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Use of Pop-Up Satellite Archival Tags to Quantify Mortality of Marine Turtles Incidentally Captured in Longline Fishing Gear

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The incidental capture of marine turtles in longline fishing gear is generally accepted to be a significant factor contributing to the decline of sea turtle populations in both the Pacific and Atlantic Oceans (Heppell *et al.* 1999; NMFS 2001a). Pelagic stage juvenile hard-shelled turtles e.g. loggerheads *(Caretta caretta)* are generally hooked in the mouth, which presumably results from them actively biting the baited hook, whereas leatherback turtles (*Dermochelys coriacea*) are most often hooked in the flippers or become entangled in the fishing lines. While most turtles interacting with longline gear are eventually released alive, animals are often released with hooks remaining in their mouths, throats, gastrointestinal tracts, or flippers (Aguilar *et al.* 1995; Oravetz 1999). The ultimate effects of these hooks and the stress of capture are unknown. Rates of post-release mortality have not yet been adequately quantified, and available estimates remain highly controversial. Given the growth in U.S.-permitted longline fishing vessels in both the Pacific and Atlantic Oceans (Hoey 1996; Ito & Coan 1999) over the past two decades, the question of post-release mortality rates is of growing importance.

The assessment of sea turtle mortality attributed to hooking or entanglement is difficult and current estimates are based on a combination of known recorded mortality (i.e., the turtle was dead upon retrieval of the longline gear), cessation of transmissions from satellite tags (Parker *et al.* in press), and captive studies where turtles hooked on longlines were placed in tanks and observed over time (Aguilar *et al.* 1995). Needless to say, the range of mortality estimates is extremely variable (ranging from 8 – 95% for loggerheads and leatherbacks), thus rendering a reasonable overall mortality rate following interactions with longline fishing gear undefinable (Aguilar *et al.* 1995; McCracken 2000; NMFS 2001a).

Our goal is to quantify the rates of mortality and morbidity in turtles released from longline gear by using state of the art pop-up satellite archival tags (PSATs). PSATs record data on swimming depth, water temperatures, and a daily estimate of geolocation (Hill & Braun 2001; Musyl *et al.* 2001). Originally designed to track the movement of large pelagic fish (Arnold & Dewar 2001; Lutcavage *et al.* 1999), PSATs can be programmed to automatically release after durations of up to two years after deployment, thereby providing an opportunity to determine long-term movement patterns and their associated physical environments. More important, however, PSATs will likewise release and begin transmission of stored data if the turtle either dies and sinks, or the tag is shed. Unlike conventional satellite tags, PSATs therefore provide data clearly differentiating mortalities from shed tags. Depth data collected by the tags may also be used to determine extent of morbidity following release.

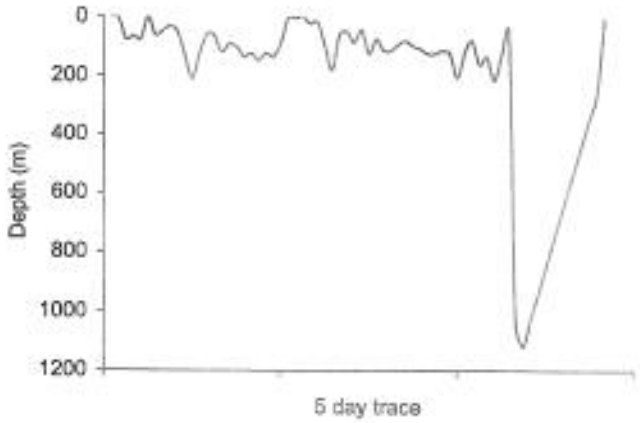

Figure 1. Depth data for a blue shark (*Prionace glauca*) tagged with a PSAT in April 2001.

Once at the surface, the tag will automatically transmit its archived data (including the pop-off location directly determined by ARGOS) to an overhead satellite. Some of the tags can conserve battery power by transmitting only when the satellite is in view (SIV). For a tag that has collected data for a year, it normally takes two to three weeks for the archived data to be downloaded.

In order to differentiate between the death of an animal and a shed tag, one can scrutinise depth data immediately prior to the tags release (and subsequent transmissions). We assume that if the tag is not released in response to a set parameter (e.g. at constant depth for 4 days, exceeds 1,500 m), and if the dive behaviour prior to the tag's transmission is considered normal behaviour, then the tag was simply shed.

