Accelerating Electronic Tag Development for Tracking Free-Ranging Marine Animals at Sea

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LONG-TERM GOALS

The objective of this proposal is to complete the development, testing, and deployment of archival and satellite tags for the Tagging of Pacific Pelagics (TOPP) pilot program of the Census of Marine Life. Efforts have centered both on improving existing technologies and on developing new tools that are now allowing us to address more complex questions about the animals and their environment. First, electronic tags are providing TOPP with the tools necessary to address fundamental questions in biological oceanography concerning the distribution and critical habitats of pelagic organisms. This information is being used to describe the movements and behaviors of marine vertebrates and large squid in the North Pacific and to identify hotspots and migratory corridors. Second, with the new tags developed under this effort we are now using the tag-bearing animals as autonomous ocean profilers and we are providing oceanographic data to the growing global databases. The vertical and horizontal movements of tagged marine vertebrates allow sampling of more remote, traditionally under sampled areas, as well as providing unprecedented temporal and spatial coverage of the North Pacific. Not only are these data of great value to oceanographers but when the biological and physical data are merged, we can obtain an "organism-eye" view of how marine animals from several trophic levels use distinct oceanic regions.

OBJECTIVES

To accelerate the electronic tags available to track marine animal movements. The specific objectives were to: Develop a Conductivity Temperature depth tag (CTD), develop a GPS tag, further test and refine the archival and satellite tags currently available. This included testing and modification of tags built by archival and satellite tags from Wildlife Computers and archival tags from Lotek Wireless. Finally our goal was to test these tags and further the ability to use animals to acquire oceanographic data.

APPROACH

To accelerate tag technology, TOPP scientists have been working with engineers at Wildlife Computers (USA), Wildtrack (U.K), Sirtrack (New Zealand) Lotek Technology (Canada), and the Sea Mammal Research Unit (U.K.). New tags have been tested on elephant seals, salmon sharks and bluefin tuna, all proven test platforms for tag deployment. Tags and algorithms that have been developed include Conductivity – Temperature – Depth (CTD), GPS, and single and dual light wavelength tags for estimating primary productivity. For marine mammal deployments, tags were initially tested through a series of 2-5 day elephant seal translocations experiments followed by longer deployments on seals during their post-breeding or post-molt migrations. Prior to deployment and after recovery, each tag is rigorously calibrated to determine instrument drift. Currently tags being tested include a number of archival tags, pop-up satellite tags, single position only tags, and Satellite Relay Data Loggers (SRDLs). Tag performance is carefully evaluated by assessing the durability under field conditions, effectiveness of attachment on the animal, battery performance, accuracy, and responsiveness of tags to measure temperature, depth, light, and other variables. For fish and shark deployments, the focus is on solving algorithm problems and increasing the longevity of deployment duration without tag failure.

WORK COMPLETED

By working internationally as a team (TOPP, SMRU, Lotek, Wildlife Computers) we have used the support from NOPP to bring to fruition GPS tags for increasing the accuracy of marine mammal positions, CTD tags that provide salinity data along with temperature profiles, single position only tags for monitoring five species of shark (SPOT), archival tags for electronic tagging of tuna and seabirds, and algorithms that provide a measurement for in vitro chlorophyll in the ocean (Teo 2006). Using Fast-GPS tags, it is now possible to obtain animal locations to within 10m with a corresponding water temperature profile that has a resolution of 0.05°C and an accuracy of ±0.1°C. The tests in 2006 with seals and sea lions demonstrated that GPS tags allow identification of water column features significantly greater than ARGOS and at a much higher resolution than satellite remote sensing. We are now exploring incorporating Application-Specific Integrated Circuit (ASIC) technology to reduce the cost and size of the tags. ASIC chips in the tuna light-based geolocation tags would allow us to reduce the size of the tags and extend TOPP technology to coastal species such as salmon or smaller seabird species. This would be a significant advance for the biologging community.

