Five Tags Applied to a Single Species in a Single Location: The Tiger Shark Experience

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Key words: tiger sharks, sonic tracking, archival tags, tag-and-recapture, home range

Abstract: Five different types of tags were used to monitor the horizontal and vertical movement patterns of tiger sharks and to document site fidelity. Sonic tracking experiments gave insight into the fine-scale movement patterns of the sharks for periods of up to 50 h whereas long-lived, acoustic pingers and automated, anchored data loggers (listening posts) provided data regarding the long-term periodicity and frequency of return of tiger sharks. These electronic recaptures were compared with the rate of traditional recaptures of sharks tagged with standard dart tags and recaptured with fishing gear. In the most recent phase of research, archiving tags capable of downloading stored data via sonic modem technology (CHAT tags) were implanted in sharks. The characteristics of data derived from these tags were compared with data acquired by active sonic tracking. A single pop-up satellite tag was provided to the shark tracking project by the manufacturer. This tag was attached with a saddle fitted around the anterior edge of the dorsal fin of a shark. Again, the active sonic tracking data were used to evaluate the veracity of the data acquired form the satellite tag. Data from these various sources are beginning to paint a consistent picture of tiger shark home range size and site fidelity in the Hawaiian archipelago.

1. INTRODUCTION

In this report we present data from five different types of tag used to determine the movement patterns of tiger sharks (*Galeocerdo cuvier*) along the southern coastline of Oahu, Hawaii. Because this report is presented within the context of a symposium on electronic tags, we intend to emphasize evaluation of the congruency of data produced by the different types of tags rather than present an extensive discussion of shark behaviour. We will discuss the contributions of the different tag types in constructing an overall picture of tiger shark movements but this research is ongoing and, consequently, the sample sizes are small for some tag types and the results are preliminary.

The impetus for this research was to acquire a better understanding of the movement patterns of tiger sharks near shorelines where there are high levels of human activity. Within this general framework, one specific goal was to evaluate whether or not fishing could cause a localized reduction in the size of a tiger shark population along a limited section of coastline. A related objective was to evaluate the possibility of catching a culprit shark after an attack (Holland et al., 1999). The feasibility of localized population reduction depends on whether the sharks are site-attached and, if so, on the typical size of the home range and the duration of site fidelity. Thus, the core question is: How often does a tiger shark return to square one? In the case of this study, square one is about 3.5 kilometers offshore of Honolulu Harbor where the sharks in this study were caught, tagged and released.

2. METHODS

Five types of tags were used in this study: 1) standard identification tags as developed by Casey and colleagues, 2) pressure sensitive acoustic tags used in active tracking, 3) long-life acoustic tags detected by submerged data loggers, 4) archiving acoustic tags that sonically download stored data to a submerged data logger, and 5) a pop-up archival tag that transmits stored data to a satellite.

2.1 Study Site and Fishing Methods

Fishing for tiger sharks was conducted along the south shore of Oahu. The entire coastline is heavily populated and the fishing area where the sharks were caught, tagged, and released is less than 5 km from the resort area of Waikiki. To capture sharks, two or three longlines were set on or near the bottom at depths of 17-75 m, about 3.5 km offshore. Each longline was fitted with 10 to 13 branch lines 10 m in length and each ending with 1.5 m of stainless steel braided leader and a 12/0 hook. These branch lines were clipped to the main line at 40-m intervals. Lines were typically baited with tuna heads provided by a local fish market, and were set around dusk and retrieved at sunrise the next morning. Soak times ranged between 8 and 13 hours.

2.2 Tag Attachment

When the mainline was retrieved, any branch lines that had caught a shark were unclipped and attached to a large float. This allowed the shark to swim freely but not escape while the rest of the gear was retrieved. The float made it possible to easily relocate the shark when the remaining gear had been retrieved and stowed. Using the branch line attached to the float, the shark was pulled alongside a 6-m skiff and a rope was placed around the caudal peduncle. This tail rope and the branch line connected to the hook in the shark's mouth allowed the shark to be restrained and rolled onto its back to induce tonic immobility (Gruber and Zlotkin, 1982; Henningsen, 1994). In this position, sharks could easily be measured, their sex determined and the tags attached or implanted. All captured sharks were tagged with identification tags but only cleanly hooked sharks >2 m total length (TL) were selected for attachment or implantation of electronic tags. Following attachment of the various types of tags, the sharks were released by removing the hook or occasionally, by cutting the leader near the hook.