In the absence of any mechanical/electronic failure or an unusual biological event (e.g., the tag is eaten by a shark), we are confident in the usefulness of PSATs for differentiating shed tags from mortality events. Our confidence is based partly on earlier success of tagging blue sharks (*Prionace glauca*). In a collaborative effort between the University of Hawaii and the National Marine Fisheries Service, 14 sharks were tagged with PSATs in the central Pacific following capture by longline gear. The tags were programmed to release at a depth (1200 m), which is well beyond the depth blue sharks would normally reach (Carey & Scharold 1990; Scarotta & Nelson 1977). The depth data record from one shark is shown in figure 1. The animal clearly exhibited normal movement patterns for the first five days following release. After this point, it succumbed presumably to injuries sustained during the interaction with longline fishing gear. This is clearly evidenced by the sinking and eventual release of the PSAT at the programmed 1,200 m. We believe similar tag programming and function will be useful to indicate mortality events in marine turtles.

Given their longevity, PSATs also provide an opportunity to determine the long-term movement patterns of turtles and their associated physical environments (i.e., to correlate data on turtle dive-depth profiles and migratory routes with information on currents, sea surface temperatures, and primary productivity collected simultaneously by orbiting satellites). Collection of long-term data will, in turn, allow for the design of time-area fishery closures that are effective at reducing rates of turtle-longline gear interactions, but that are likewise acceptable to the fishermen.

We are currently employing PSATs designed by both Microwave Telemetry, Inc. (Columbia, Maryland, USA; www.microwavetelemetry.com) and Wildlife Computers (Washington, USA; www.wildlifecomputers.com). Algorithms used to estimate geographical positions from PSAT data are currently assumed to allow accuracy of $\pm 0.5°$ longitude and $\pm 1.0°$ latitude (Musyl *et al.* 2001), but double-tagging studies (i.e., placing both conventional platform terminal transmitters [PTTs] and PSATs on the same animal) are currently underway on leatherback turtles. The resultant data should allow us to better determine, and eventually further refine, the accuracy of light-based algorithims for providing daily geopositions from moving pelagic animals.

Attachment of PSATs to hard-shelled turtles

As PSATs had never before been used on marine turtles, our first task was to design an attachment method that would be strong, long-lasting, and non-harmful to the turtles. Furthermore, the chosen method had to be easily and reliably employed, even by inexperienced fisheries observers, under very difficult field conditions associated with small (generally less then 30 m) U.S. commercial longline vessels operating on the high seas. To meet all of these requirements, we designed a base plate that could be simply glued to the turtle's carapace, to which the tether to the PSAT is attached (photos submitted to editors and available from author). As the base plate must be resistant to crushing and loss of buoyancy at depth, we decided on a syntactic foam material designed to maintain its buoyancy down to 2,500 meters. The material, manufactured by Syntech

