JIMAR, PFRP ANNUAL PROGRESS REPORT
FY 2004

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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

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 still need to be 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 11E and 25EC. About 75% of all movements were found between 20E and 25EC. 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 mating behavior may be a possible route of tags being shedbefore their pop-off dates. ElevenPSATs were released from the fish before their sheduled popoff dates.. 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.

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, moved south for several months and then turned back northwards. These observations fit Strausberg and 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 analysed data from double-tagging experiments to document the extent and possible nature of geolocation errors from PSATSs affixed to GPS drifter bouys.

2. Progress during FY 2004. 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 senior PI (Musyl) for FY 2005.

To date we have deployed 128 pop-up satellite archival tags (PSATs) on 28 swordfish, 38 marlin (36 blue, 1 black, 1 stripped - see Musyl, Moyes, Brill and West PFRP project), 7 tunas (4 bigeye & 3 yellowfin), 55 sharks (7 bigeye thresher, 32 blue, 8 oceanic white-tip, 4 short fin mako & 4 silky sharks) in the central north Pacific Ocean. The objectives of the project are to determine horizontal and vertical movement patterns, and rates of survival following release from longline and recreational trolling gear. In a companion study, led by colleague Chris Moyes at Queens University, we are trying to quantify rates of morbidity and mortality in pelagic sharks and billfishes using a suite of biochemical assays to determine levels of stress from blood andtissue samples (see related PFRP projects by Moyes et al. and Musyl et al.). We thus hope to develop cost-effective biochemical techniques capable of predicting the chances of long-term survival in released fish.

PSATs were either directly harpooned with nylon or metal tag heads (swordfish, tunas, marlins, and bigeye thresher sharks), or placed through the dorsal fin (other sharks) with a stainless steel cable harness. PSATs were programmed to release 1,2 4,8, and 12 months following deployment. Early detachment is a continual problem. However, our new tether system with stainless steel ball-bearing swivels and arrowhead design augmented with spear gun flopper blades (to promote greater resistance) appears to be working well and numerous colleagues have

requested the design and materials. Tag head improvement is an ongoing project and recently project personnel have collaborated with Eric Prince(NOAA Fisheries, Southeast Fisheries Science Center) in this endeavor.

Overall, 43% of the deployed PSATs have failed to report. Eleven percent have reported on schedule after reaching their "pop-off" date. In aggregate we have 527, 2138, 119, and 3706 days of observations from swordfish, marlins, tunas and sharks, respectively (6490 total days or almost 20 yrs.). There have, however, been sex and species related differences in PSAT reporting rates. For example, of 25 male sharks tagged, only 48% of PSATs have reported. Whereas of the 23 PSATs deployed on female sharks, 74% have reported. This difference appears to occur in blue, mako, oceanic white tip, and silky sharks (*nb*: as bigeye thresher sharks were tagged in the water, sex was not determined). And deep diving species such as swordfish (32%) and bigeye thresher sharks (29%) similarly exhibited low PSAT reporting rates. We hypothesize that tag failure/damage may be caused by nuptial bites and deep oscillatory diving which may ultimately weaken and compromise PSAT housings and seals over time.

Rates of survival of sharks following release from longline gear, however, appears excellent. We have only one clearly confirmed mortality out of 29 tags reporting data from sharks (97% survival rate). Vertical data from one blue marlin tag clearly indicate the fish sank and died approximately 4 months release. The depth data indicate movements were relatively normal until 113 days after tagging. There were no indications in the vertical data prior this apparent mortality that of abnormal behavior. We are confident that this case represents a mortality because the PSATworked as designed to detect a mortality (i.e., tag reached a "fail-safe" pressure release depth of around 1136 mmjettisoned, to surfaced, and transmitting data). This fish was captured after a 25 min. fishing bout on live bait (hooked in the mouth). As correlated by a steady rise in SST estimated by the PSAT, the fish moved due south and covered ca. 855 nmi in 113 days. Since this fish apparently died about 4 months after the initial insult (catch-tag-release), we suggest that it would be very difficult to attribute this mortality to the initial insult, and that other factors (e.g., predation, disease, etc.) could have intervened.

