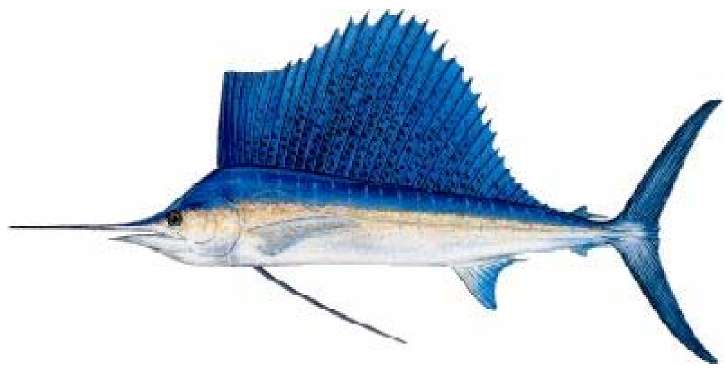
Report on Pop-up Satellite Archival Tag (PSAT) Operations, Conducted on Sailfish, *Istiophorus platypterus*, by Research Scientists of the Fisheries Research Institute, Eastern Marine Biology Research Center, and Institute of Oceanography, College of Science, National Taiwan University, 6-7 June 2007, Chengkong, Taiwan, R.O.C.



Submitted by

Michael K. Musyl, Ph.D.• Lianne M. McNaughton
Pelagic Fisheries Research Program
Joint Institute for Marine and Atmospheric Research
University of Hawaii at Manoa
Kewalo Research Facility/NOAA
1125B Ala Moana Boulevard
Honolulu, HI 96814 USA
Email: Michael.Musyl@noaa.gov
Phone: +1-808-983-3705, Fax: +1-808-983-3700

Prepared for at the request of:

Dr. Wei-Cheng Su
Director General
Fisheries Research Institute
Council of Agriculture
Executive of Yuan
199, Hou-lh Road
Keelung 20246, Taiwan, R.O.C.
•
Dr. Chi-Lu Sun
Professor
Institute of Oceanography
College of Science
National Taiwan University
No.1, Sec.4, Roosevelt Road
Taipei 106, Taiwan, R.O.C.

PREFACE AND BACKGROUND

At the request of Drs. Wei-Cheng Su, Director General, Fisheries Research Institute, Council of Agriculture and Dr. Chi-Lu Sun, Professor, Institute of Oceanography, College of Science, National Taiwan University; Dr. Michael Musyl, University of Hawaii, Pelagic Fisheries Research Programme, was invited to present two lectures at the Pacific Billfish Symposium, 4-5 June 2007, Institute of Oceanography, National Taiwan University, Taipei, Taiwan. Dr. Musyl was also asked to evaluate and assist in the Pop-up Satellite Archival Tag (PSAT) operations, conducted on sailfish, *Istiophorus platypterus*, by research scientists of the Fisheries Research Institute, Eastern Marine Biology Research Center, Chengkong, and Institute of Oceanography, College of Science, National Taiwan University, 6-7 June 2007, Chengkong, Taiwan, R.O.C. Specifically, Musyl was asked to comment on PSAT tagging procedures, different types of tagheads available, tethers, as well as data recovery and analysis procedures, including estimating most probable tracks from the raw geolocations (Musyl et al. 2001) and sea surface temperatures (SSTs) using the Kalman Filter (Sibert et al. 2003; Nielsen and Sibert 2005, Nielsen et al. 2006; for more information and to obtain *kfsst* software written in "**R**", see the following website (https://www.soest.hawaii.edu/tag-data/tracking/kfsst/).

For their generous hospitality and courtesy afforded to him during his visit, Mike was very grateful and appreciative to Drs. Su and Sun. Additionally Mike would also like to also thank Dr. Wen-Yie Chen, Chief; Dr. Wei-Chuan Chiang ("Riyar"), and scientists of the Fisheries Research Institute, Eastern Marine Biology Research Center, Chengkong, for their assistance and hospitality.

INTRODUCTION

Because pelagic fishes are so highly mobile, robust population assessments depend on a thorough understanding of both short- and long-term movement patterns. Traditionally, these data have been obtained either by analysis of catch statistics, conventional tag and release studies, or direct observation of individuals carrying ultrasonic (usually depth sensitive) transmitters. Although all three methods can be effective, each has limitations. Analysis of catch statistics to determine movement patterns requires high spatiotemporal contrast in the data and, as important, the ability to differentiate changes in abundance from changes in specific fishing gear vulnerability (Brill and Lutcavage, 2001; Musyl et al. 2003). Tag and release studies provide fish positions at release and recapture, but offer no data on daily movements. Ultrasonic telemetry can provide detailed data on vertical and horizontal movements, but the length of observation (usually no longer than 60 h) is limited by ship time, crew fatigue, or battery life of the transmitter. In contrast, recent advances in electronic data storage technology have made it possible to construct devices that allow the long-term recording (months to years) of vertical and horizontal movements of marine fishes.

Archival and pop-up satellite archival tags (PSATs) are electronic storage devices that are either surgically implanted or attached to the outside of marine animals with an anchoring device. These tags/devices record data on ambient light levels (from which daily geolocations can be calculated), swimming depth, and temperature (external and internal) and have been used to chronicle horizontal and vertical movement patterns, residence times, feeding bouts, and possible spawning areas. Information has also been used to refine indices of abundance, such as CPUE, of bigeye tuna in the Pacific (Bigelow et, al. 2002).

Unlike archival tags, which are "fishery dependent", and therefore must be physically returned to download data, one of the most compelling reasons to use PSATs is that they are "fishery independent", and therefore need not be returned to acquire stored data. Current generations of archival tags can store data from up to four sensors (e.g., internal temperature, external temperature, pressure (i.e., depth), and light intensity) taken at one minute intervals for over one year. Because PSATs are fishery independent, archived data are downloaded using the Advanced Research and Global Observation Satellite (ARGOS) system of geosynchronous satellites. Due to limitations in battery life and available bandwidth, however, PSATs do not have the data storage (and transmission) capacity as archival tags. For a comparison, PSATs can store data from three sensors (external temperature, pressure (i.e., depth), and light intensity) at one-hour intervals for approximately 244 days (8 months).

Secondly, the other important consideration is that PSAT tags can specifically identify post-release mortality (Moyes et al. 2006; Swimmer et al. 2002, 2006). However, one condition for using PSATS is that they must be able to save themselves at depth, thus indicating a mortality event. Of the two manufacturers currently producing PSAT tags, both have different philosophies to deal with such problems. One methodology is "mechanical" (Wildlife Computers - WC) and the other is "physico-chemical" (Microwave Telemetry - MT).