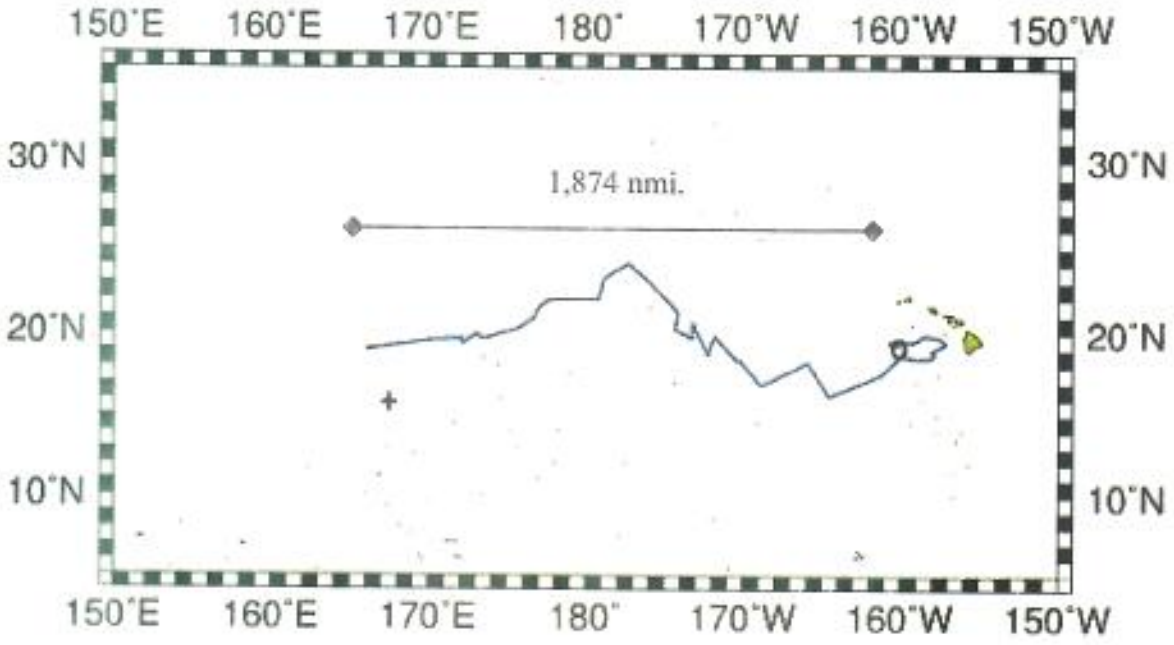

Figure 2. Preliminary daily geolocation estimates for an olive ridley turtle caught on commercial longline gear, fitted with a PSAT and released. Data generated for this graph have been analyzed using a state space Kalman filter statistical model, which was used to estimate geolocation errors, movement parameters and most probable tracks from the recovered data (Sibert *et al.* in press).

Materials, Inc.,Springfield, Virginia, USA; www.syntechmaterials.com) is relatively inexpensive and easily fabricated into any desired shape using common tools.

We did find, however, that the length of the tether was critical. It had to be long enough such that the PSAT would float with its antenna upward (to allow successful transmission to an overhead satellite) in the event that the tag was shed with the base plate attached. Using a 123 kg (270lb) test fluorocarbon line, we found the minimum tether length to be 28 cm. To attach the PSAT and base plate to the tether, we used simple stainless steel crimps (available directly from Nicopress Inc.; The National Telephone Company, Cleveland Ohio, USA; www.nicopress.thomasregister.com) and that are matched to the diameter of the fluorocarbon line.

Most important, we have found that a simple marine epoxy (Marine Fix® Fast, Eclectic Products Incorporated, Houston, Texas, USA) to be highly suitable for attachment of the base plate to the carapace of hard-shelled turtles. It is inexpensive and available at local marine supply and home improvement stores. The two parts of the epoxy are simply mixed, and are then easily spread on the flat side of the base plate. The base plate is then applied to a relatively flat portion of the carapace, and gently pressed down. The epoxy generally hardens enough within one hour (depending on ambient temperature) for the turtle to be released. Moreover, the epoxy will cure and adhere even if wet. In order to prevent the tag from sinking in the event that it is shed, the amount of epoxy used should be monitored. For example, with a 7.5cm diameter base plate, the amount of epoxy used should not exceed 165 g.) Furthermore, as the two-part epoxy needs only to be mixed in equal proportions, it is simpler to use than fiberglass resin. Our procedures and relevant observer training manual have been reviewed and approved by the NMFS Office of Protected Species.

We confirmed the suitability of this epoxy using four subadult green turtles maintained in captivity at the NOAA/NMFS Honolulu Laboratory Kewalo Research Facility. We found the dummy PSATS would remain attached for up to 9 months, but that the base plates could be removed by a firm tug on the tether. In other words, we found that the epoxy and foam base plate combination results in adequate adhesion to the carapace, yet still provides a margin of safety in that the PSAT will detach if it becomes entangled in marine debris. As important, we found no evidence of damage or obvious pathology in the area of the carapace covered by the base plate even after 9 months.

Practical Considerations PSAT Limitations

PSATs are designed to be deployed at sea by scientific observers, many of whom are likely to have little to no experience with sea turtles. Therefore, the PSAT attachment method described above is designed to provide the highest level of safety both to a turtle as well as to the person attaching the tag. There is some chance that adhesion with epoxy may allow the PSAT to detach sooner than if holes were drilled through the carapace and the tether "bolted" onto an animal. However, we prefer that the turtle have the ability to shed its tag, rather than risk it becoming trapped under a ledge or entangled in marine debris with the PSAT being so firmly attached as to prevent the turtle from freeing itself.

