmental data for integration into oceanographic databases.

OBJECTIVES

The work is focused on improving and testing the use and application of existing electronic tags and developing new, more complex hardware and software. For currently available archival and satellite tags we are 1) testing performance and durability, 2) improving light based geolocation estimates using sea surface temperature, 3) determining whether light levels recorded by archival tags can be used to estimate chlorophyll *a* concentrations, 4) examining the use of stomach temperature tags to document feeding behavior, and 5) testing light based geolocation for use on birds. New tag technologies under development include a conductivity, temperature, depth (CTD) sensors for both archival and satellite tags and a GPS tag.

APPROACH AND WORK PLAN

Tag performance: To test the archival tag, we took a two-pronged approach with tests both in captivity and in the wild. Such tests involved fish and marine mammals. The captive environment provides the opportunity to control conditions while examining behaviors, the animal, and tag condition. Deployments in wild provide for longer, more rigorous and realistic tests of the technology and methods. For both wild and captive experiments the condition of the tags and animals (when available), the quality of data, and performance of the tags has been carefully examined. Studies with bluefin tuna are being conducted by Dr. Block and the staff and students of the TRCC. Kurt Schaefer of the IATTC is conducting the studies with yellowfin tuna. Additional tests of archival tag performance are being conducted with elephant seals and California sea lions. Tags are deployed over their bi-annual foraging migrations in conjunction with a series of other tags to which the performance can be compared. This work is being conducted by Dan Costa, Mike Weiss, Carey Kuhn and Yann Tremblay of the University of California Santa Cruz (UCSC).

TOPP is currently using three types of satellite tags. All work with the satellite tags is done in the wild; however tests for oceanographic sensors are being conducted in Monterey Bay. To date the following tag types are being utilized: Pop-up satellite tags (PAT tags); Single position only satellite tags (SPOT) and satellite delayed relay tags (SDLR).

Use of SST to improve light based geolocation estimates: A major limitation of the light based geolocation tag has been the challenge of discerning the accuracy of the estimated positions and the difficulties in obtaining accurate latitude estimates (Gunn *et al*. 1994, Welch and Eveson, 1999, Musyl *et al.* 2001). Our objectives were to develop and validate an algorithm that uses sea surface temperatures (SST) to improve the latitude estimates from electronic tag data. To estimate latitude, the algorithm basically takes the SST recorded by the PAT and compares it to values obtained from AVHRR imagery along a line of longitude transmitted by the PAT. The performance of the algorithm was assessed from double tagging experiments with free-swimming sharks. The sharks were tagged with both a PAT and a satellite telemetry tag. These experiments allow a direct comparison between Argos positions provided by the satellite telemetry tags and geolocation estimates derived from light level longitudes and SST based latitudes using an algorithm developed by Teo et al. (In press).

Chlorophyll *a* estimates from archival tag light records: The archival tags record light levels for geolocation estimates. By taking the first-order differential of the light level profile with respect to depth, we can determine the diffuse attenuation coefficient profile. Based on previous work done by Morel (1988), the diffuse attenuation coefficient can be related to the chlorophyll concentration in case I waters (e.g. open ocean waters). To test this, estimates of chlorophyll concentrations were compared to measurements made using standard methods including a fluorometer and chlorophyll extractions of water samples. Additional efforts are ongoing to determine if the light data from existing records from elephant seals and bluefin tuna can be used to document chlorophyll levels.

Use of stomach temperature sensors to document feeding: The goal of the sea lion tagging group is to quantify the foraging and diving behavior, food habits, and at-sea distribution of California sea lions in relation to climate-induced shifts in productivity. Time-depth recorders (TDR), satellite tags (PTT), Stomach temperature recorders (STR) have been deployed on adult male and female sea lions.

One objective of the research is to measure feeding rates in free-ranging California sea lions using stomach temperature technology. When sea lions feed, a drop in stomach temperature is observed, followed by a recovery of temperature as food is warmed. Theoretically, the magnitude and/or duration of the temperature change is proportional to the amount of food consumed. Thus, stomach temperature can be used to identify and potentially quantify feeding events in free-ranging animals. Experiments with both captive and wild sea lions are being used to develop this approach.

