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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

Funding Agency: NOAA/NMFS

Project Purpose 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 to 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 indices in the Pacific.
Of 14 blue sharks (120-204 cm FL, 3 males, 11 females) captured from longlines and tagged with PSATs in FY2001, data from 10 of those deployments have been transmitted via ARGOS satellites. These represent in aggregate 731 days at liberty. Deployments ranged from 1 to 238 days with a mean of 73 days ∀ 72 (SD). A PSAT affixed to a female oceanic white-tip tagged in 2001 has also reported after 169 days. One PSAT tagged blue shark clearly represented a mortality. In all cases, however, transmissions were initiated before the pre-programmed pop-up date. We are expecting one additional PSAT (affixed to a female blue) programmed to release after 13 months and to transmit it's data on or about 5 June 2002.

In brief, the vertical data show that blue sharks exhibit typical pelagic fish "W-shaped" vertical movement patterns during the day, traversing from near the surface to well below the uniformed temperature layer and reaching maximum depths of around 400 m. Nighttime movements are almost exclusively contained within the uniform surface layer. In summary, 90% of movements were contained at depths less than 220 m at temperatures between 11-25EC. About 75% of all movements were found between 20-25EC temperature bounds. Although our current sample size and composition (2 males:8 females) does not have an undisputed impact, nonetheless, we observed a possible sex specific diving pattern. Males and females exhibited different depth distribution patterns as identified with Kolmogoriv-Smirnov tests. 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 behaviour or represents other temporal or spatial phenomenon. Further samples (10 males and 7 females) from tagging operations in 2002 will even out sex ratios and increase the sample size allowing us to investigate these possibilities.

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 blue sharks in tagging operations conducted in March/April of 2001 and 2002, we believe this spawning behaviour may be a possible route of tags getting to the surface early before their pop-off dates. Ten 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 vacinity and that the tag was liberated as a consequence.

Further, it appears that 3 of the deployments (2 females) represent instances where the tag failed to transmit data. A logical extension is to hypothesize that spawning behaviour (i.e nuptial bites) 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 electrosensory 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 7 blue sharks, represented of mixture of movements. No clear directed movement patterns were evident. Four of the sharks constrained their movements near the main Hawaiian Islands while only about two exhibited possible latitudinal movements. Before these data are further scrutinized however, 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 this end, it would also be premature to link these movement data with oceanographic data because of the likely differences in the resolution of temporal and spatial scales.

To elucidate these errors, 6 double-tagging experiments (i.e. pairing a PTT [which give ARGOS positions based on Doppler shift] on the same carapace with PSATs) on leatherback turtles apparently all failed but the mode of failure was unclear. Clearly the PSATs did not transmit data and it has been suggested that the close proximity of the PTT and PSAT to one another may have caused interference, thus disrupting the internal clock and programming of the PSAT. Land based experiments testing this relationship did not produce the same result and further tests in seawater are underway. Lastly, program personnel have designed additional experiments to document the extent and possible nature of geolocation errors from moving objects as described below.

Project Activities and Progress During FY 2002: During an April 2002 cruise of the NOAA RV *Townsend Cromwell*, project personnel PSAT- tagged a total of 17 blue sharks (120-196 cm FL), 6 bigeye thresher sharks, 3 longfin mako sharks, 2 oceanic white-tip sharks (2 females, 107-200 cm FL) and one bigeye tuna captured from longlines. The operational areas centered around 28-31E N, 157-161EW (16 blue sharks sharks, 10 males and 6 females; 17 swordfish) and near Kona, Hawaii (18EN, 158EW) where six bigeye thresher sharks and one 150 lb. bigeye tuna were tagged. Longfin mako sharks (3 males, 118-190 cm FL) were caught between 158-161EW but at three diffeent latitudes (i.e. 19, 26, and 31 EN). Most of the female blue sharks sharks tagged up North showed evidence of "nuptial bites" (indicating mating). This may represent a possible route of tag loss which has been described elsewhere. As identified with attached temperature-depth recorders (TDRs), five hook Hawaiian-style longline baskets (i.e. green chemical light sticks, circle hooks baited with squid) fished at depths < 80 m. Longlines were usually deployed after dusk and were retrieved at first light (i.e. about 8-12 hrs. soak time).

