Marine Turtle Newsletter 142:10-13, © 2014

Marine Turtle Newsletter

First Use of a GPS Satellite Tag to Track a Post-Nesting Hawksbill (*Eretmochelys imbricata*) in the Hawaiian Islands With an Indication of Possible Mortality

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Hawaiian hawksbills (*Eretmochelys imbricata*) have been satellite tagged in the main Hawaiian islands (MHI) with standard Argos tags since 1997 (Parker *et al*. 2009). These turtles showed short inter-island migrations. However, the number and quality of transmissions for these tags were relatively poor with few positions with high accuracy. This poor accuracy may be a result of hawksbills having short surface periods and longer dive times (van Dam *et al*. 2008). Global Position System (GPS) tags have become increasingly popular (Jones *et al*. 2013) and obtain GPS data using a rapid "quick fix" technology producing positions that are more accurate than regular Argos data, which they also obtain (50 m. vs. 150 m. accuracy, Argos User's Manual 2011).

An adult post-nesting hawksbill was satellite tagged after the turtle's third nest was laid on 4 October 2011 during its first recorded nesting season at Makena State Park, Maui. A Telonics GPS tag (model TGM-4410; Telonics, Inc., Arizona) was attached to the turtle using modified procedures based on Balazs *et al*. (1996). We attached a GPS tag to this hawksbill turtle (the first GPS tag deployed for Hawaiian hawksbills) in order to obtain more detailed information on the movements of post-nesting hawksbills in Hawai'i. Nearly all documented hawksbills nesting on Maui have been tracked to their foraging grounds with either radio or satellite tags (Parker *et al*. 2009, NOAA unpub.). We combined the diving data received from the tag in this study with the positional data (GPS and Argos) to better understand diving and surfacing behavior. Most hawksbill turtles spend regular intervals diving and surfacing, spending more time underwater than on the surface (Blumenthal *et al*. 2009; van Dam *et al*. 2008). Hence, we interpreted our dive data to include the idea that a healthy hawksbill turtle would spend a percentage of time both above and below water over any multiple day period.

The satellite tag obtained GPS positions every 6 hr. and obtained Argos positions and dive data via a 6 hr. on/24 hr. off duty cycle. This duty cycle was used for transmitting data as well and the satellite tag transmitted GPS data preferentially, followed by Argos positions and lastly dive data. Dive data included the percent time spent underwater in 12 hr. and the number of dives in 12 hr. as well as dive durations; a dive was recorded if the turtle was underwater for more than 10 s. The GPS tag was programed so that it would transmit constantly if the salt-water contacts were continually bridged for more than 24 hr. (fail-safe), and the tag would revert to the programed duty cycle once the contacts were no longer continually bridged. Days were expressed as a linear progression rather than dates. Percent time on surface was defined as the time recorded not spent underwater. Averages of percent time on the surface, dive duration, and number of dives in a 12 hr. period were examined for differences between near shore and offshore areas, as well as compared with the corresponding track data over the course of the track. Distance of travel was calculated using the single highest accuracy position per day as close to 12:00 UTC as possible. The coastline data were Global Self-consistent Hierarchical High-resolution Shoreline (GSHHS) data (Wessel & Smith 2013) and bathymetry data were obtained from School of Ocean and Earth Science and Technology (SOEST) and General Bathymetric Chart of the Ocean (GEBCO) databases. Distances from shore were calculated from the estimated nearest coastline position, extrapolated from Google Earth (2012), and best Argos positions for that day using the great circle method of calculation (Bowditch 1995). Near shore was defined as within 2 km. of shore, while offshore was over 2 km. from shore. The islands of Hawai`i are volcanic mid-ocean mountains, so near shore areas are not as extensive as those involving a continental shelf. In addition, depths usually drop off steeply between 1-2 km. off shore, except between the islands of Moloka`i, Maui and Lana`i (Google Earth 2012; GEBCO data).