Regardless of which PSAT tag is used, two ''fail-safe'' options are programmed into the device. First, if an animal (e.g. shark) dies with the tag affixed, the negative buoyancy of the shark would cause the tag to sink. Once the PSAT registers a pressure corresponding to a depth of ≈ 1,200 m (for at least 15 minutes), a corrosional link on the MT tag is activated, jettisoning the tag from the shark (Fig. 1, a), allowing the tag to float to the surface, to transmit acquired data to ARGOS. By contrast, the system used to save a tag at depth for WC is different, and is comprised of a mechanical unit, similar to a guillotine. This unit is attached along the monofilament tether, which is activated ≈1500-1800 m, and severs the mono, allowing the tag to surface and download stored data (Fig. 1, b). Alternatively, both MT and WC tags employ a similar secondary "fail-safe" strategy (corrosional link), to deal with shed tags and tags that don't go beneath the threshold limit. For example, if the tag experiences no significant pressure change within a user-defined period of time (e.g. Moyes et al. 2006, Swimmer et al. 2006 – used four consecutive days in their studies), it will automatically initiate data recovery procedures. This might occur if the tag was shed, causing it to float at the surface, or if the tag was otherwise stationary at a depth less than 1,200 m (Fig. 1, c). The most important consideration using this system is that if the tag is shed, it must float to the surface, thereby providing unambiguous discrimination between a mortality and a shed tag (i.e. can tell "shed" from "dead"). Table 1 provides details about the tags.

Although archival and PSATs are valuable and welcome tools for fisheries research, an important consideration in evaluating their utility is the accuracy of the estimates of geographical positions. The use of light data (i.e., times of dawn and dusk) to estimate longitude (from local noon) and latitude (from day length) is not a new concept. However, the application of this idea to estimating geographical positions of fishes carrying archival tags can be problematic because of systematic and random errors resulting from equinoxes, light attenuation with depth, water clarity, weather patterns, accuracy of astronomical algorithms, clock errors, resolution of light sensor, and behavior of animal. Because raw, unfiltered geolocations from PSAT tags can be in error by as much as several thousand kilometers (Musyl et al. 2001; Fig. 2), a method to calculate most probable tracks and movement parameters (from raw, unfiltered geolocations) is required using a state-space Kalman filter (Sibert et al. 2003). As this methodology evolved, a newer version of the Kalman filter uses Sea Surface Temperature (SST) recordings in PSATs and compares them to those from satellites within the guts of the Kalman filter to calculate most probable tracks and movement parameters (Nielsen et al. 2006). Provided a suitable reference standard exists –and there is sufficient temporal and spatial gradient– ancillary information such as geomagnetism, ocean colour, tidal information, and temperature-at-depth, could also be used in the Kalman filter to improve geolocation estimates (Sibert et al. 2003, Nielsen et al. 2006).

EVALUATION, REVIEW AND RECOMMENDATIONS

Tagging–The overall methodology used by scientists of the Fisheries Research Institute, Eastern Marine Biology Research Center to capture, tag and then release electronically tagged sailfish, *Istiophorus platypterus* was efficient and well coordinated. From start to finish the procedure generally took ≈30-50 sec. Because sailfish were captured in stationary set nets, they did not appear to be under duress and were thus in optimal condition for tagging. As the set nets closed, the captain of the boat hauled the fish directly aboard by grabbing the snout and placing it on a sling over a wet mattress. Scientists then placed a moist chamois cloth over the fish's eyes to calm the subject while other scientists restrained the fish during the tagging procedure. A saltwater hose was placed in the subject's mouth for ventilation during the procedure. After the procedure was completed, the fish was immediately lifted with the sling and liberated. For documentary purposes, the procedure was generally filmed. Four sailfish (≈20 kg, 170 cm LJFL) were tagged on 7 June 2007. Two of the sailfish were tagged with PTT-100 PSAT tags from MT (http://microwavetelemetry.com/index.php) and two with MK-10 PSATs from WC (http://www.wildlifecomputers.com/).

Our suggestions to improve the tagging procedure would be to place a large soaked mattress (or sponge) over the body of the fish to restrain it whilst it is being tagged instead of placing hands on the animal which might cause abrasions and/or bruising to the epithelium. In addition, a conventional plastic tag should also be affixed to the base of the dorsal fin. This "double-tagging" strategy would provide information on PSAT shedding rates should a double-tagged specimen be re-captured. Lastly, for the sizes of sailfish likely captured in the set nets, the stainless steel applicator needs to be driven in ≈ 5-7 cm, so that the flopper blades of the taghead will toggle correctly.

Target area–It was noticed that some of the tag placements were probably too low from the base of the dorsal fin. In order for maximal "mechanical" resistance and therefore better retention times, the taghead should be inserted the near the base of the dorsal fin between spaces of the interneural and neural spines (Fig. 3)

Tagheads–This tagging system was specifically designed to take advantage of both biological and mechanical principles to optimize tag retention. To maximize retention times, it is recommended that the scientists use a type of taghead that increases surface area (the surgical grade nylon "flopper" taghead designed by Musyl, West, and Prince; Fig. 4, 5). Figure 5, illustrates retention rates of billfish using a variety of tagheads. The design of the taghead takes advantage of not only surface area but also "mechanical" resistance by placing it between adjacent interneural and neural spines near the base of the dorsal fin, as seen in figure 3. To assemble the flopper blades to the taghead, stainless steel rivets were used (Riffe small rivets, part no. H-3010). Because biological tissues will adhere and grow on nylon substrate, it is recommended to use this type of taghead instead of one using stainless steel or titanium. In a small study on captive tagged milkfish, *Chanos chanos,* towing model PSATs in tanks, Musyl (unpub. results), could demonstrate much longer (5x) retention times and cleaner insertion sites (no ulceration or open wounds) using nylon tagheads over metal ones. More research, particularly from a biomaterials aspect, however, is needed to determine the best combinations of material(s) and tether system.

Tether–The tether used was monofilament (to work in conjunction with the Wildlife Computers RD1800 guillotine) but the breaking strength was not known in the two MK-10 deployments. Because regular monofilament hydrates and gets brittle over time, it is suggested that the scientists use fluorocarbon line (123 kg) in the tether (as used in the PTT-100 deployments). Chaffing gear (protects monofilament) is not needed along the tether. As a caution, it is assumed that the "fully" equipped tag (with tether and taghead) will float (i.e. can tell "shed" from "dead"). Therefore, it is critical that scientists test this assumption before deployment. All crimps used to construct the tether must be stainless steel (to reduce electrolysis which might drain tags' batteries) and must match the diameter of the tether. The crimping tool must also match the size of the crimp. Figure 4 details the tether and tagheads used in the present study (except the entire taghead was made of surgical grade nylon). The length of the tether used was ≈ 16-20 cm. For comparison, Figure 6 gives an example of a harness and materials used to PSAT tag sharks.