Of the 28 swordfish tagged, only 9 have reported data (32%) with no indications of mortality. PSATs have provided excellent data on vertical movements patterns. Swordfish have been shown to exhibit an oscillatory diel vertical movement pattern, where they are shallow at night (< −80 meters), but descend to −80 - 1000 meters during the day. Bigeye thresher shark, bigeye tuna (and occasionally blue and shortfin mako sharks) show similar patterns whereas marlin, silky shark and oceanic white-tips spend the majority of time (day and night) in the uniform surface layer. Extensive vertical movements, particularly at crepuscular times, have prevented the PSATs' light sensors from acquiring sufficient ambient light data to calculate geolocations. Of the 1015 days (in aggregate) where PSATs remained attached to swordfish and bigeye thresher sharks, we received only 44 estimates of daily geolocations. It appears that extant light-based geolocation methodologies can be severely confounded by exceeding the limits of the light sensor. Therefore, only some pelagic species will be ideal candidates for this technology. Light-based geolocation data, along with empirical data from mooring line and double tagging studies suggest that it is highly unlikely that PSATs will be useful for deriving fine-scale movement patterns in relation to mesoscale oceanographic variability. However, the incorporation of SST into the Kalman filter (i.e. satellite derived SST fields are matched to SST

estimates recorded from PSATs) appears to significantly improve geolocation estimates.

3. Plans for the next fiscal year.

In FY 2004, 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. Additional PSATs provided in-kind through NMFS will be used to opportunistically tag rare and other pelagic fish and shark species.

In other project 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. With Nielsen, Bigelow, Sibert, Musyl and others, a manuscript is being prepared on results of the PSAT-GPS double tagging study incorporating SST to improve latitude estimates. Mike Laurs and colleagues at NOAA/PFEL have designed and constructed a "Live Access Server" whereby tracks estimated by the Kalman filter can be overlaid with a suite of oceanographic parameters to look for patterns and correlation in the various species.

Project personnel will also work with Dr Sibert and Johnoel Ancheta of PFRP to develop a meta database for archival and PSAT data. Archival data from a mooring line experiment (see Musyl et al. 2001.) and bigeye tuna (Musyl et al. 2003., Sibert, et al. 2003) will officially launch the project. PSAT data from this and other PFRP studies will be added to the database after publication.

To further investigate PSAT reporting rates and possible explanatory factors, project personnel has organized the construction of a meta database which will incorporate PSAT information from a number of different researchers (*i.e*. Musyl, Brill, Swimmer, Lutcavage, Wilson, *et al*.) on many different species to explore for patterns and commonalities (*e.g*. comparing serial numbers of non-reporting tags, *etc.*).

Next, personnel will try and 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, with our "team" of PSAT collaborators (Oceanographic Correlations: Mike Laurs, Dave Foley, Keith Bigelow; Data Analysis and PSAT function: Molly Lutcavage, Yonat Swimmer; Physiological Modeling: Hans Malte, Christina Larsen; Biochemical Correlates of Delayed Mortality: Chris Moyes; Kalman Filter Development: John Sibert, Anders Nielsen; Habitat Based Models and Stock Assessments: Pierre Kleiber, Keith Bigelow; Visual Capability of Pelagic Fishes: Eric Warrant, Kerstin Fritsches) we intend to explore many different avenues of investigation that may help explain vertical and horizontal movement patterns of pelagic fishes that may uncover vertical and thermal niche partitioning in the pelagic ecosystem.

4. List of papers published in refereed journals during FY 2004.

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 seamount 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.

Brill, R.W. K.A. Bigelow, M.K. Musyl, K.A. Fritsches, and E.J. Warrant. Bigeye tuna behavior and physiology... their relevance to stock assessments and fishery biology. Invited presentation at the Second World Meeting on Bigeye Tuna, Madrid, Spain. March 2004.

Brill, R.W. K.A. Bigelow, M.K. Musyl, K.A. Fritsches, and E.J. Warrant. Bigeye tuna behavior and physiology... their relevance to stock assessments and fishery biology. ICCAT SCRS Report. (submitted)

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*. (submitted).

Musyl, M., Moyes, C., Brill, R. and West, A. Predicting post-release survival in blue marlin. SSC Meetings, Honolulu, HI, 15 October 2003.

Swimmer, Y., Arauz, R., Musyl, M.., Ballestero, J., McNaughton, L., and Brill, R. 2004. Survivorship and dive behavior of olive ridley sea turtles after their release from longline fishing gear off Coasta Rica. (manuscript).