Conventional external identification tags (M capsule tag, Casey and Kohler, 1992) were attached with a stainless steel barb inserted into the dorsal musculature at the base of the first dorsal fin. Contact and reward information was contained in the tag capsule.

2.3 External Acoustic Tags

External acoustic transmitters (16 mm by 75 mm, weight in water 10 g) with a nominal life-span of 3 days were attached with a stainless steel barb to the dorsal musculature at the base of the first dorsal fin (Klimley and Nelson, 1984). Only tiger sharks >2.0 m TL that were in good condition and cleanly hooked were tracked. Tracking was conducted from a 12-m vessel equipped with a directional hydrophone and acoustic receiver (Holland et al., 1983; 1990). Geographical position was determined by GPS and was automatically paired with depth data from the transmitters and stored on a computer on the tracking vessel (Holland et al., 1999).

2.4 Internal Acoustic Tags

Larger cylindrical transmitters (47 mm by 197 mm, weight in water 135 g) with a nominal life span of 8-12 months were placed intraperitoneally by inserting them through an incision in the ventral body wall while the shark was in tonic immobility alongside the skiff. The incision was sutured with nylon thread. A mixture of 3:1 paraffin to beeswax was used to thinly coat these transmitters to reduce immunological response and physical irritation.

Similarly sized transmitters of a later generation (with increased nominal life spans in excess of 18 months) were also implanted into sharks. These sharks were not actively tracked but the implanted tags could be detected by data loggers placed on the sea floor in the fishing area. That is, these transmitters were used in *passive monitoring* of whether or not the animals returned to their point of initial capture and release.

2.5 Acoustic Archival Tags

Based on our moderately high recapture rate of conventionally tagged tiger sharks and high rate of detection by the submerged data loggers of sharks implanted with long-life internal pingers, a newly developed archival acoustic tag was selected for continuation of the site-fidelity research. These tags (CHAT tags, 28.8 by 6.6 cm, nominal life-span 24 months, Vemco Ltd.) sample and store depth and water temperature data at pre-selected intervals. These data are then periodically condensed into histograms that are also of pre-selected dimensions. For this series of experiments, we selected a five-minute sample period and the data were averaged into six-hour bins. Maximum and minimum values for each six-hour period were also stored in the tag's memory.

Data stored on board the tags were sonically downloaded via acoustic modem technology to a data logger moored to the ocean floor near the normal fishing grounds where the sharks were caught and the tags implanted. Data transfer from the tag to the data logger was initiated by an exchange of recognition and identification tones between the tag and the data logger. Range tests indicated that 500 m is around the maximum effective range for data transfer. That is, data can be downloaded when the shark comes within 500 m of the data logger. The tag is programmed to download the earliest stored data first and to work forward toward the present. If contact is broken (i.e., the shark moves beyond detection range), transmission is interrupted until contact is re-established at which time data transfer recommences at the point where it was interrupted.

2.6 Data Loggers for Automated Data Collection

Data loggers were placed on the sea floor in the area where fishing and tagging were conducted. These devices continuously monitored the area in order to detect the return of sharks carrying the various types of internally implanted transmitters. The time of day and duration of contact were recorded. These data were downloaded to a computer on board the research vessel when the data loggers were retrieved by divers about every 4 to 8 weeks. Data from archival acoustic tags were recorded by data loggers modified to allow two-way (acoustic modem) communication between the tag and the data logger.

2.7 Archival Satellite Tag

One tiger shark was fitted with an archival satellite tag (Wildlife Computers Ltd.) which recorded depth and temperature information and condensed these data into histogram format for storage. This tag was externally attached to the first dorsal fin with a specially designed harness. On a pre-programmed date, an electrical current applied to a corrosible link released the tag so it could float to the surface (pop-up) and begin transmitting data to a satellite. Data were stored in pre-set depth and temperature bins and the final data were in the form of percent time spent in each bin for each four-hour time block.

