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Project Proposal Title: Pop-off satellite archival tags to chronicle the survival and movements of blue sharks following release from longline gear

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1. Purpose of the project and indicative results.

Our proposal to use "fishery independent" pop-up satellite archival tags (PSATs) to study the horizontal and vertical movements, and distribution of blue shark is intended provide critical knowledge in three areas.

> i. Daily horizontal and vertical movement patterns, depth distribution, and effects of oceanographic conditions on the vulnerability of blue sharks to longline fishing gear. The time blue shark spend at certain depth or temperature strata, can be used to better refine CPUE indicies in the Pacific. For example, Bigelow et al. (2002, *Fisheries Oceanography*, 11:143-155) used archival tagging data on bigeye tuna to adjust their CPUE estimates. The much larger amount of environmental data collected through time (and space) by PSATs used in our proposed research will have immediate application to CPUE estimates (see Musyl et al. 2003, *Fisheries Oceanography* 12:152-169; Sibert et al. 2003, *Fisheries Oceanography*, 12: 141-152).

To date, 31 blue sharks (120-204 cm FL, 13 males, 18 females) captured from longlines have been tagged with PSATs in FY2001 and FY2002. Data from 16 of those deployments have been transmitted and downloaded via ARGOS satellites. These represent in aggregate 1,841 days of downloaded data for the deployments. Recovered data from deployments ranged from 1 to 247 days with a mean of 116 days ± 96 (sd). Five tagged sharks (4 females) reported their data on time (i.e. data was transmitted on their pre-programmed pop-off date, ~ 8 months) whereas the remaining 11 tags represent instances where the tag reported data before the pop-off date. In these cases, it is believed that the tag was prematurely shed, thereby triggering and intiating "fail-safe" options in the tag to report archived data. It is hypothesised that nuptial bites and/or stimulation of the biting response (possibly illicited by the electrical field produced by the tag) are likey routes of tag shedding although this idea still lacks direct experimental confirmation (see below).

In brief, although recently acquired data in March 2003 need to collated, analyzed and incoporated into the final database, the vertical data suggest that blue shark exhibit "typical" pelagic fish diving patterns with "W" movements traversing from near the surface to those below the mixed layer during the day to a baseline depth of around 400 m. Some sharks tagged in FY2002, however, made occassional forays into depths reaching 500-600m. Nighttime

movements were almost exclusively contained within the uniform surface layer. In summary, it appears that about 90% of movements were contained at depths less than 220 m at at temperatures between 11° and 25°C. About 75% of all movements were found between 20° and 25°C. Although our current sample size and composition (3 males:13 females) does not have an undisputed impact, nonetheless, we observed a possible sex specific diving pattern. As identified with Kolmogorov-Smirnov tests, males and females exhibited different depth distribution patterns. Females spent 75% of time at depths less than 80 m whereas males only spent about 50% of the time within this strata. It is unclear whether this is a result of spawning behavior or represents other temporal or spatial phenomenon.

ii. The survival rates of blue sharks captured and released from commercial longline fishing gear. The morbidity of released fish will also be determined by examination of diel horizontal and vertical movement patterns (Carey and Scharold 1990) and correlated to biochemical assays performed on the tagged fishes (Linked to the Moyes et al. PFRP project to examine stressor proteins and other biochemical correlates of delayed post-hooking mortality). These results will have immediate impact in terms of management strategies for this species.

We have had at least one blue shark die, sink, and the tag automatically jettison, float to the surface and download its data. The tagged shark showed some apparently normal vertical behaviors for the first five days, then expired and sank. We have complete confidence in the conclusion that what we're seeing is a mortality. Because of the capture by longliners of a PSAT tagged shark (after 41 days-at-liberty) we are confident in our attachment procedure to rule out tag shedding over this time period. Most importantly, we also now have confidence that the pressure-sensitive depth release mechanisms (which prevent crushing of the tag's float), downloading procedures, and analysis of ARGOS data all work.

Because of the high prevalence of nuptial bites in female (and occasionally male) blue sharks in tagging operations conducted in March/April of 2001 and 2002, we believe this spawning behavior may be a possible route of tags getting to the surface early before their pop-off dates. Eleven of our deployments represent cases where tags reached the surface before the pop-up date. In one short-term deployment, the PSAT recorded only about one day's worth of data before transmitting. In this situation, it was evident from digital photographs that the female shark was bleeding profusely at the surface after release. We believe this may have attracted other sharks in the vicinity and that the tag was liberated as a consequence.