Probably one of the most common routes for tag shedding is through continual movement of the taghead in the flesh which inflames the surrounding tissue thereby providing a site of secondary infection. Over time the surrounding tissue becomes necrotic and the taghead simply rots out. To reduce or alleviate these vitiating forces, a swivel is placed halfway along the tether to reduce torque and precession. Therefore, it is recommended to use a good quality stainless steel ball bearing swivel (Sampco, size 6, Division of Rome Specialty Co., Inc.) along the length of the tether (Fig. 4). In further attempts to keep the tag and taghead as stationary as possible, a "secondary" short monofilament tether" was wrapped around the float end of the tag and anchored to the side of the fish with a regular nylon taghead. Much more research on optimal tether and taghead design incorporating devices to reduce torque and precession, however, need to be investigated. For example, a piston-type "shock absorber" tether with a universal joint would reduce vitiating forces during episodes of burst swimming common in pelagic fishes.

In a comprehensive study of 662 PSAT deployments on 18 different marine species examining several performance criteria, Musyl et al. (unpublished results) demonstrated an overall 79% (520 tags) reporting rate. However, of those tags, only 87 (17%) hit their pre-programmed pop-off date ***indicating that most PSATs are prematurely shed.*** For completeness, it should be pointed out that the 21% (142) of PSATs that did not report data should not be confused as being synonymous with mortality. Many factors (e.g. shark predation, biofouling, faulty circuit boards, pressure breeches, etc.) might cause a non-reporting tag. By examining several factors and information about PSATs attached to vastly different pelagic species, it is anticipated that certain patterns/commonalties may emerge to help improve our understanding of attachment methodologies, selection of target species and experimental design.

Hygeine–A broad spectrum bactericide should be used in the procedure. The taghead, tether and applicator tips should be liberally bathed in Betadine solution (a 10% solution of povidone-iodine) immediately before insertion.

Choice of tagging subject–Scientists tagged specimens in ostensibly good condition. However, the sizes of the four sailfish tagged (≈20kg) is probably on the low side to accommodate the size of the tag and taghead. If possible, scientists might consider "triaging" samples so that specimens ≈ 30-35 kg are tagged. Never-the-less, tagging results from the four tagged sailfish will give us information to determine minimum size requirements. For smaller sailfish, the use of the new 40g "X-tag" from MT might be an option to using larger PSATs (Table 1).

Previous PSAT tag deployments–After examination of several documents, it was apparent that MK-10 PSATs (serial nos. 62518-05A0278, 62520-05A0280) were set to incorrect specifications in the ARGOS technical file. The correct technical file should have been set-up as follows: 31 sensors x 8 bits, A1 (decimal) processing, ALP (Auxiliary Location Plus; also called LSP, Location Service Plus, in countries outside North America), MSAT (Multi-Satellite), and tags should have 60 second reporting rates (all other satellite tags normally have 45 second reporting rates). The technical file specifies the amount and type of data, data formatting, and location services required for the tag. An incorrect specification (as in this case) will prevent recovery and salvage of data stored in the tag. In other words, data recovery is not possible in this case. However, the ARGOS data (i.e. pop-off position estimates by Doppler shift and satellite diagnostics) can be used. Check out the ARGOS website for additional details and an online manual (https://www.argos-system.org/manual/).

Choice of tags–Currently, only two manufactures make PSATs for tagging marine fish, sharks, and turtles; 1) Microwave Telemetry and 2) Wildlife Computers. Each of the tags have different strengths and weaknesses which are outlined in Table 1. The tags from WC offer user programming and data download procedures but the data are summarized as histograms (raw data are unavailable unless the tag is physically re-captured). PSATs from MT record and store raw data in time series and data recovery procedures are maximized by SiV ("Satellite in View" – PSAT broadcasts data to ARGOS satellites when they are in view instead of continuous broadcast). Users need to determine what tag will best fit their experimental design and goals of their research. Raw, unfiltered geolocations, however, from both tags need to be processed by the Kalman filter to produce most probable tracks and movement parameters.

Table 1. Features of PSAT tags currently in use. PTT-100 and X-tags from Microwave Telemetry and MK-10 tags from Wildlife Computers. Information in the table was taken from manufacturer's websites and from personal experience by the authors.

Microwave Telemetry	**Option or variable**	**Wildlife Computers**
By manufacturer	Tag Programming	By user
Remove magnet	Deployment	Activates either by computer command and/or swiping a magnet and receiving confirmation with LEDs
ARGOS – data transmission maximised by SiV (Satellite in View).	Data transmission	ARGOS No SiV feature
64Mb non-volatile	Memory	64Mb non-volatile
10,000 to 15,000+ with SiV in the X-tag	ARGOS message bandwidth	10,000
By manufacturer	Data transcription	By user
Raw time series of external temperature, pressure (depth) and a daily estimate of geolocation using changes in ambient light levels (provided by manufacturer). Temperature and depth are acquired at 15 min. to 60 min. intervals in the X-tag and PTT-100 (depends on mission time). Fine scale acquisition rates of 1-6 minutes available in the PTT-100HR (high rate) tag for up to 30 days.	Data products	Summarized histograms of external temperature, depth. Profiles of depth and temperature. User must specify a *priori* 14 temperature and depth bin dimensions plus how bins are assembled by time (e.g. 4 to 6 hr. bins appear to be common in studies although 1 hour bins can be used for short missions). Daily estimates of geolocation using changes in ambient light levels by user with supplied software.