3. RESULTS

3.1 Conventional Identification Tags

From May 1994 to August 1999, 133 tiger sharks were caught and tagged. Overall CPUE was 3.67 tiger sharks/100 hooks, although there were large short-term variability and some evidence of seasonal fluctuation around the mean. Seventeen individuals were recaptured (12.7%). Six of these individuals were recaptured more than once, for a total of 24 recaptures (18.0%). Average time at liberty from tagging to the first recapture was 136 days with a range of 14 to 336 days.

3.2 Active Tracking

A total of eight sharks were tracked—four with internal tags and four with tags attached to the dorsal musculature. One shark was tagged and tracked on two different occasions, resulting in a total of nine tracks ranging in duration between 7 and 50 hours (Holland et al., 1999).

Sharks tracked by acoustic telemetry showed remarkably consistent offshore movements with extended periods of straight-line swimming and movements over large distances (Figure 1). All but one of the tracks ended at

Penguin Banks (an underwater extension of Molokai'i), about 32 km away from where the tracks were started (Holland et al., 1999).

Depth data were obtained from four sharks. When in shallow water (<300 m) on the fringing reefs of Oahu and the Penguin Banks, the sharks were predominantly close to the bottom but when they moved offshore into open water they were predominantly in the mixed layer between depths of 40 and 100 m. Occasional deep movements were observed both on the outer slopes of island reefs and in open water but the open water dives were usually brief "bounce" dives. The maximum dive depth observed during active tracking was 330 m.

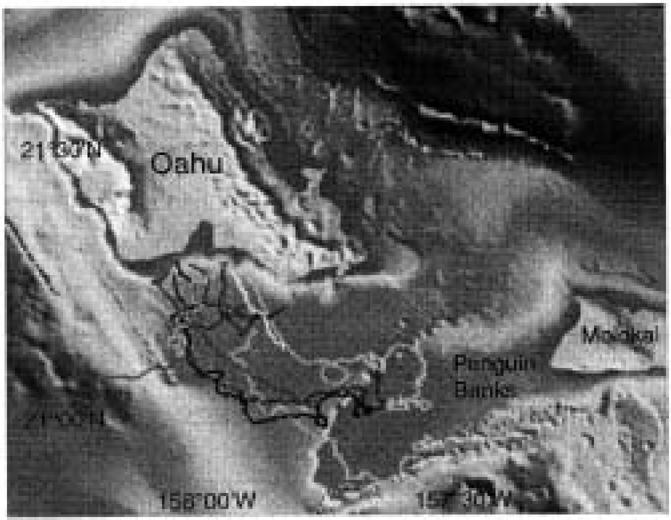

Figure 1. All nine shark tracks. All tracks started on the south shore of Oahu, and all but two ended at Penguin banks. (redrawn from Holland et al., 1999)

3.3 Internal Long-Life Pingers

Twenty sharks were implanted with long-term pingers and 10 (50%) of these were subsequently detected by data loggers in the original fishing area. Sharks were detected at all times of day, with contact durations ranging from less than 5 to 72 minutes. Figure 2 shows the duration and time of day for all detections of one shark that was a relatively frequent visitor to the site. These data are typical of all sharks that were detected in that there was no obvious rhythmicity or periodicity in the pattern of visits and they do not appear to be correlated to environmental factors such as tide or moon phase. Daytime detections were more frequent than nighttime detections. Twenty-six days elapsed between placing the tag in this shark's abdominal cavity and the first detection by the data logger.

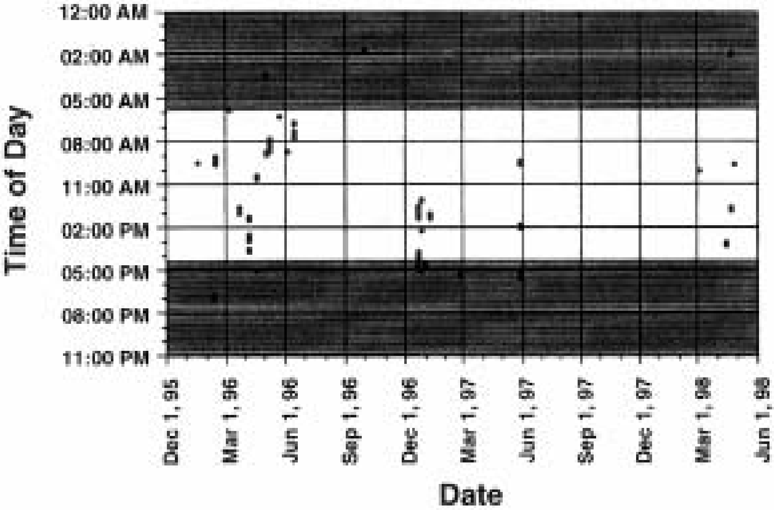

Figure 2. All detection times of a single shark with an internal pinger. Vertical height of bars indicates the duration of contact with the data logger.