Advances in electronic tag technology have provided TOPP with the tools necessary to describe the movements and behaviors of marine vertebrates and large squid in the North Pacific and to identify hotspots and migratory corridors. The tag-bearing animals continue to serve as autonomous ocean profilers providing key oceanographic data to the growing global databases. The vertical and horizontal movements of tagged marine vertebrates have provided the sampling of more remote, traditionally undersampled oceanic areas, as well as providing unprecedented temporal and spatial coverage of the North Pacific. To date, over 2,500 tags have been deployed and several million ocean observations have been documented. Efforts to database the entire TOPP data set are on-going and new collaborations with JPL-NASA for data assimilation into ocean general circulation models have been established.

RESULTS

GPS tag: Development of a GPS tag using *Fastloc* technology has made it possible to study animal movements on a scale of 1-10 meters compared to the 1-10 kilometers possible with ARGOS satellite tags (Figure 1). The development of a GPS system that could work with marine animals was a major goal of this grant as the achievement of this precision would allow measurements of animal movements relative to the mesoscale features, and would significantly improve the quality of the physical oceanographic data collected by the animals. We supported engineer Ed Bryant of Wildtrack

Telemetry Systems Ltd (Leeds, England) to develop a functional prototype of a small GPS system that can operate within the narrow bandwidth confines of the ARGOS system. This system is called

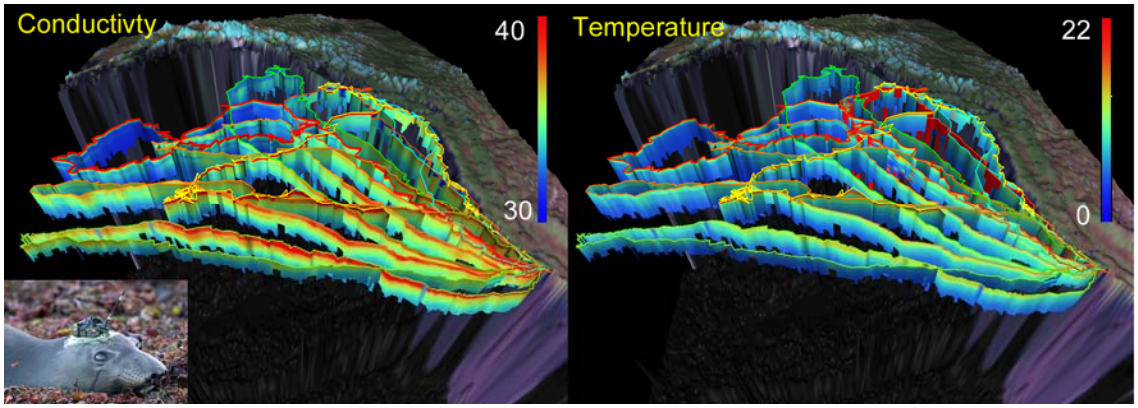

Figure 2. The inset at lower left shows an elephant seal with the CTD tag. The two images show the coverage across the North Pacific from only 7 CTD deployments on female elephant seals from the Año Nuevo rookery.

Fastloc and uses a novel intermediate solution that couples brief satellite reception with limited onboard processing to reduce the memory required to store or transmit the location. *Fastloc* first acquires a 10-20 ms snapshot of GPS satellite signals (stage 1) and then uses a digital signal processor (DSP) chip to identify the observed satellites and their pseudo-ranges (Stage II). DSP calculations take about 5 s, but this can be carried out when an animal is underwater. The resulting processed data are only 29 bytes long and so *Fastloc* data can be relayed via the ARGOS system or it can be archived for later retrieval if and when the tag is recovered. Final stage 3 *Fastloc* location determinations are calculated in the lab using GPS constellation orbitography data from archives available on line (e.g.). Satellite-linked GPS tags from Sea Mammal Research Unit (SMRU), Sirtrack, and Wildlife Computers have been tested on 20 elephant seals, 16 California and 5 Galapagos sea lions, 5 Australian fur seals and 1 Cape fur seal.