Table 1 continued…

Microwave Telemetry	**Option or variable**	**Wildlife Computers**
-4°C to +60°, 0.176°C resolution for ARGOS data and 0.04°C resolution for archived data.	Temperature Range and Resolution	-40°C to +60°, 0.05°C resolution
0-1296m, 5.38m resolution for ARGOS data and 1.27m resolution for archived data.	Depth Range and Resolution	0-1000m, 0.5m resolution
<u>Corrosional – threshold depth</u> Corrosional link on nosecone of the tag itself, activates ≈ 1200m (for at least 15 min.), to jettison tag to initiate transmission procedures at surface. <u>Corrosional – shed tag</u> Constant pressure (user-defined period, e.g. 4 days), will jettison tag to initiate transmission procedures at surface	Pressure Release and "Fail-safe" Mechanisms to detect mortality (or how a tag saves itself from imploding at depth).	<u>Mechanical – threshold depth</u> RD1800 mechanical guillotine (Depth ≈ 1800m activates release mechanism which cuts monofilament tether and jettisons tag). <u>Corrosional – shed tag</u> Constant pressure (user-defined period, e.g. 4 days), will jettison tag to initiate transmission procedures at surface
From 40g (X-tag) to 65-68g [PTT-100]	Weight of tag (in air)	75 g, MK-10
40mm x 216mm (+ 121mm antennae) PTT-100 120mm x 32mm (+ 150mm antennae), X-tag	Dimensions	21mm x 175mm, MK-10 (length of antennae not given)
2000m (3000psi), PTT-100, 2500m (3500psi), X-tag	Pressure Rating	2000m (3000psi), MK-10
150lbs, X-tag 120 lbs, PTT-100	Pull Strength of Eyelet, which secures the tether	Not given
No	Archival Tag function if physically recovered?	Yes
$3800-4200USD (X-tag)	Cost	Not given, but probably ≈$3800 to $4000+USD – depends on options

KFSST–Because raw geolocations (i.e. latitude estimated by day length and longitude estimated by comparing local noon to Greenwich noon) produced by PSATs can be in error by several orders of magnitude (Fig. 2; Musyl et al. 2001, Sibert et al. 2003, Nielsen et al. 2006), it is necessary to compute "most probable tracks" (MPTs) from the raw, unfiltered geolocation data using the Kalman filter (Sibert et al. 2003). Further refinement of (principally) latitude estimates can be accomplished by comparing Sea Surface Temperature (SST) measurements recorded in the PSAT to those from satellites within the algorithm of the Kalman filter (Nielsen et al. 2006)[Figure 7]. Research scientists using light-based derived geolocations must use the *kfsst* software (or equivalent) written in "**R**" (https://www.soest.hawaii.edu/tag-data/tracking/kfsst/) to calculate most probable tracks and movements parameters from the raw geolocations. A new "unscented" Kalman filter (www.nielsensweb.org/ukfsst/) can also be used which streamlines the SST smoothing procedure. Contact Dr. Anders Nielsen (andersn@hawaii.edu), University of Hawaii/JIMAR for more details.

CONCLUSIONS AND FUTURE COLLABORATIONS

Research scientists of the Fisheries Research Institute, Eastern Marine Biology Research Center, Chengkong, and Institute of Oceanography, College of Science, National Taiwan University, Taipei, Taiwan are embarking on electronic tagging studies on sailfish *Istiophorus platypterus* to determine migration corridors and level of fishery interactions by examining vertical habitat utilization through space and time. It is also possible that the researchers may wish to try and refine indices of abundance (e.g. CPUE) by incorporating PSAT data into stock assessments (e.g. Bigelow et al. 2002). By utilization of a set net fishery, researchers have ample supply of sailfish specimens in which to apply tags. These samples appear to be in excellent condition. However, it was suggested that researchers might consider tagging sailfish only > ≈30 kg. They have the ability to evaluate and "triage" samples prior to tagging and should consider doing this to optimize data returned by the PSATs. Another option would be to use the smaller X-tags.

Dr. Musyl agrees that that there are substantial opportunities and common interests in which to conduct collaborative studies with his Taiwanese counterparts. He (and his colleagues at the University of Hawaii and NOAA Fisheries) will collaborate by contributing results from 2 Microwave Telemetry PSAT deployments on sailfish and combine them on a paper documenting horizontal movement patterns and vertical habitat partitioning in this species (it is anticipated that Taiwanese scientists will take senior authorship). Musyl will assist researchers by providing technical advice and calculating MPTs for sailfish tracks (from raw geolocation data) as well as providing advice in the analysis of vertical temperature and depth data. To assist him and colleagues on his studies on movement patterns of blue marlin in the Pacific, Musyl would like to request the assistance of Taiwanese researchers in the PSAT tagging of blue marlin from the harpoon fishery. Other potential collaborations include a study to examine black marlin horizontal and vertical movement patterns using PSATs.

Lastly, Musyl and his collaborator from Virginia Institute of Marine Science, Dr. Richard Brill, would like to explore the possibility of conducting various physiological experiments on live captive samples (or freshly caught ones) of pelagic fishes (swordfish, tunas, mahimahi) for cardiac function and hearing experiments. These studies are designed to investigate limitations on vertical mobility and distribution as well as testing the hypothesis that these fishes locate fish aggregating devices by the sound produced by these structures and their associated prey fauna. Species-specific depth distribution of tuna and other commercially important species may be influenced by the physiology of the heart. The potential exists that a collaborative arrangement involving students and scientists from the Fisheries Research Institute, Eastern Marine Biology Research Center, Chengkong, and Institute of Oceanography, College of Science, National Taiwan University, could be realised.

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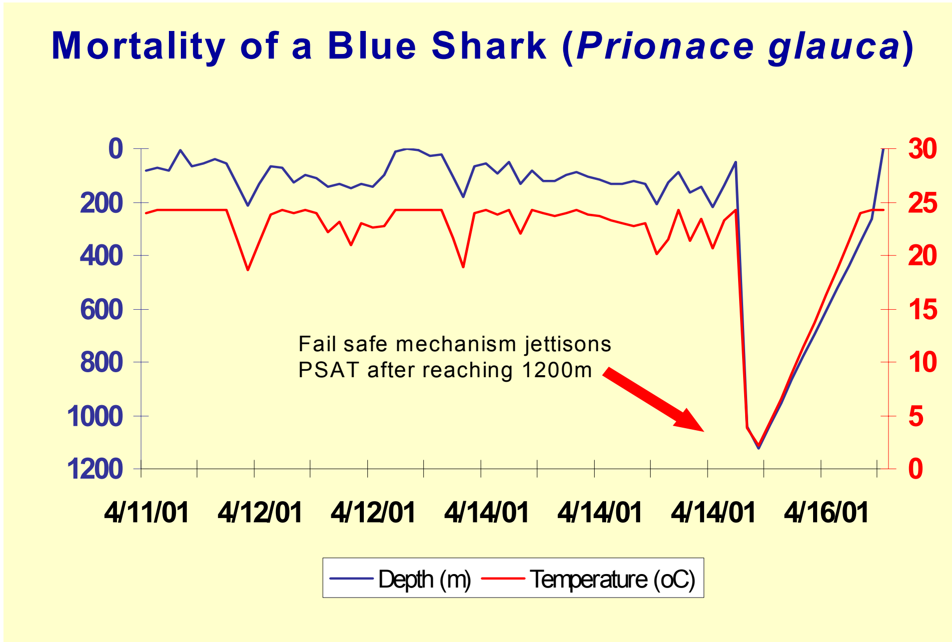

Figure 1. (a) Post-release mortality of blue shark, *Prionace glauca*, after about 5 days. This specimen was tagged using a PSAT from Microwave Telemetry. Notice how the fail-safe system works at ≈1200m to jettison tag to surface. Since the tag and tether will float (when not attached to animal), the data described in this graph represents an unequivocal representation of a mortality (Moyes et al. 2006).