Light based geolocation in birds: The main objectives concerning tag development for use on seabirds are as follows: 1) develop and test tag attachment techniques; 2) test the application and performance of satellite tags, archival geolocation tags, and GPS tags; and 3) obtain comparable data at multiple sites. Another initiative is the application of tags on smaller species (< 1 kg), Sooty and Pink-footed Shearwaters. The Lotek 2400 geolocation tag combines a small size (< 6 g) with sufficient memory to record long migrations. These projects involve 10 principal investigators and 5 students or field technicians from 7 academic or government institutions from 4 countries.

New technologies/ GPS and CTD tags: One of the goals of this project is to merge mesoscale satellite remote sensing data with fine-scale data collected from the tags, particularly subsurface environmental data, generating major benefits for both biological and oceanographic research. To accomplish this we are developing a new set of animal based CTD loggers and a GPS tag. The CTD tag will allow subsurface sampling of salinity across the North Pacific and the GPS tag will make it possible to study animal movements on a scale of 1-10 meters compared to the 1-10 kilometers currently possible with Argos satellite tags. For this program the collaborative partnership is between Wildtrack Telemetry Systems, the SMRU and UCSC. Wildtrack Telemetry systems is integrating the *FastLoc* GPS technology into a robust marine animal tag based on the SMRU archival design.

This GPS and CTD tags being tested are first deployed on juvenile elephant seals during short (matter of days) translocation experiments in Monterey Bay. Upon release data collected by the tags are compared to equivalent data collected simultaneously using a standard SEABIRD CTD. Long-term testing will be conducted by deploying tags during the bi-annual foraging migrations of elephant seals. Testing is being conducted by Dan Costa and Yann Tremblay (UCSC) and Dan Crocker (Sonoma State). Tag development is occurring in collaboration with Mike Fedak of the SMRU.

WORK COMPLETED

Tag performance: To date 4 different models of archival tags have been implanted in bluefin and yellowfin tuna both in the wild and in a captive environment including the Lotek 2310, 2410, and 1100 and the Wildlife Computers MK 9. A total of 213 and 68 archival tags were implanted in bluefin and yellowfin tuna respectively off California and Mexico. Captive experiments at the TRCC with PAT tags lead to the development of a double attachment method to improve retention on wild fish. In captive studies on yellowfin tuna Kurt Schaefer of IATTC implanted a total of 29 archival tags. This past summer the rapid response temperature sensing archival tags were tested on northern elephant seals. A total of 6 tags were deployed in June 2003. The seals are currently returning to the Año Nuevo rookery and the first tag was just recovered.

Use of SST to improve light based geolocation estimates: Double tagging experiments to develop algorithms to improve latitude using SST were conducted with salmon and blue sharks in 2002 and 2003. Using the data from these tags we have completed the development and validation of the first phase of the geolocation algorithm (Teo et al. In press). An automated routine will be incorporated into the Live Access Server being developed, with NOAA, as a part of TOPP.

Chlorophyll *a* estimates from archival tag light records: On a cruise from Hawaii to Palmyra archival tags were secured to a Niskin bottle rosette and CTD during series of casts from the *S.S.V. Robert C. Seamans*. The chlorophyll profiles estimated by the archival tags (LTD2310s and Mk9s) were compared to those obtained from both the flourometer and water samples taken every 25 m. A preliminary version of the algorithm that uses light level data from electronic tags to estimate chlorophyll profiles was developed as a result.

Use of stomach temperature sensors to document feeding: Over 300 trials have been conducted on 6 captive California sea lions and more trials are scheduled for 2003. Preliminary analysis indicates that both the time to recovery for stomach temperature and the area under the curve can be used to estimate meal size. In 2003, 15 free-ranging adult female California sea lions were equipped with an archival dive recorder, satellite transmitter, and stomach temperature recorder. Eleven animals were recaptured and all tags were recovered. Data analysis is in progress. We successfully deployed 22 SMRU-SRDLs on adult male sea lions in 2003.