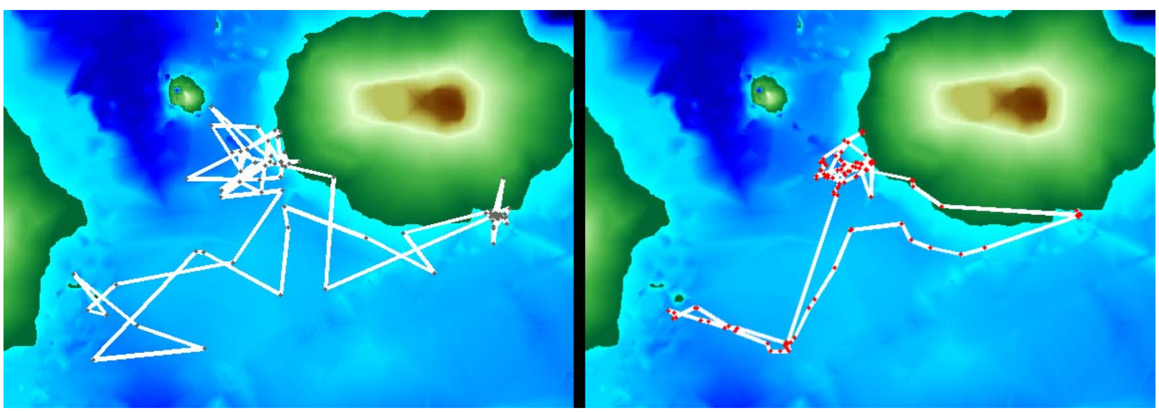

Figure 1. Track of a Galapagos sea lion with ARGOS locations on the left compared to that obtained with the new *Fastloc* GPS tag on the right. Notice the higher resolution and more consistent quality of the track obtained with the GPS tag.

CTD tag: The CTD tag is now commercially available from the Sea Mammal Research unit. The CTD-SRDL tag has operational characteristics of -5 to +35 ºC with an accuracy of 0.005 ºC and a resolution of 0.001 ºC. Following successful tests with CTD tags, long-term deployments were conducted on northern and southern elephant seals and sea lions. In the spring of 2005 and winter and spring of 2006, 16 CTD tags, which relay near real-time data to Argos satellites, were deployed on elephant seals at Año Nuevo, California (Figures 2 & 3). From these deployments (excluding spring 2005), 20,190 dives, 7,150 filtered Argos locations, and 1,826 CTD casts were obtained. The overall performance of the tags was good but several earlier models malfunctioned and post recovery calibrations on others were anomalous. Upon recovery of the tags that malfunctioned we were able to discover that the CTD casing had leaked. Given this information the Valeport LTD, the CTD manufacturer, undertook a complete redesign of the CTD head. These newly redesigned tags have just been received and are about to be deployed on southern and northern elephants. In addition to the deployments on northern elephant seals, 19 CTD tags were also deployed on southern elephant seals from the South Shetland Islands in the Antarctic Peninsula with funding from the National Undersea Research Program, NOAA (7 tags in 2005) and Office of Polar Programs NSF (12 tags in 2006).

Archival tags: Between June 1, 2005 and May 31, 2006, three hundred and forty-six Lotek archival tags were deployed. Seventy-six tags were deployed on bluefin, 168 tags deployed on yellowfin, and 102 tags deployed on albacore tuna off the coast of California, USA and Baja California (Figure 4). Recovery of the current D-series of tags has indicated that algorithms to correct passivation problems employed have been useful for increasing the longevity of the track missions. From August 2002 until June 2006 a total of eight hundred and sixty-six Lotek archival tags were deployed on bluefin, yellowfin, and albacore tuna off the coast of California, USA and Baja California. Increased sampling intervals were tested (4 - 20 seconds) for comparison to prior deployments and increased oceanographic sampling. The data recovered from recaptured tunas (mean of 320 days) will allow for improved chlorophyll a estimates and water column temperature profiles. From previous deployments, we have recovered nearly 50% of deployed tags from bluefin (158) and yellowfin (133) tuna. Lotek Wireless 2400 archival tags were deployed on 60 albatrosses and 49 shearwaters for durations up to 313 days. These tags revealed post breeding movements and diving behavior of the birds as well as SSTs for a significant portion of the North and South Pacific. Locations of dives for shearwaters reveal strong