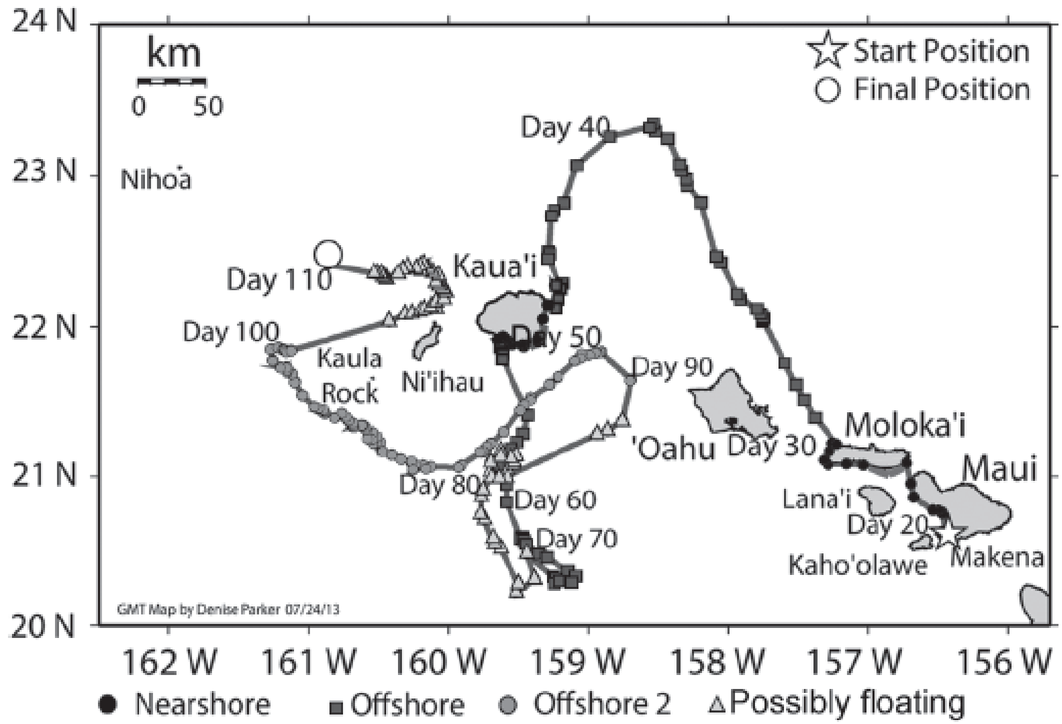

Figure 1. 2011-2012 post-nesting movement of female hawksbill turtle Argos ID 71908. Near shore (black circles), off shore (squares and light grey circles), and periods of floating or fail-safe mode (light grey triangles) are indicated. Capture position is indicated by a white star and final location position is indicated by a large white circle.

Day	Positional data (based on map in Fig. 1)	Mean percent time on surface (SD)	Range of percent time on surface	Mean number of dives (SD)	Ragne of number of dives	Mean dive duration, sec. (SD)	Range of dive duration (s.)
1-8	Near shore†	No data	No data	No data	No data	No data	No data
9-18	Near shore†	2% (0.004)	1.1 -2.5%	14 (4.6)	9 – 21	56 (38)	10 – 146
19-30	Traveling near shore	No data	No data	No data	No data	No data	No data
31-43	offshore1	No data	No data	No data	No data	111 (343)	11 – 2875
44-54	Traveling Near shore	3.6% (0.003)	3.1 – 4.1%	22 (14)	8 – 50	No data	No data
55-66	offshore1	10% (0.1)	1 – 20%	169 (109)	30 – 395	No data	No data
67-71	no positions	6% (0.1)	0 – 30%	7 (13)	0 – 38	3647 (7723)*	10 – 26984*
72-90	Contacts bridged	100%	100%	0	0	No data	No data
91-100	offshore2	36% (0.3)	0.5 – 96%	451 (321)	64 – 1028	36 (94)	10 – 1316
101-102	no positions	No data	No data	No data	No data	No data	No data
103-107	Floating	47% (0.5)	0.01 – 99.95%	347 (439)	2 – 1087	13 (3)**	10 – 23**
108- 111	Floating	100	100	0	0	No data	No data

Table 1. Mean, Standard deviation (SD), and range for percent time on surface, number of dives and dive duration grouped by areas defined by the track (see Fig. 1). † = internesting period. * = Day 67 only. ** = Day 106 only.