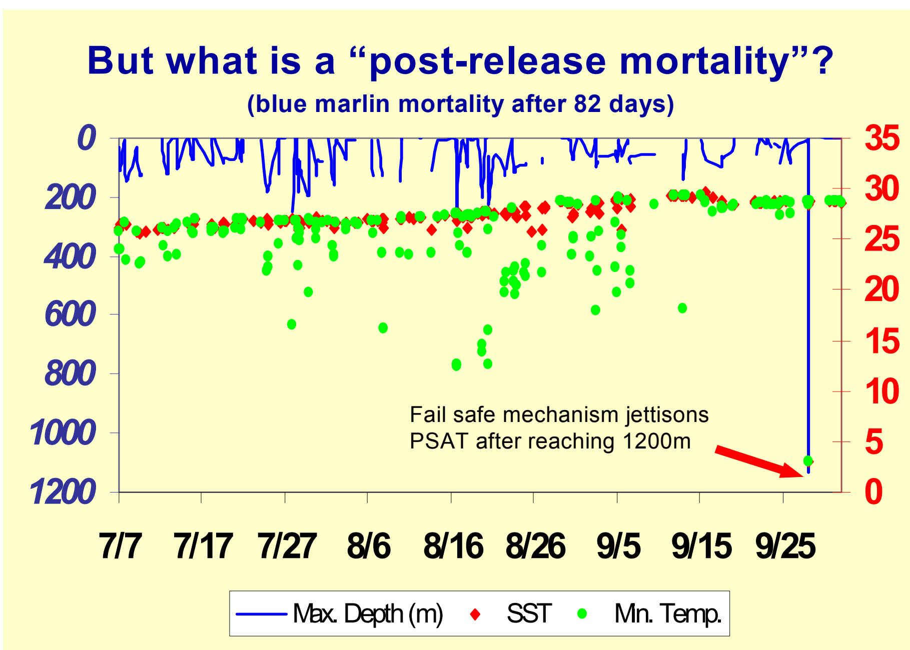

Figure 1. (b). Post-release mortality of blue marlin *Makaira nigricans,* after ≈ 3 months using Wildlife Computer’s PSAT with RD1500 release mechanism. Since the tag and tether will float (when not attached), the data described in this graph represents an unequivocal representation of a mortality.

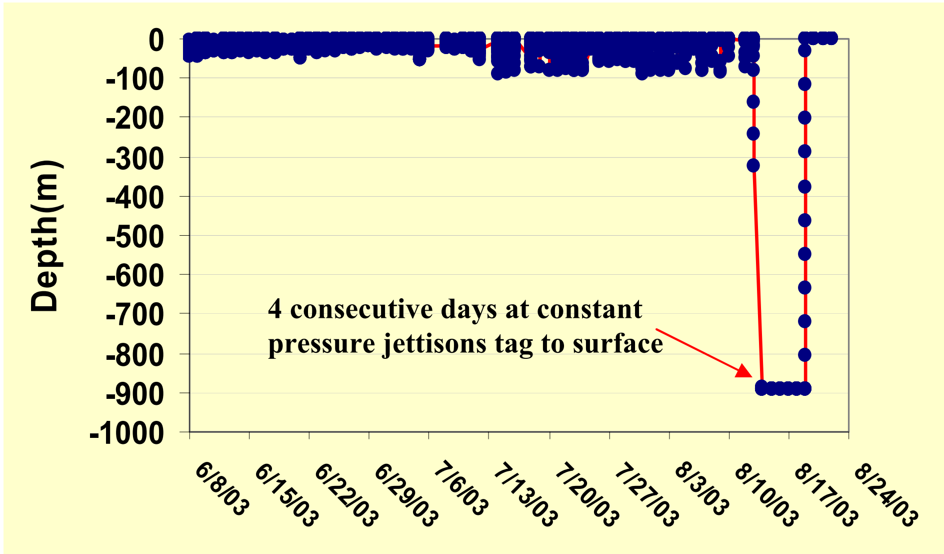

Figure 1. (c). Post-release mortality of an Olive Ridley turtle *Lepidochelys olivacea* exhibiting how the fail-safe system works on a Microwave Telemetry PSAT for an animal that perished and sank to a shelf area, but not below 1200m (to start the corrosional link). In this instance, 4 consecutive days without significant pressure recordings initiates data recovery procedures. Since the tag and tether will float (when not attached), the data described in this graph represents an unequivocal representation of a mortality (Swimmer et al. 2006).

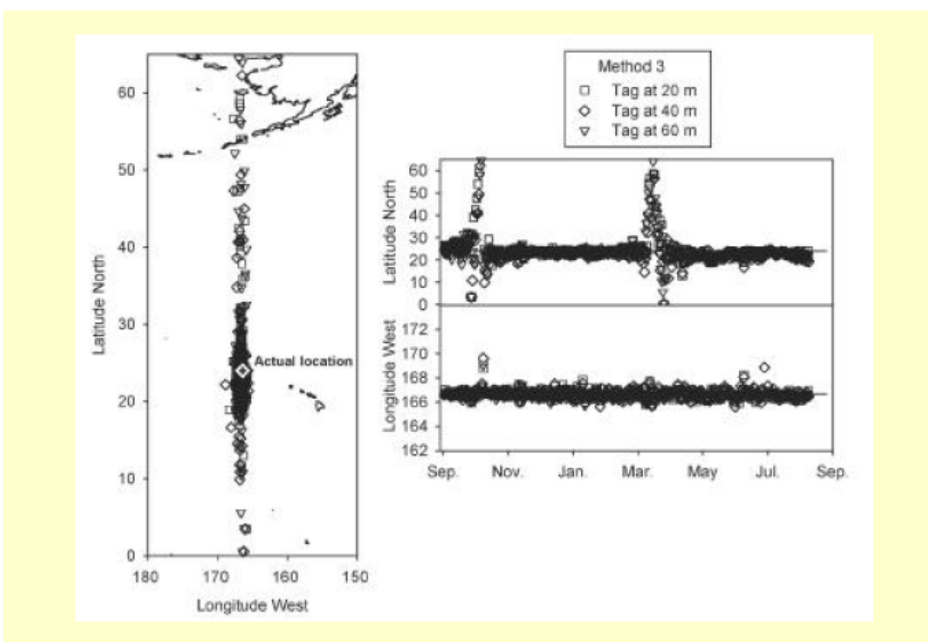

Figure 2. Raw, unfiltered light-based geolocation estimates for tag on a stationary mooring line in the Pacific Ocean. Notice that the algorithms fail completely during the Equinox (Musyl et al. 2001).