Light based geolocation for marine birds: Two field seasons occurred at four sites (Tern Island, Hawaii; Guadalupe Island, Mexico; Snares Island, New Zealand; Juan Fernandez Islands, Chile). From the 80 deployments on Laysan and Black-footed Albatrosses at Tern and Guadalupe Islands, we obtained over 10,000 valid locations from the satellite tags and over 700 locations from the geolocation tags. The GPS tags performed well on albatrosses, but saltwater intrusion caused malfunction at sea. Improvements in tag design have since resulted in successful deployments of GPS tags on Waved Albatrosses at the Galapagos Islands.

Two deployments of tags on both shearwater species were carried out in 2003. At Snares Island, 20 Lotek 2400 tags plus 6 dummy tags were deployed on sooty shearwaters. Nine birds were recaptured after 2-11 days and tag performance was excellent. All tags were left attached for the migration and we made and effort to retrieve them in 2003. Despite recapturing 16 of the 26 birds, no tags were recovered. Nevertheless, this work proved that shearwaters could be successfully recaptured. Improvements in tag attachment design are ongoing. A smaller field effort was made on Pink-footed Shearwaters at the Juan Fernandez Islands were 5 Lotek 2400 and 7 dummy tags were deployed in Mar 2003. A research team is currently at the Juan Fernandez Islands to recover the tags.

New technologies/ CTD and GPS tags: During the summer of 2003, Alec-Electronic CT recorders, coupled with time depth recorders with fast response temperature probes, were deployed on yearling northern elephant seals at the Año Nuevo rookery. These seals were also equipped with Argos and VHF transmitters, transported into Monterey Bay and released. At the time and place of release a CTD cast was initiated from the boat, using a CTD SEABIRD. The animals returned to their molting sites within 2 to 5 days.

Dr. Ed Bryant, Wildtrack Telemetry Systems Ltd. (Leeds, England), has been leading the development of a small GPS system. The *Fastloc* uses a novel solution that couples brief satellite reception with onboard processing to reduce the memory required (29 bytes), which can be stored or transmitted. Using post processing, the final stage 3 *Fastloc* location determinations are conducted in the lab. The GPS sub-system will be incorporated into archival data loggers within the standard SRDL. Prototype SMRU CTD and GPS tags will be delivered to UCSC for field trials in February 2004.

RESULTS

Tag performance: In the first 18 months since deployment, a total of 25 (14%) archival tags have been recovered from Pacific bluefin tunas. Although most fish remained in the Eastern Pacific, one tuna was recaptured off Japan after 296 days. This is the first archival record for a bluefin documenting the return trip to Japan. We have collected over 6000 days of data including at least 10,000 profiles of the California Current to 200-300m. Data was also obtained from 100% of the PAT tags.

The recovery rates for archivally tagged yellowfin are over 27%. To date, over 1,500 days of cumulative data on the movements and behaviors of Pacific yellow tuna have been obtained. The majority were recaptured within a few hundred miles of the release location. Several tags recovered span the period when the tuna begin to associate with dolphin schools. Information on habitat selection and behavioral changes over this period will provide insight into tuna-dolphin associations.

The high tag recovery rates and captive studies have allowed us to examine tag performance and attachment methods. Results indicate that intramuscular implantation of archival tags is not effective and intraperitoneal methods will be continued. Also, double attachment methods for PAT tags improved tag retention in the wild. In the first tests of a new generation of archival tag, the MK9 Wildlife Computers Inc. archival tag died shortly after implantation. This prevented a large deployment in the field. These tags are currently being retested to insure the problem (battery failure) has been fixed. An additional problem identified with both manufacturers tags was clock drift. Time has to be extraordinarily accurate for light based geolocation. The TOPP team discovered that the dramatic temperature fluctuations that can occur during shipping or if the fish is placed in a freezer can cause the crystal oscillators temperature compensation to fail. This alerted the team and manufacturers to modifications necessary in tag handling and design. In general, the tags have performed quite well with respect to time, and tags out as long as 570 days have had very small time drifts.