Previous published data on the movements of Hawaiian hawksbills showed only short distance movement within the main Hawaiian islands (Parker *et al*. 2009). Previous tracking has shown that Hawaiian hawksbills stay close to shore during their postnesting movement except when moving between islands, with most turtles ending up in a foraging area near shore (Parker *et al*. 2009). The hawksbill in this study traveled from Maui along the islands of Moloka`i and Kaua`i, then far offshore with transmissions ending on Day 111 (Fig. 1). During the inter-nesting period near Maui (days 1-18), the hawksbill stayed within 2 km. of the nesting beach while staying approximately 250 m. from shore in waters around 15 m. deep. The turtle nested one last time on day 18 before moving away from the Makena State Park area (Fig. 1, 20.6°N 156.4°W). Positional data as well as dive and surface data were fragmented. All three data types were not received every time the tag transmitted so only available data types were compared (Table 1). GPS positional data were not received immediately, with only Argos positional data available for the first 12 d. and surface and diving data were not collected and transmitted until day 9. The hawksbill initially traveled along the coasts of Maui and Moloka`i (Fig. 1). However, diving and surfacing data were not available during this near shore traveling period (Table 1). During the first offshore (open water) period between days 33 and 43, the turtle moved from Maui to Kaua`i (Fig. 1). The limited dive duration data available indicated regular dives (Table 1). Between days 44 and 54, the turtle traveled south along the coast of Kaua`i from Anahola to Port Allen (Fig. 1). During this 10 d. period, the turtle stayed 1.5 km. near shore and in water depths no greater than 20 m. The average number of dives and percent time spent on the surface were slightly higher than during the inter-nesting period (Table 1). The turtle in our study also stayed close to shore while traveling near islands (Fig. 1), but then moved offshore and stayed pelagic so that no specific near shore foraging area could be identified. On day 55, the turtle traveled south from Port Allen out to open ocean, and mean dive numbers in a 12 hr. period increased during this time from tens of dives to hundreds of dives while mean percent time on the surface stayed low (Table 1). Starting on day 67 and continuing to day 72, no Argos or GPS positional data were received. However, the dive data received for these days indicated the turtle was submerged multiple times for long periods: once for a 24 hr. period on day 69 and then for 12 hr. periods on days 70, 71, and 72. While underwater hibernation has been documented in some turtle species (Carr *et al*. 1980; Felger *et al*. 1976; Hochscheid *et al*. 2005), it has not been documented in hawksbills. The transmitter switched to fail-safe mode on day 72 indicating the salt water switch contacts had been bridged for over 24 hr. Surfacing behavior changed around day 67, the percent time on the surface had stayed clustered <25% for both near shore and offshore movements before day 67, after this time the surfacing behavior and dive numbers varied widely (Fig. 2, Table 1). The transmitter stayed in fail-safe mode from day 72 to day 90. Surfacing data during this time indicated that the turtle was on the surface 100% of the time with 0 dives. GPS data during this time were limited, with only 5 GPS transmissions between day 67 and day 87. The Argos data received during this time were of moderate accuracy (mostly LC B, A, 0 and 1 positions). The satellite tag resumed normal, non-fail safe mode operation on day 91 (Fig. 1, Table 1). Surfacing behavior, dive numbers and dive durations after this time period were varied; for example, on day 91, dives averaged 46 seconds long with 144 dives in a 12 hr. period and a total of 57% of time spent on the surface, on day 94 dives times averaged 3.5 min. with 244 dives in a 12 hr. period and a total of 1% of time spent on the surface, and by day 99, dive durations averaged 13 s. long, and the turtle was spending 90% of its time on the surface, with over 600 dives recorded in a 12 hr. period. Between day 91 and day 100 the number of Argos highest accuracy LC3 positions increased from 2 in 90 d. (days 1-90) to 10 in 9 d. (days 91-100) and LC2 positions also increased from 3 in 90 d to 18 in 9 d. No dive, surface time or positional data were received for days 101 and 102 (Table 1). On day 103 the transmitter recorded 0.1% surface time, with 8 dives recorded, however the tag did not revert back fail-safe mode. The percent time on the surface increased from 1% to 100% between day 104 to day 107, and the turtle continued to spend 100% of its time on the surface with 0 dives until the GPS tag stopped on day 111 (Table 1). When the GPS tag stopped transmitting, the turtle had traveled a circuitous route totaling 1,787 km., with a straight-line distance of 502 km. between the release point and the end position. Besides this study, only one other Hawaiian hawksbill has been tracked into pelagic waters, a post-nesting turtle from Kamehame, Hawai`i in 2007 (S. Graham unpub.). Hawksbill turtles have documented long-distance post-nesting migrations between islands in the Caribbean (Hillis-Starr *et al*. 