3.4 Archival Acoustic Modem Tags

To date, four sharks (209-370 cm TL) have been implanted with archival acoustic modem tags, and one (25%) has been detected and successfully downloaded stored data. Time at liberty before first detection was 34 days. Three days of depth and temperature data (averaged into 6-hour bins) have been acquired to date. These data were downloaded from the shark during four separate detection events which occurred over a span of 30 days. The total contact time for these various occasions totaled 61 minutes. Depth data indicated that the shark spent most time between 30 and 80 m (Figure 3) and there were no differences between daytime and nighttime depth distributions.

3.5 Satellite Tag

An archival satellite tag was deployed on one shark (male, 180 cm TL). The tag was attached on 17 November 1999 and was programmed to release on 15 December 1999. Successful transmission of data from the tag to the satellite occurred but initial analysis of the depth data indicated that the tag came off prematurely during the night of 30 November 1999 yielding 13 days of shark movement data (temperature and depth) and 15 days of drifting at the surface. At the time of transmission (15 and 16 December 1999), the tag was located in open water approximately 140 miles southwest of

Oahu. Figure 4 shows the average percent time spent in each depth bin during the 13 days that the tag was attached to the shark.

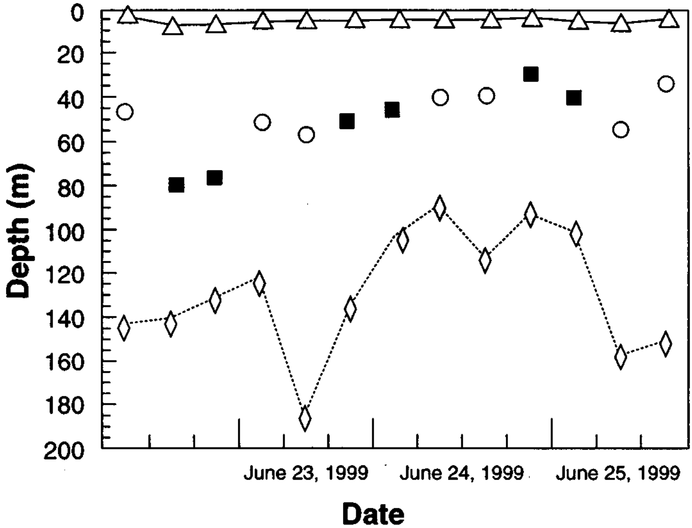

Figure 3. Data from archival acoustic tags. Depth data are recorded in 6-hour bins. The first 6-hour bin is not shown as it contained data collected before, during, and immediately after surgery. Black squares represent nighttime mean, circles daytime mean, diamonds max depth, triangles min depth.

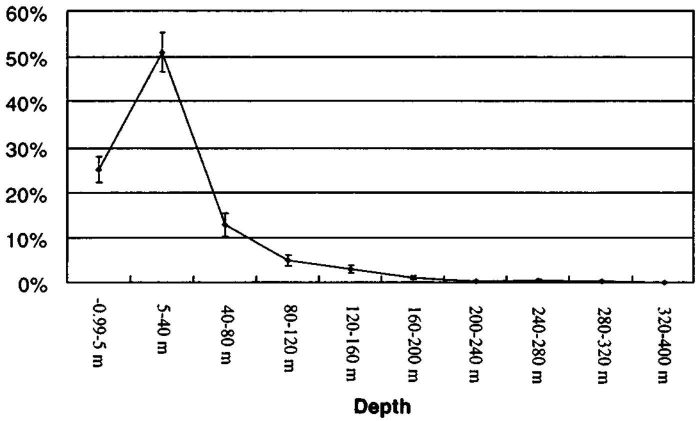

Figure 4. Depth data from archival satellite tag. Data are recorded as percent time in each depth bin over 4-hour intervals. Points are averages over all time intervals for 13 days. error bars = std error.