Further, it appears that 15 of the deployments (10 males) represent instances where the tag failed to transmit data. A logical extension is to hypothesize that mating behavior (i.e nuptial bites) or other biting behaviors may represent a possible mechanism of physical tag damage thereby causing complete tag failure. Elasmobranch predators could be attracted to electrical fields (e.g. Haine et al., 2001, Range of electro sensory detection of prey by *Carcharhinus melanopterus* and *Himantura granulata*, *Mar. Freshwater Res.*,52, 291-296) produced by PSATs. For example, Keinath & Musick, (Movements and diving behavior of a leather back turtle, *Dermochelys coriacea*, *Copeia*, 1993(4), 1010-1017) suggest that a shark ate the PTT (platform terminal transmitter, similar to the one inside PSATs) affixed to a leatherback turtle in the Virgin Islands

probably because it was attracted to the electrical field emitted by the PTT. We intend to test this experimentally with captive sharks (see below).

iii. Stock identification, dispersal, and possible fishery interactions. These, as well as critical pupping areas and possible genetic structuring in blue shark, will be elucidated by the examination of dispersal patterns (Hays, 1992; Avise, 1994; Lutcavage et al., 1999). In addition, knowledge of the movement patterns of cohorts tagged near the Hawaiian Islands will help elucidate the overall stock composition in the Pacific, and the relationship of fish caught here to those caught elsewhere. That is, are blue shark caught near Hawaii part of a larger ocean-wide population or could they be considered a separate group for management and conservation purposes?

Horizontal dispersal patterns, estimated from light-based geolocation techniques for 16 blue sharks, indicated some clear patterns. For example, most sharks tagged in April 2001 and 2002 north of Hawaii, proceeded to go south for a couple of months and then turned back northwards which fits with Nakano's general distribution and migration model. Before these Kalman filtered data are further scrutinized, it is evident that researchers will need an estimate of geolocation errors provided by light-based techniques (from moving objects) before strong conclusions can be drawn. To elucidate these errors, program personnel have designed additional experiments to document the extent and possible nature of geolocation errors from moving objects as described below.

2. Progress during FY 2003. Provide a thorough discussion of accomplishments and problems.

In addition to the blue shark data outlined above, the project personnel will also be responsible for the following PSAT data, and associated analyses and preparation of reports and articles. For these data, the project is requesting a half-salary for the senior PI for FY 2004.

Swordfish
In 2001, 8 swordfish were tagged with 4 of the tags reporting 156 days of data in-aggregate. For 2002 deployments, 17 fish were tagged with 5 tags reporting 371 days of data in-aggregate. Three swordfish were tagged in 2003 with pop-off dates expected in mid-May.

Oceanic white-tip sharks
Two of three white-tip sharks (all female) tagged in 2001 & 2002 reported their data representing 183 days in-aggregate. Another five sharks tagged in 2002 & 2003 have not reached their pop-off dates.

Bigeye thresher sharks
In 2002, 2 of 6 tagged bigeye thresher sharks reported their data on time which represents about 500 days worth of data. Another shark tagged in 2003 is not scheduled to reach it's pop-off date until June.

Other species
Data from 4 silky sharks, 3 yellowfin tuna and 3 bigeye tuna are expected in August 2003. None of 3 tagged male shortfin mako sharks reported their data.

In this relatively nascent field, it is apparent that the "Achilles heel" of this technology may be the PSAT attachment and/or anchor methodology and the magnitude of geolocation errors from light-based techniques (described below). PSATs, whether affixed to sharks, billfish or tunas, all exhibit a common phenomenon of tag shedding. For sharks, our harness system appears to be work well in the short-term but certain behaviors, such as nuptial biting, may compromise this system. Still, were are experiencing some long term deployments in 7 sharks (~8% of all deployments >8 months). Indeed, it remains an open question as to why PSATs are shed by a variety of different pelagic species with different anchoring techniques. History may prove that researchers are experiencing a random distribution of deployment times and that a "magic bullet" anchoring system may never be devised that accomplishes 100% success.