2000; Horrocks *et al*. 2001) and the South Pacific (Vaughan & Spring 1980). However, the 2007 Hawaiian hawksbill (S. Graham unpub. data) was not successfully tracked from the MHI to another Pacific island, the positional data for the track stopped in pelagic waters approximately 2,100 km. southwest of Kaua`i. The tag in this study stopped only 120 km. from Kaua`i. Unlike data from the present study, dive data for the 2007 turtle continued to transmit for 4 months after the last position was received. However, the present status of this 2007 hawksbill is unknown because the turtle has not been re-sighted at monitored hawksbill nesting beaches on the Island of Hawai`i or Maui since 2007. Hawksbill turtles have shown differences in diving behavior between near shore and pelagic waters, but no extended floating or time on the surface behavior has been recorded (Blumenthal *et al*. 2009, Parker *et al*. 2009). Dives for adult hawksbills average about 1 hr. in inter-nesting or resting areas, so near shore dive numbers are usually low (Blumenthal *et al*. 2009, D. Parker unpub.). Dive number data from near shore inter-nesting periods around Maui (mean = 14 dives in 12 hr.) and near shore travel along the coast of Kaua`i (mean = 22 dives in 12 hr.) are consistent with these findings. Previously recorded mean dive durations in a 12 hr. period for Hawaiian hawksbill turtles ranged between 5 and 19 min. when traveling in open water between nesting and foraging areas (Parker *et al*. 2009). Dive duration data obtained while the turtle was traveling between Moloka`i and Kaua`i were comparable to this, with a mean of 2 min. and one dive as long as 48 min. After the turtle left Kaua`i heading south into pelagic seas, dive data initially showed normal offshore dive behavior with an average of 10% time spent on the surface and a mean of 169 dives in a 12 hr. period. However, starting on day 67 the percent surface time, dive duration and dive number data began to deviate from previously published data. Comparing our data to published data and the idea that a healthy hawksbill sea turtle will spend at least some time of a multiple-day period underwater and some time on the surface, our data suggest that this turtle was not behaving normally. Between day 67 and day 72, there were no positional data and percent time on the surface data indicated that the turtle spent 4 consecutive days with periods of 12 hr. or greater completely submerged. While dive durations of 7 hr. have been recorded in hibernating loggerhead turtles (Hochscheid *et al*. 2005), the conditions associated with sea turtle hibernation (including water temperatures below 15o C and sheltered areas near shore to rest on the bottom) were not present in the open ocean environment near Hawai`i. The reason for this observed submergence behavior can only be speculated about. One possible reason for the extended submergence could be interaction with a predator, such as a shark attack or an aggressive billfish that injured the turtle (Frazier *et al*. 1994). Another reason could be interaction with fishing gear or floating debris, which ultimately caused a forced submergence. The tag entered fail-safe mode after this 5 d. period of no positional data and the fail-safe mode continued for an extended period (18 d.). For the transmitter to continue in fail-safe mode, water or material of some kind would need to continue to bridge the salt-water contacts on the transmitter during this 18 d. period, however the surfacing data for the tag indicated that the turtle was floating. If the turtle was truly floating during this time as indicated by the dive data, the transmitter should have given frequent GPS positions as well as an increased number of LC3 Argos positional data. A floating GPS tag would be unobstructed to the Argos receiving satellites and the satellites would be able to freely obtain GPS positions as well as more than the required 4 hits per overpass to calculate LC3 positions, because the tag was transmitting constantly. However, this was not the case, positional data did not increase with few GPS positions and no LC3 Argos data were obtained during the 18 d. fail-safe period, which suggests that the turtle was not prone-floating during this time period. After this 18 d., the tag returned to its programmed duty cycle and data collection.