At present, the geolocation capabilities of PSATs are not as accurate and precise as conventional PTTs. Therefore for questions where fine-scale locations are required, PTTs are the more appropriate tool. For our purposes, however, one of the most important features of the PSAT is our resulting ability to differentiate between a shed tag from a mortality event, a situation not usually possible with conventional satellite tags, and for this, we sacrifice some fine scale geolocation resolution. Therefore, depending on the questions asked, use of a conventional tag may be preferred over a PSAT. For example, for use on marine turtles that live primarily in the neritic where fine-scale resolution of movement patterns is desired and where entrapment under ledges may be more likely than in the pelagic environment, a small conventional PTT glued to the carapace would likely be a better choice.

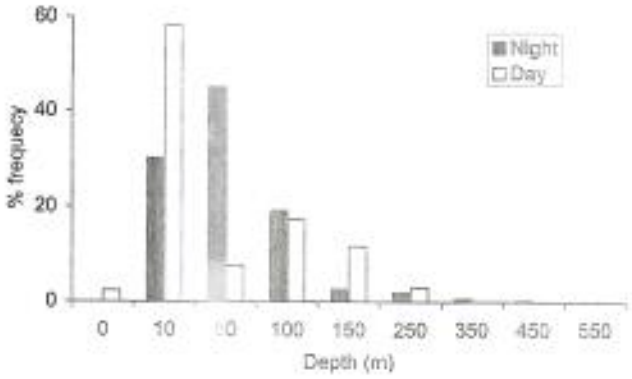

Figure 3. Histograms of time at depth (day and night) for an olive ridley turtle captured, fitted with a PSAT and released from a commercial longline vessel operating near the Hawaiian Islands.

Turtle successfully tagged at sea

On July 28, 2001, an olive ridley (*Lepidochelys olivacea*) was brought on board a Hawaii-based commercial longline vessel after being hooked in the mouth. The hook was not retrievable. The observer on board successfully applied a PSAT and released the turtle at 19° 22' N, 160° 7' W. The turtle was at liberty for 82 days before the tag was shed. During that time it traveled from 19° 22' N, 160° 7' W to 16° 1 N, 127° 30'W, indicating the turtle generally swam in a southwesterly (263°) course and covered a straight line distance of 1,874 NM (Fig. 2). (Detailed analysis of the actual daily geolocations of the turtle is still underway.) Histograms of dive-depth profiles (Fig. 3) indicate that during the day, the turtle spent nearly 60% of it's time within the surface 50m, and in general, the turtle rarely exceeded depths of 250m. During the night, the turtle remained in somewhat deeper water, spending nearly 45% of the time between 10-100m. The maximum dive depth was recorded at 544 m, with a corresponding temperature of 4° C. More important, the data indicate that the turtle was still functioning normally after 3 months, despite the presence of the longline hook.

To date, observers on Hawaii-based commercial longline vessels have taken PSATs on over 55 longline trips over the last seven months. Because of current court-ordered restrictions on gear setting practices designed to reduce turtle interactions, the turtle described above has been the only one tagged with a PSAT within our program from the Hawaii-base longline fleet.

In an effort to tag a larger number of longline-caught turtles, we therefore recently traveled to Costa Rica where there is a substantial commercial longline fleet primarily targeting dolphin fish (dorado or mahimahi, *Coryphaena hippurus*) operating off the Pacific Coast. This fleet experiences a relatively high sea turtle bycatch (primarily juvenile olive ridley turtles). In collaboration with Randall Arauz (Central American Director, Sea Turtle Restoration Project), and with the full active cooperation of the commercial longline fishermen, we were able to deploy PSATs on four long-line caught animals. The severity of injury due to hooking differed among the four turtles was varied, and will eventually be correlated with data received from the PSAT. We were also able to capture three free-swimming juvenile olive ridleys. Turtles caught while free-swimming are especially valuable as data generated by these turtles will serve as true controls with which to compare the behaviour (and possible mortalities) of the hooked animals. The PSATs deployed were programmed to release after 6 or 12 months.

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