Use of SST to improve light based geolocation estimates: The results from the double tagging experiments demonstrate that SST can be used in conjunction with light level data to significantly improve the geolocation estimates from electronic tags. The error in latitude estimates is reduced from 6 to 11 ^{o} to less than 2 ^{o}. Results also provide error estimates for both latitude and longitude. Consequently, we can now define the movements of pelagic predators with a quantified error distribution, critical for linking tracks to oceanographic features and developing models. The computer simulations indicated that the difference between the remotely sensed and recorded SST was the predominant influence on the accuracy of SST latitude estimates.

Chlorophyll *a* estimates from archival tag light records: The preliminary results from this study indicate that using light level data from electronic tags is a viable approach to estimating chlorophyll over large expanses of open ocean. (Fig 1). More interestingly, results also suggest that the deep

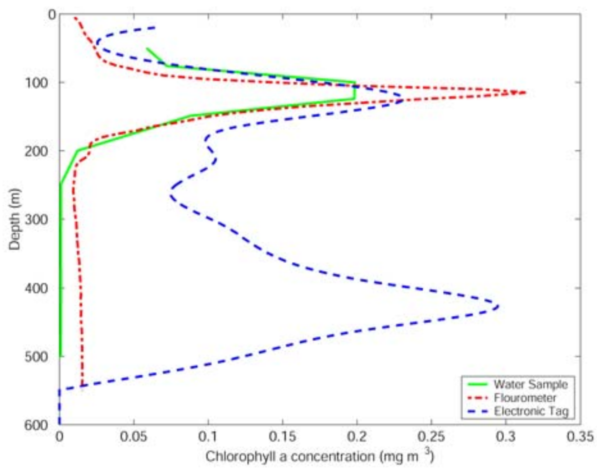

Figure 1. The estimated profiles of chlorophyll a concentration, with depth, in the tropical Pacific Ocean using chlorophyll extracted from water samples at 25m intervals (green line), a fluorometer (red dashed line), and an archival tag (blue dashed line) during the same CTD cast.

scattering layer (DSL) is also apparent. The deeper peak in Figure 1corresponds to the DSL depth estimated by the shipboard ADCP. The potential to document both chlorophyll and the DSL across the North Pacific provide an opportunity to examine how oceanographic features aggregate marine predators and will improve our ability to identify links between physical processes and productivity.

Use of stomach temperature sensors to document feeding: The analyses of the controlled feeding trials provide strong evidence that stomach temperature will not only identify feeding events at sea, but when combined with specific foraging locations, may also provide an accurate estimate of meal size of free-ranging animals. Temperature profiles of adult male sea lion dives will elucidate the role of temperature in their sub-surface foraging and diving behavior and provide oceanographers with valuable three-dimensional profiles of the water-column. Initial validation of temperature profiles obtained with SMRU SLDR instrumented sea lions were very similar to those obtained using the standard CTD profiler. This technology is very promising with the first 4 tags having transmitted 417 temperature profiles with a max depth of 387m with 1.7-3.3 profiles per tag day.

Light based geolocation for marine birds: The results of our field tests on seabirds indicate that a multitude of different electronic tags can be deployed on the albatrosses. The archival geolocation tags with SST correction can provide sufficient information on the long-range distribution where as the GPS tags can be used to acquire finer scale resolution of foraging behavior. Results provide the first year-long track for any Northern Hemisphere albatross and will allow inter-annual comparisons of foraging patterns. Examination of tracks in relation to wind patterns indicated that both wind direction and intensity influences movements. For Shearwaters, the data on short-term foraging excursions show impressive dives to greater than 50 m. With modifications in tag attachment, it should be possible to obtain new and exciting information on the long-range foraging and migration.