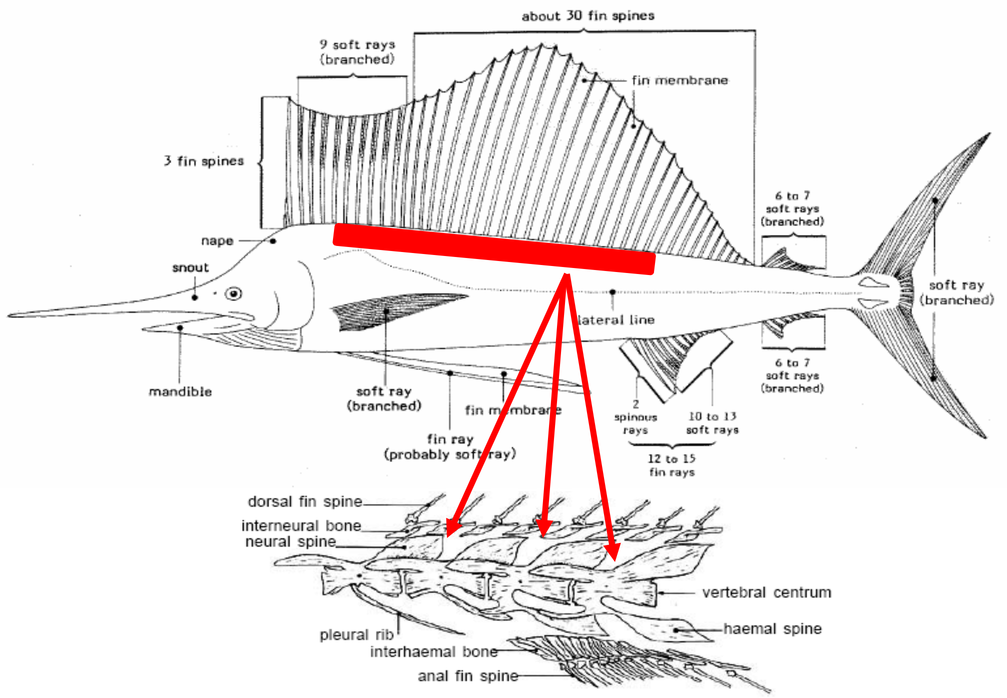

Figure 3: Optimal placement of PSAT taghead in sailfish *Istiophorus platypterus* is shown in red. The area comprises the base of the dorsal fin between spaces of the interneural and neural spines.

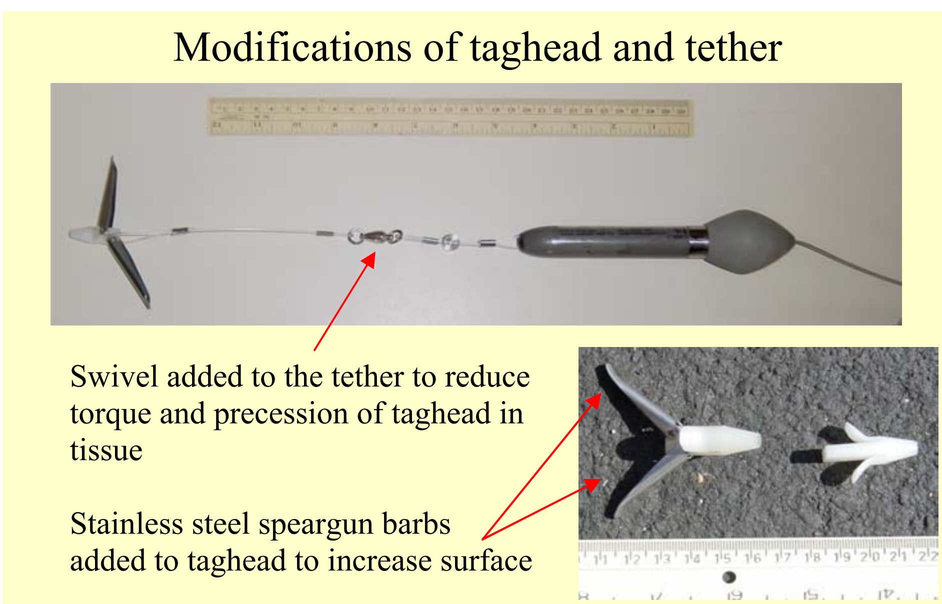

Figure 4. Tether and modified taghead for PSAT tag. Tether is made of 123kg fluorocarbon line put together by stainless steel crimps matching the diameter of the line. Stainless steel ball bearing (Sampco, no. 6) is used to reduce torque and precession of taghead and tag. Taghead is made of surgical grade nylon and stainless steel crimps.

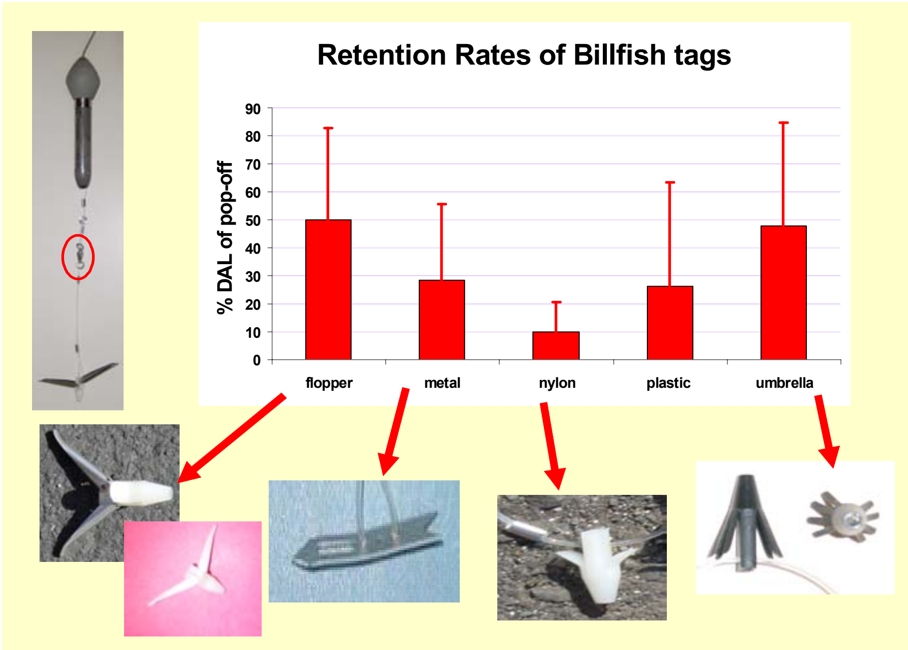

Figure 5. Shows average retention times of various tagheads used to PSAT tag billfish. DAL= "days-at-liberty". %DAL = DAL/Programmed pop-off period *100. For example, a PSAT programmed to pop-off after 100 days is prematurely shed at 50 days; ∴%DAL=50.