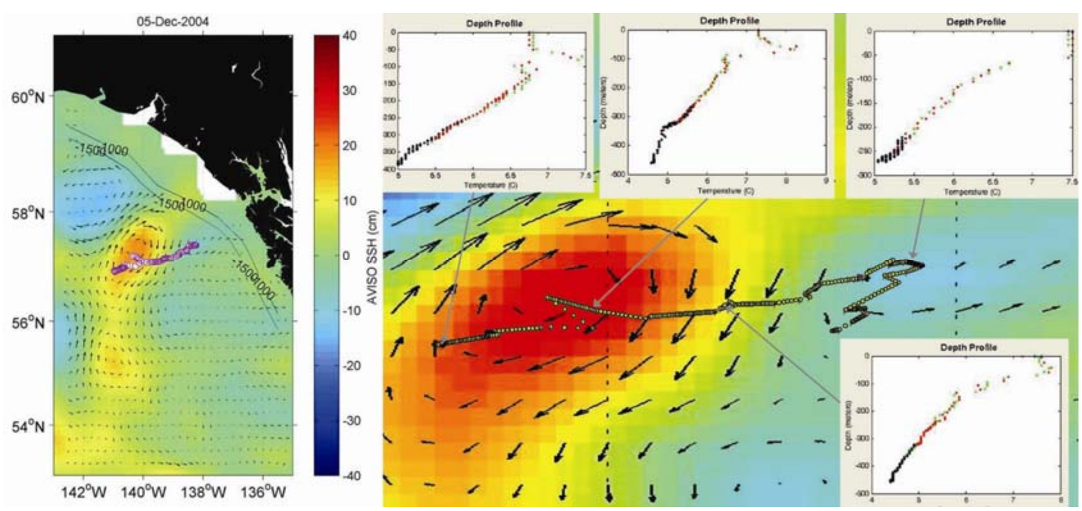

Fig 3. Elephant track showing temperature profile as the animal moves through the eddy.

relationships with remotely sensed primary productivity data. In fall 2005, we obtained the first tag

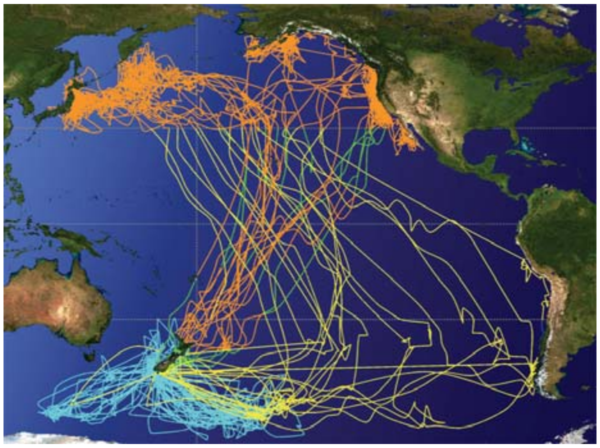

Figure 5. Tracks of sooty shearwaters tagged at New Zealand. From Shaffer *et al.* 2006 PNAS.

recoveries from migrating sooty shearwaters equipped with archival geolocation tags during the breeding period in January 2005 at two breeding colonies in New Zealand. Upon completion of breeding in New Zealand, each bird migrated to one of three destinations in the North Pacific: 1) western Pacific, 2) Alaska, and 3) Coastal California and Mexico (Figure 5). Sooty shearwaters spent nearly half the year (May – late September) at these over-wintering zones in the northern hemisphere. Shearwaters traveled more than 60,000 km roundtrip, which is one of the longest animal migrations yet recorded. This strategy of breeding in New Zealand during the austral summer followed by a migration to the northern hemisphere during the boreal summer allows sooty shearwaters to enjoy an endless summer while exploiting oceanic resources on a global scale (Shaffer et al. 2006).