4. DISCUSSION

The use of different tagging methods applied to the study of tiger shark movements in a single location serves to highlight the way in which different tagging methodologies can complement each other in constructing a more complete understanding of fish behaviour. The pattern of constant motion and cross-channel movements elucidated by the active sonic tracking indicated that these sharks travel large distances on a daily basis. They did not appear to spend much time repeatedly reworking small sections of habitat and had no reticence in undertaking offshore movements. Two of the tracked sharks were subsequently recaptured at the site of release and this raised the possibility that at least some of the sharks in the area were affiliated with a home range.

Site fidelity and the possible existence of large home ranges was reinforced by the recapture of 12.7% of the sharks equipped with identification tags and by the pattern of visitation revealed by the submerged data loggers. The data logger results indicated that a large number of the sharks (50%) revisited the area of coastline where they were first captured but the visits were irregular and are often interspersed by absences of several weeks. Further, the periods of time that the sharks were within range of the data loggers were usually brief and there was no evidence of any shark spending extended periods of time in close proximity to the data logger. In summary, these results all paint a consistent picture of the behaviour of tiger sharks in this area of the ocean. They display fidelity to a home range but the size of the home range is probably very large. The sharks are constantly moving within the home range and may not revisit any particular section for periods of several weeks.

Depth profiles collected by active tracking and both types of archival tags (CHAT, pop-up) were similar, even though the collection and storage of data varied between the different methods. The similarity of the data lends confidence to the interpretation that the various tagging methods are revealing normal patterns of behaviour and that there is minimal impact on behaviour of either the external or internal tag attachment methods. Depth data from all three sources indicated sharks spent most of their time between 30 m and 100 m, although there were occasional deeper dives. It is not possible to say if the maximum depths contained within the archived data represent orientation to the bottom or blue water dives occurring during periods of open water transit.

At the outset of the phase of work using CHAT acoustic modem tags, it was recognized that data from these tags would be somewhat tangential to questions concerning shark home range site fidelity. These tags only record depth and temperature data and do not attempt to estimate geographical location. Nevertheless, depth data collected over long periods of time can indicate how much of the sharks' movements are within the typical depths used in human ocean activities. Further, this use of the CHAT and acoustic modem technologies was seen as an opportunity to demonstrate the feasibility of this technology. The preliminary results indicate that archived data can be successfully downloaded across several hundred meters from internally placed transmitters. This distance was feasible even in the noisy coastal oceanic environment. Data transfer times can probably be reduced to expedite faster transfer of the data stored in the tag.

One of the most striking aspects of the data gathered in this study is the difference in recapture rates of animals with conventional tags and those with electronic tags. The overall recapture rate of 50% for sharks with internal acoustic pingers was four times as high as for conventional tags (12.7%) and one of the four CHAT tags (25%) has been heard on four separate occasions. The probable explanation for this difference is the large disparity in sampling effort attributable to the different techniques. Whereas the fishing gear was deployed for approximately 13 hours per week, the data loggers were constantly in place and listening for tagged sharks. At least one shark was detected on the data logger on the same night that fishing gear was deployed in the immediate vicinity but which did not catch the shark. These results suggest that, for wide ranging fishes, acoustic tagging and remote monitoring techniques can be an excellent method for investigating site fidelity and residence phenomena. Similar positive results have recently been acquired in a study of tuna behavior around fish aggregating devices (Klimley and Holloway, 1999).

One underlying impetus for this research was the evaluation of the feasibility of using fishing to cause localized depletions of tiger sharks if such a reduction were deemed necessary or appropriate to improve human safety. The results from the various tagging technologies suggest that in Hawaii tiger sharks are constantly moving within very large home ranges and have a vertical distribution ranging from the surface to at least 300 m. These results indicate that localized coastal fishing would probably not result in localized population reduction unless fishing was conducted continuously for a prolonged period of time sufficient to reduce the population in the overall region of the Hawaiian Islands.

ACKNOWLEDGEMENTS

Many thanks to Tamashiro Fish Market for supplying bait for the duration of this study. Funding was provided by the division of Aquatic Resources, State of Hawaii Department of Land and Natural Resources and by the University of Hawaii Sea Grant College Program (Project R.MR-50) under an Institutional Grant from the NOAA Office of Sea Grant, U.S. Department of Commerce.

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