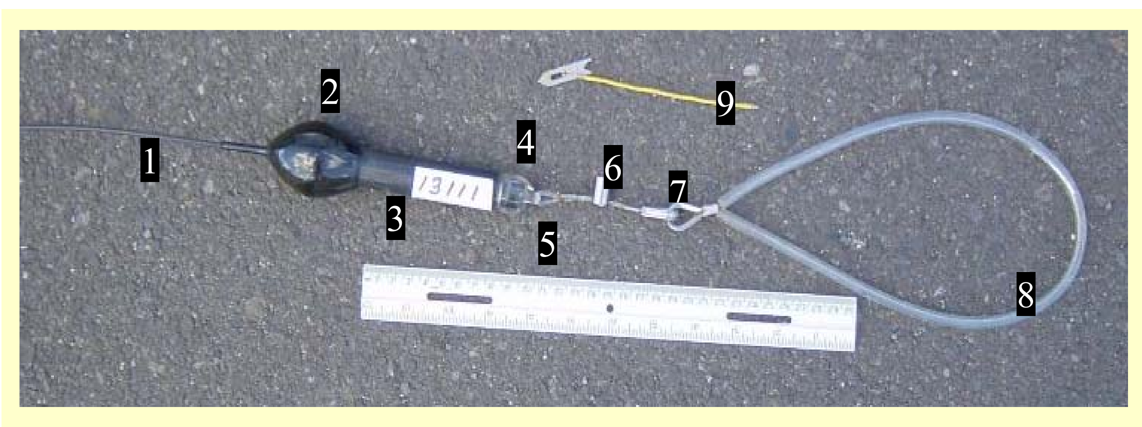

Figure 6. Harness used to PSAT tag sharks. This tag/tether was out for 41 days, with no obvious abrasions or cuts caused by dermal denticles. This PSAT was physically cut out of the dorsal fin of a blue shark by the Japanese longline crew that captured her. <u>Tag Description</u>; (1) Antennae, (2) Float with pressure sensor, (3) Tag body with thermistor, (4) Light sensor, (5) Nosecone with corrosional link, (6) RD1500 guillotine placed on 270# fluorocarbon line, (7) Stainless steel thimbles, and (8) 49 braid stainless steel wire encased in Tygon tubing. Conventional plastic tag is shown for perspective (9).

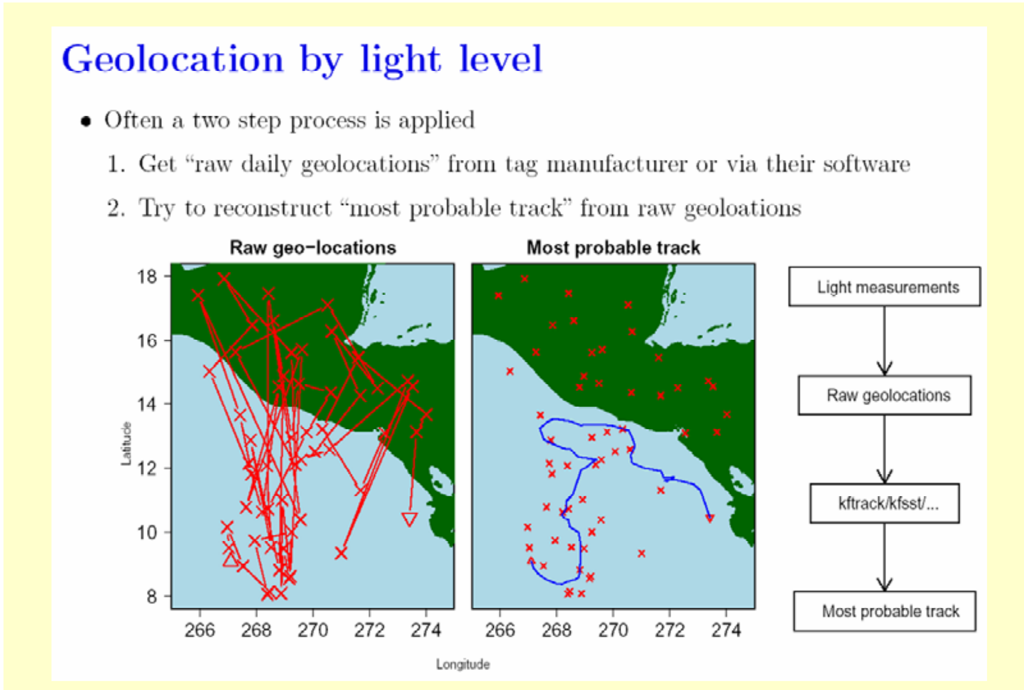

Figure 7. (a) Steps in calculating most probable tracks and movement parameters from raw, unfiltered light-based geolocations using the Kalman filter (Sibert et al. 2003; Nielsen et al. 2006).