New technologies: CTD and GPS tags: As proof of concept we deployed a CT Alec tag coupled with a TDR on elephant seals, to provide CTD data in the Monterey Bay. These tags were calibrated at the lab, and tested under more realistic condition in the field by comparing results with a CTD SEABIRD profiler. For salinity, these results indicate that accurate salinity profiles are possible to collect using elephant seals as oceanographic platforms, but that careful calibration and correction needs to be made. The figure below shows a salinity profile obtained across the Monterey bay from a juvenile elephant seal. In these experiments, even the small number of animals provided over 500 CTD profiles throughout Monterey Bay, along recorded transects.

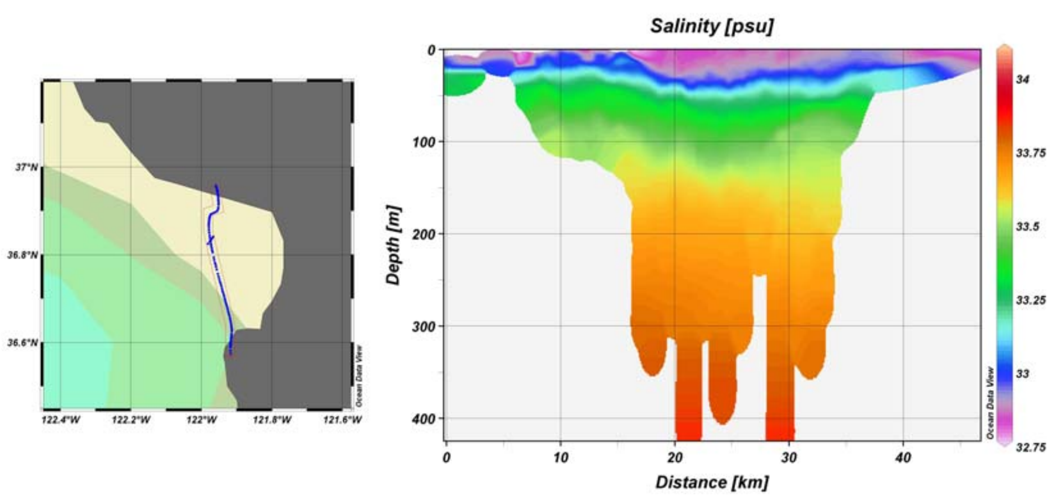

Figure 2. Left: transect of an Elephant seal across Monterey Bay. Right: salinity profile section (from south to north) obtained along this path.

IMPACT AND APPLICATIONS

National Security (Delete this section if there are none)
An improved understanding of the dynamic ocean forces will help us to model and predict the distribution of marine mammals. This will simplify military operations where marine mammals encounters are an issue.

Quality of Life (Delete this section if there are none)
As populations expand and we demand more from the oceans it becomes critical that marine resources are sustainably managed. This will not happen without an improved understanding of the marine ecosystem and how dynamic ocean forces influence it. In addition, the oceanographic data that are collected will improve our ability model ocean processes and improve models of the global heat balance.

Science Education and Communication (Delete this section if there are none)
A major goal of the TOPP program is to take advantage of the charismatic nature of the species and technologies used to educate the public about marine ecology and conservation. Any result obtained using NOPP resources are included into the education program which includes a website with field reports, popular media. Currently a internet dynamic visualization system is under development. , Also, TOPP has received considerable press including articles in *Smithsonian*, *Discover*, *Boston Globe*, and *Alaska Airlines* in-flight magazine. On the broadcast media side, TOPP was featured in two segments on NPR's "Earth and Sky" program, and the TOPP team worked with documentary film crews from National Geographic and BBC to create programming which is scheduled to air in the coming months.

TRANSITIONS

Economic Development (Delete this section if there are none)
CTD tag is being deployed in the southern Ocean. Still in the early stages of development, in the long run we expect that other programs will adopt the system of data management, analysis, integration and visualization. Currently most programs are using antiquated systems that are cumbersome and not designed to meet the programs needs. Two manufacturers are pursuing a licensing agreement with Wildtrack Telemetry Systems to commercially produce the GPS tag.

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