PAT: Between June 1, 2005 and May 31, 2006 a total of (68) pop-up satellite archival (PAT) tags were deployed on blue, mako, salmon and white sharks. To date more than 70% of the tags deployed on all species have reported and tag performance in general has been excellent. The fast responding thermistor now allows for more accurate measurement of the water column profile and sea surface temperature (SST), which will improve SST-based latitude estimates. Over 5,000 temperature and depth profiles have been gathered in the North Pacific from shark data sets. Over the past year the white shark team has deployed 30 tags on 29 adult white sharks. One individual was tagged with two PAT tags, one long-term deployment tag and one short-term, high resolution tag. Thus far 5 tags have released including the high resolution tag. One tag released prematurely after only 6 weeks. The remaining four PAT tags surfaced in the mid Pacific area between California and Hawaii. All tags have provided high quality data. The remaining deployed tags have been silent for over seven months, which is very promising for attaining data on white shark movements during spring and summer, a season for which previous data are sparse.

SPOT: Between June 1, 2005 and May 31, 2006 a total of (49) SPOT (Satellite Position Only Tags or Temperature SPOT: Between June 1, 2005 and May 31, 2006 a total of (49) SPOT (Satellite Position Only Tags or Temperature Transmitting) tags were deployed on blue, mako, and salmon sharks. Sixteen of the 25 tags deployed on salmon sharks and 1 of 9 tags on mako sharks were still transmitting on 31 May 2006, after nearly one year. We continue to receive transmissions from 1 tag deployed in 2003 and 8 tags deployed in 2004 on salmon sharks. SPOT tags have provided a phenomenal amount of data for both the salmon (Figure 2) and mako sharks. The SPOT tags on blue sharks have not performed as well and currently only 2 of 15 tags are transmitting after 9 months. We continue to use SPOT tags for our colony based research on albatrosses, which now totals 233 individuals tracked.