Swimmer, Y., Arauz, R., Musyl, M.., Ballestero, J., McNaughton, L., and Brill, R. 2004. Survivorship and behavior of olive ridley turtles off the coast of Costa Rica following interactions with longline fishing gear". Poster presented at the 24th Annual Symposium on Sea Turtle Conservation and Biology22 - 29 February 2004, San Jose, Costa Rica..

Swimmer, Y, Brill, R., Arauz, R., Mailloux, L., Musyl, M., Bigelow, K., Nielsen, A., Sibert, J. 2003. Survivorship and Behaviors of Sea Turtles after their release from Longline Fishing Gear. In: Proceedings of the 54th Annual Tuna Conference. Lake Arrowhead, California, May 13-16. 2003.

Manuscripts currently in preparation:
Musyl, M. and Brill, R. Post release mortality and movements in blue shark identified with PSATs .

Brill, R. and Musyl, M. Movements and habitat preferences of swordfish in the Pacific Ocean.

Bigelow, K., Musyl, M., and Poisson, F. Manuscript detailing the effects of current vectors on predicting catenary depths for over 600 longline sets instrumented with TDRs.

Nielsen, A., Bigelow, K., Sibert, J., Musyl, M. et al. Manuscript detailing results of PSAT-GPS double tagging studies with incorporation of SST into the Kalman filter.

ISC Meetings 26 January - 4 February 2004, Honolulu, Hawaii, USA

Papers:
Robert L. Humphreys, Jr., Michael Musyl and Edward E. DeMartini. SC/04/SWO-WG/02 Biological Research Conducted During 2002-2003 in Support of Swordfish Stock Assessment

Michael Musyl, Chris Moyes, Rich Brill and Andrew West. Evaluating biochemical and physiological predictors of long-term survival in released Pacific Blue Marlin tagged with PSATs. ISC Meeting, Marlin Working Group, Honolulu, Hawaii, 30 January 2004.

Talks:
Michael Musyl and Rich Brill. Results of PSAT attachments to swordfish. ISC Meeting, 29 January 2004, Honolulu, HI, USA.

Michael Musyl, Chris Moyes, Rich Brill and Andrew West. Predicting post-release survival of blue marlin. ISC Meeting, 29 January 2004, Honolulu, HI, USA.

PFRP Principal Investigators Workshop, December 9 - 11, 2003, Imin Conference Center, Asia Room (2nd floor), 1777 East-West Road, University of Hawaii at Manoa.

Yonat Swimmer, Mike Musyl, Lianne McNaughton, Anders Nielson, Richard Brill, and Randall Arauz
Sea Turtles and Longline Fisheries: Impacts and Mitigation Experiments

Christopher Moyes, Michael Musyl, Richard Brill, Queen's University, Canada & NMFS-HL
Physiological Predictors of Blue Shark Survival

Christopher Moyes, Michael Musyl, Richard Brill, Andrew West, Lianne McNaughton
Predicting Post-release Survivability in Blue Marlin using PSATs and Biochemical Assays

Michael Musyl, Richard Brill, NMFS-HL
Movements and Post-release Mortality in Oceanic Sharks tagged with PSATs

Richard Brill, Michael Musyl, NMFS-HL
Fishery Interaction and Movements of Swordfish as Determined with PSATs

JIMAR Review March 4-5, 2004, East-West Centre, Honolulu, Hawaii - Poster Session

Survivorship and Behavior of Olive Ridley Turtles off the Coast of Costa Rica Following Interactions with Longline Fishing Gear.
Yonat Swimmer, Randall Arauz, Michael Musyl, Jorge Ballestero, Linane McNaughton, and Richard Brill

Pop-up Satellite Archival Tags (PSAT) Studies of Pelagic Fisheries and Turtles in the Pacific Ocean.
Michael Musyl, Yonat Swimmer, Lianne McNaughton, Richard Brill, John Sibert, and Anders Nielsen.

Predicting Post-release Survival in Blue Sharks
Christopher Moyes, Nuno Fragoso, Michael Musyl, and Richard Brill

Predicting Post-Release Survival of Blue Marlin
Michael Musyl, Lianne McNaughton, Richard Brill, John Sibert, Anders Nielsen, and Andrew West

6. Names of students graduating with MS or Ph.D. degrees during FY 2004. Include title of thesis or dissertation.

None

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