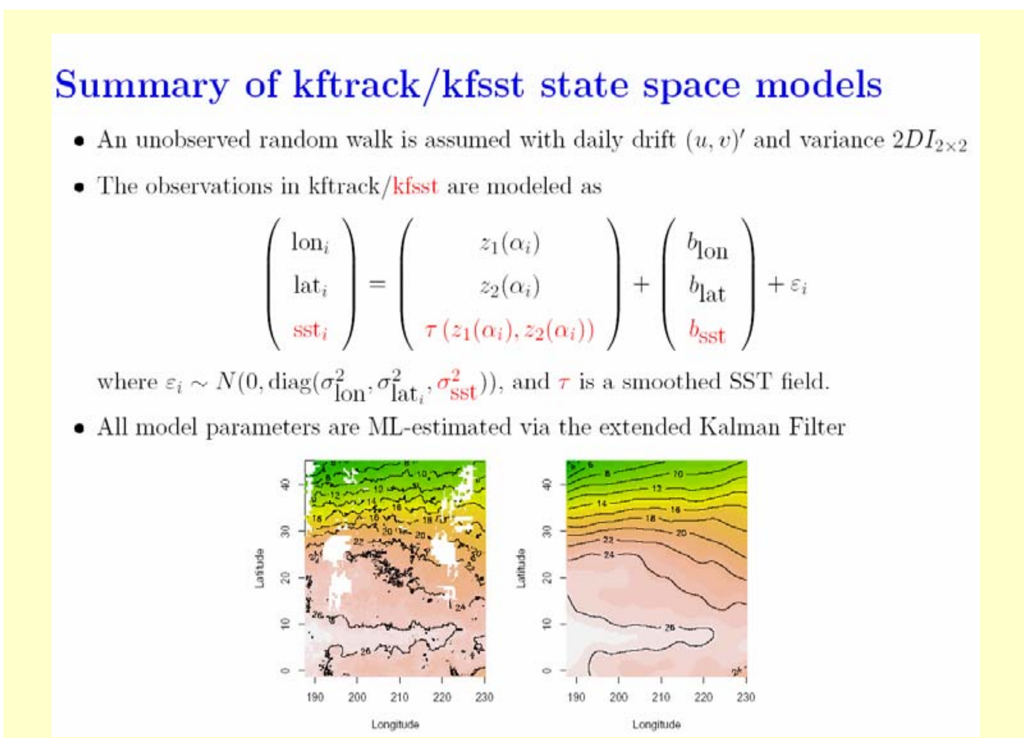

Figure 7(b) Summary of Kalman filter models and example of a smoothed SST field produced by the kfsst software (Nielsen et al. 2006).

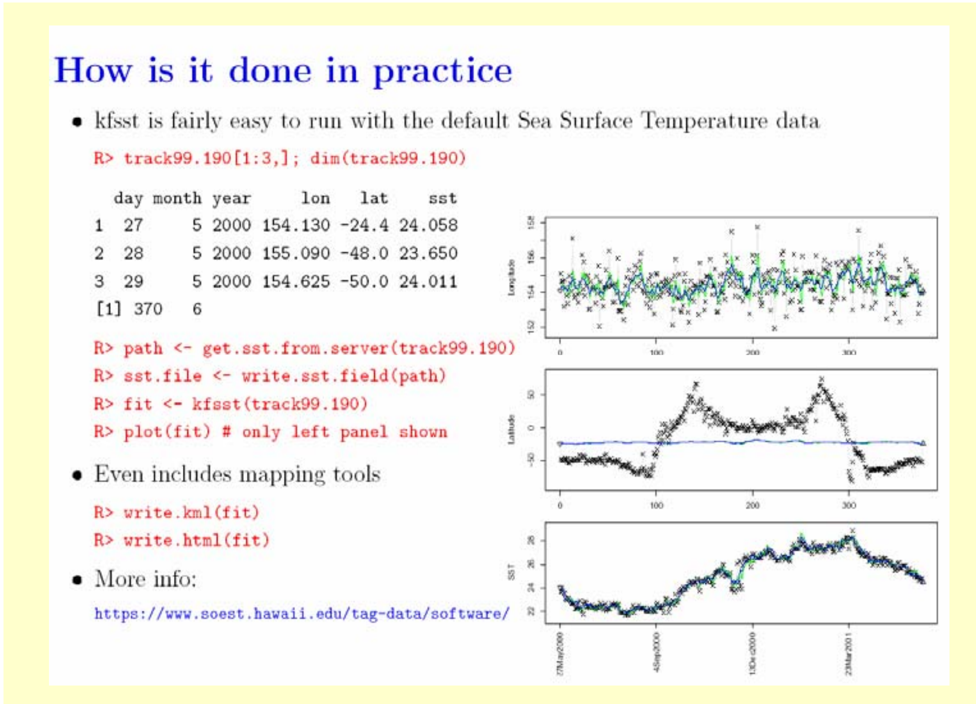

Figure 7(c) Example of Kalman filter run with sample graphic output using the kfsst package in "R".

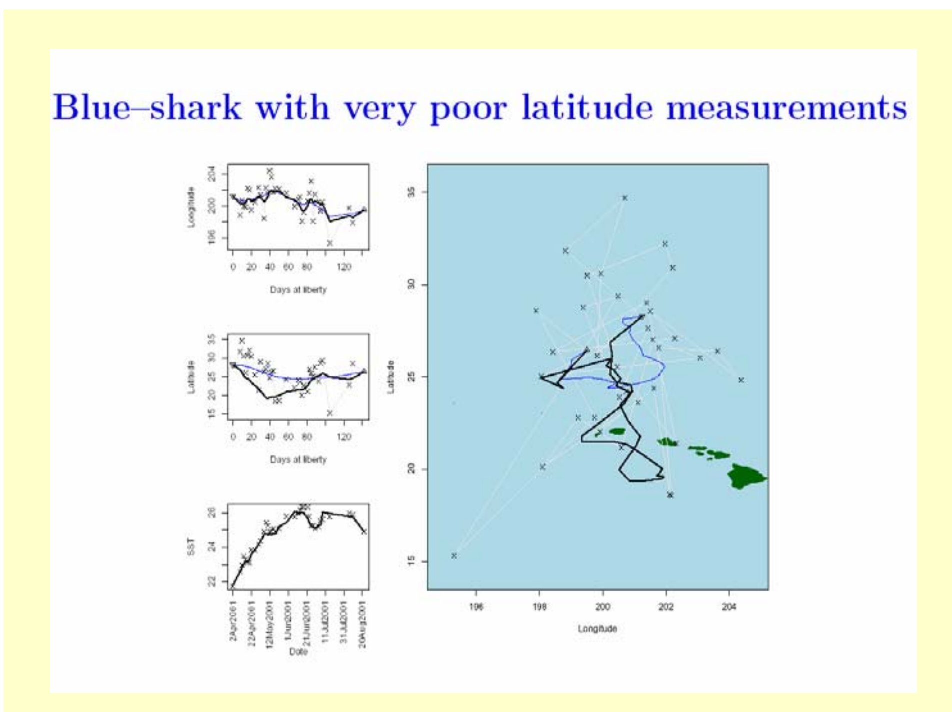

Figure (d) Kalman filter using SST for blue shark tracks. Raw geolocations are marked by "x" whilst the most probable track is given in thick black line. The track in black is an example of the Kalman filter without using SST. Notice on the lower panel that this track relies heavily on SSTs to refine the latitude estimates (Nielsen et al. 2006).