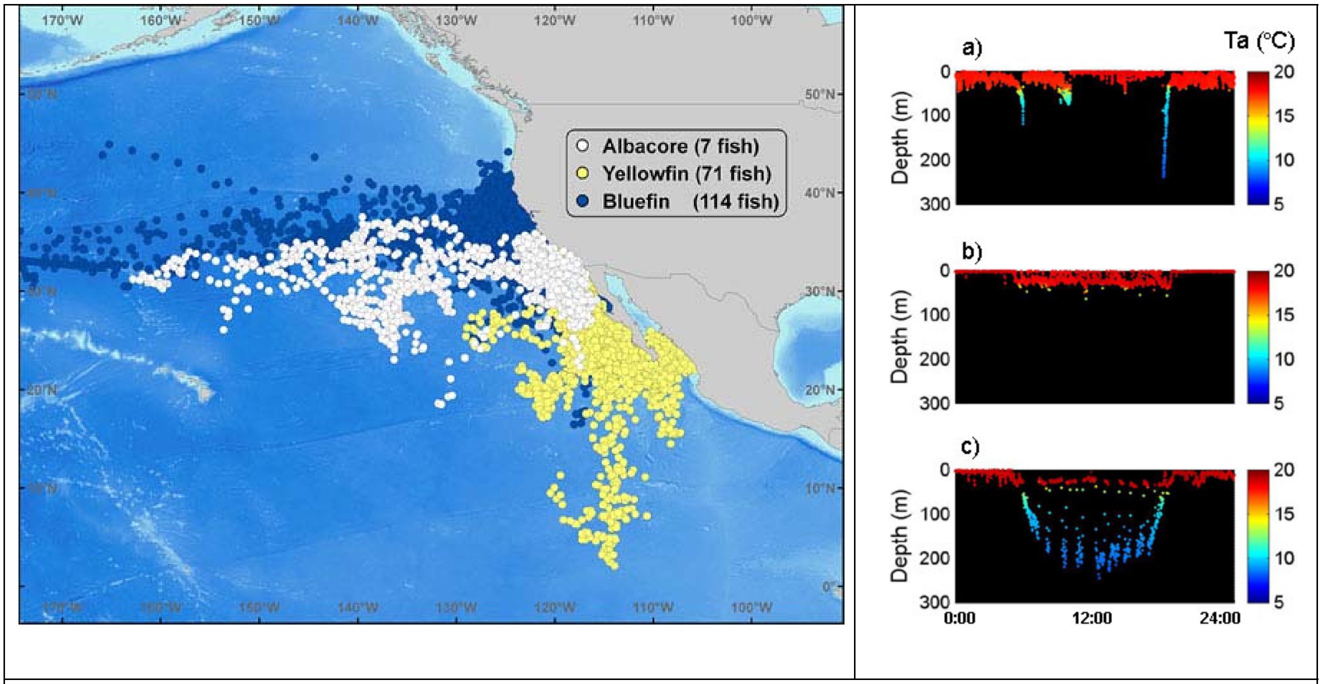

Fig. 4. A) Geolocation estimated for albacore (white), yellowfin (yellow) and bluefin (blue). B) The depth and temperature of bluefin, b) yellowfin and c) albacore for one day during the summer when all species are in the same regions off Northern Baja, Mexico.

TOPP's animal oceanographers include tracks from 32 elephant seals that generated 9,697 CTD profiles along the CCS and the NEP (Figure 2 & 3). These CTD profiles are augmented with 109,405 temperature profiles from 93 elephant seal, 1,781 temperature and depth profiles from California sea lions, and 200,000 temperature profiles from 130 bluefin tuna that heavily sample the California Current ecosystem in regions where there are few ship or AUV observations. Two hundred TOPP tagged sharks have provided over 16,000 profiles throughout the North Pacific. Albatrosses have collected over 10,000 SST measurements from across the entire Pacific in one summer season. Together these data provide important physical oceanographic input to ocean observation and essential habitat models.

IMPACT/APPLICATIONS

National Security

Marine animals do not observe any national boundaries. Our work has shown that a number of species freely migrate great distances over the ocean. The sooty shearwater alone migrates over 18 different national EEZs. These data are important to understand the potential of these organisms to carry disease vectors such as avian influenza.

Economic Development

This project has already produced a number of compeltely new tags and has vastly improved on the design of existing tags. These tags are now being used by a large number of investigators to study marine organisms. This grant has had a direct economic impact by the creation of these new tags that are now currently on the market.

Quality of Life

Our ability to identify oceanic hotspots used by marine predators will have 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.

Science Education and Communication

The Pis sponsored by this NOPP award held an international workshop on Biological Hot Spots in Pacific Grove, CA, December 7-8th, 2005. The goal of the workshop was to bring together experts in biologging science, physical and biological oceanography, and remote sensing in order to come to a better understanding of how to define, identify, and classify biological hot spots. The workshop attracted more than 70 participants from eight nations. Plenary sessions were held on the integration of oceanographic and tag data, spatial mapping applications, and methods of modeling animal movement. A half-day was spent in four breakout groups, which had more in depth discussions on these topics. Highlights of the breakout groups were summarized in a final plenary session. The workshop represented a unique collaboration between three CoML projects: TOPP, the Ocean Biogeographic Information System (OBIS) SEAMAP program, and the Future of Marine Animal Populations (FMAP) program. The workshop was highly interdisciplinary, which led to the vigorous exchange of ideas on the nature of biological hot spots and the analytical methods that can be applied to their study.

The NOPP award has directly supported one post doctoral researcher, one engineer, and 2 graduate students. The results of this research are communicated to the public on the TOPP web page, www.toppcensus.org.

TRANSITIONS

The GPS tag design developed by WildTrack Ltd (Leeds England) with support from this NOPP award is now commerically available from the Sea Mammal Research Unit, Wildlife Computers Inc (Redmond WA) and Sirtrack Ltd New Zealand.

RELATED PROJECTS

This project relies on data collected by the Tagging of Pacific Pelagics program (TOPP) which is a pilot project of the Census of Marine Life (http://www.toppcensus.org). All the electronic tagging data for the project will be 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.

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