In this relatively nascent field, it is apparent that the "Achilles heel" of this technology may be the PSAT attachment 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 behaviours, such as nuptial biting, may compromise this system. Still, we are experiencing some long term deployments. 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. Data delays in getting transcribed data from the PSAT manufacturer is another area that needs further attention and we are

working with Microwave Technology to streamline this procedure.

Planned Project Activities for FY 2003: In the last year of the project (FY 2003), project personnel will continue to analyze transcribed and collated data provided by the PSAT manufacturer. It is anticipated that downloaded data from an additional 17 PSAT tagged blue sharks, 6 bigeye thresher sharks, 3 longfin makos, and 2 oceanic white-tips from year two tagging activities will be available in December/January 2002-03 (their scheduled pop-off dates) if these individuals survive long term and/or if the tags stay attached. Given our preliminary results, however, it is possible that these PSATs could start data transmissions before their pop-off dates.

In other related matters, personnel will work closely with Dr J.R. Sibert of University of Hawaii/PFRP to process horizontal movement data through his implementation of the state space Kalman filter (Sibert et al. 2002). 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. 2002), association of movement patterns to oceanographic parameters will be undertaken on a Abroad scale@. This information could possibly be later refined if there is close agreement with archival data and surrounding temperature/depth profiles as those contained in the Java Ocean Atlas (See http://odf.ucsd.edu/joa). Before this is initiated in earnest however, an overall estimate of the geolocation errors would be required from double-tagging experiments (see below).

Next, to gain insights into light-based geolocation errors from moving objects, project personnel have arranged to attach six PSATs on oceanographic drifter buoys equipped with GPS units. It is anticipated that this information will also aid in the further development of the Kalman filter as applied to movement models based on light-based geolocation methods. 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 intend to work 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. For this particular aspect, we are requesting an additional $5.6 K in the budget (under AComputer software and hardware@) as Aseed money@ to initiate this collaboration. Other funds are to cover ARGOS satellite time, travel to meetings, publication/library costs and one-half salary for PI Musyl.

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.

Papers Published in Journals During FY 2001:

Musyl *et al*. 2001, Ability of archival tags to provide estimates of geographical position based on light intensity. In Electronic Tagging and Tracking in Marine Fisheries Reviews: Methods and Technologies in Fish Biology and Fisheries, J. Sibert and J. Neilsen (eds.). Dordrecht, The Netherlands, Kluwer Press, pp. 343-368 .

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

Sibert, JR, MK Musyl and RW Brill. In press. Horizontal movements of bigeye tuna near Hawaii as determined using archival tags. *Fisheries Oceanography*

Other Papers, Reports, and Presentations During FY 2002:

Swimmer, Y, R Brill, and M Musyl 2002 Quantifying sea turtle mortality with PSATs. *PFRP Newsletter*, 7, 2, 1-5.

Musyl, M (with C. Anderson) 2001 Blue shark study nets early results. *PFRP Newsletter*, 6,3, 13-14.

May 2001 – 52nd Annual tuna Conf. Lake Arrowhead
Brill, RW, MK Musyl, CH Boggs, DS Curran, MP Seki and TK Kazama
Horizontal and vertical movements of bigeye tuna (*Thunnus obesus*) near the main Hawaiian Islands determined using archival tags

December 2001 - PFRP talks in Honolulu:
MK Musyl, RW Brill and CH Boggs
PSATs to chronicle the survival and movements of blue shark, swordfish and yellowfin tuna following release of longline gear

January 2002 – 3rd Meeting of the Interim Scientific Committee for Tuna and tuna-like species in the North Pacific Ocean (ISC):
M Musyl, R Brill, C Boggs and K Bigelow
Initial results from pop-up satellite archival transmitter (PSAT) attachments to swordfish in Hawaii

February 2002 – AGU meeting:
MK Musyl, RW Brill, CH Boggs, DS Curran, MP Seki and TK Kazama
Vertical movements of bigeye tuna (*Thunnus obesus*) associated with islands, buoys, and seamounts of the Hawaiian Archipelago from archival tagging data

Graduating Students with M.S. or Ph.D. Degrees During FY 2002: None.

BUDGET

Item	**PFRP funds Year 3 (03)**
Argos satellite time and data processing	$10.0K
Travel to scientific meetings	$4.0K
Computer software and hardware	$7.0K
Publication and Library costs	$2.0K
subtotal	$21.0K
overhead (25 % of subtotal)	$5.3K
Salary for co-PI Musyl (2 time)	$36.0K
Fringe benefits (26% of salary)	$9.4K
Total	**$74.0K**