Of the 87 PSATs scheduled to report to date, we have received data from 39 devices (45% overall reporting rate). In aggregate, we have 527, 279, 119, and 2582 days of observation from swordfish, marlins, tunas and sharks, respectively. There have been, however, species, year, and sex related differences in reporting rates. Of 22 male sharks tagged, only 23% of PSATs have reported. Whereas of the 22 PSATs deployed on female sharks, 72% have reported. This difference appears to occur in blue, mako, oceanic white-tip, and bigeye thresher sharks. As mentioned for blue shark, rates of survival of sharks following release from longline gear appears excellent. We have only one clearly confirmed mortality. Of the 8 swordfish tagged in 2001, 50% of the PSATs reported but of the 17 PSATs deployed in 2002, only 29% (5 tags) reported.

It is obvious that PSATs have provided excellent data on vertical movement patterns. For example, swordfish have been shown to exhibit diel vertical movement patterns, where they are shallow at night (< ca. 150 m) but descent to 600-800m during the day. Bigeye thresher sharks, bigeye tuna, and blue sharks show similar patterns. These behaviors, however, have prevented the on-board software in some cases from providing daily light-based geolocation estimates (i.e. the depth distributions sometimes exceed the limitations of the light sensor and deployments during the Equinox confound the algorithm). For example, of 1015 days (in aggregate) where PSATs remain attached to swordfish and bigeye thresher sharks, we received only 44 daily estimates (4%) of light-based geolocations. For blue shark, of 1841 days in aggregate for 16 sharks, we were only able to derive geolocations for 396 days (22% of the total). From these results it seems highly unlikely that PSATs will be useful for deriving light-based geolocation patterns in relation to mesoscale satellite derived oceanography for these species.

3. Plans for the next fiscal year.

In FY 2003, project personnel will continue to analyze data outlined above and other activities will consist of preparing draft manuscripts and disseminating preliminary findings to various venues such as those provided by scientific conferences and through the popular press.

In other related matters, personnel will work closely with Dr J.R. Sibert of University of Hawaii/PFRP and A. Nielsen of University of Copenhagen to process horizontal movement data through their implementation of the state space Kalman filter (Sibert et al. 2003). The Kalman filter will be used to estimate geolocation errors, movement parameters and most probable tracks. Because of the likely magnitude of light-based geolocation errors (e.g. see Musyl et al. 2001; Sibert et al. 2003), association of movement patterns (when available) to oceanographic parameters will be undertaken - *at the appropriate scale* - to look for correlation. For this task, project personnel have arranged with Keith Bigelow of NMFS-Honlab and A. Nielsen to perform the analyses.

Next, to gain insights into light-based geolocation errors from moving objects, project personnel have attached six PSATs on oceanographic drifter buoys equipped with GPS units. It is anticipated that this information will aid in the further development of the Kalman filter as applied to movement models based on light-based geolocation methods. Data from these deployments are expected in mid May 2003. Personnel have also arranged with Dr Kim Holland of the University of Hawaii/HIMB to test captive sharks' response to electrical fields emitted by PSATs and PTTs. These experiments are designed to ascertain whether sharks are attracted to electrical fields produced by PSATs and PTTs which may account for some tag failures, especially during mating when nuptial biting behavior is enhanced. Lastly, project personnel have worked closely with Hans Malte and Christina Larsen of the Zoophysiology Department, University of Aarhus, Denmark in developing mathematical models of physiological behavior and thermodynamics from archival and PSAT data.

4. List of papers published in refereed journals during FY 2003.

Musyl, MK, RW Brill, CH Boggs, DS Curran, MP Seki and TK Kazama. 2003. Vertical movements of bigeye tuna (*Thunnus obesus*) associated with islands, buoys, and seamounts of the Hawaiian Archipelago from archival tagging data. *Fisheries Oceanography* **12, 152-169.**

Sibert, JR, MK Musyl and RW Brill. 2003. Horizontal movements of bigeye tuna near Hawaii as determined using archival tags. *Fisheries Oceanography* **12, 141-152.**

5. Other papers, technical reports, meeting presentations, etc.

Malte, H., C. Larsen, M.K. Musyl, and R.W. Brill. Differential heating and cooling rates in bigeye tuna (*Thunnus obesus*); a model of non-steady state heat exchange. *American Journal of Physiology*. (to be submitted in 2003)

6. Names of students graduating with MS or Ph.D. degrees during FY 2001. Include title of thesis or dissertation.

None

7. For multi-year projects, provide budget for the next year on a separate page.