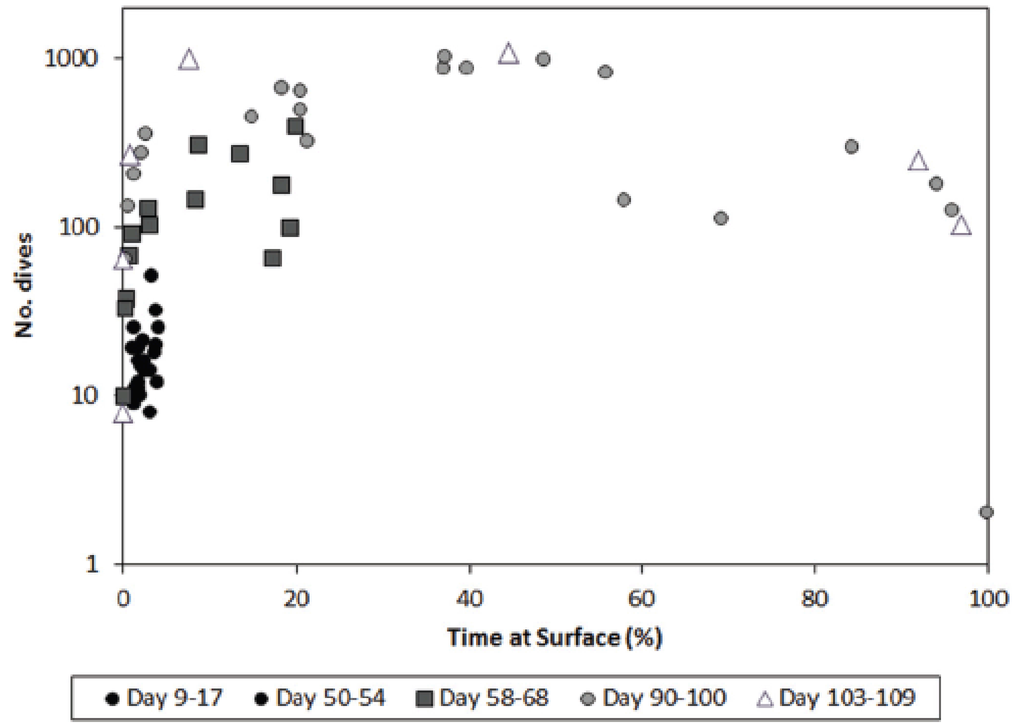

Figure 2. Percentage of time spent on the surface in a 12 hr. period and number of dives in a 12 hr. period during the near shore movements (days 9-17 and days 50-54); offshore movements (days 58-64 during period 1; days 90-100 and days 103-109 during period 2). No percent time or dive number data were accrued during days that are not indicated. Shades and shapes are linked to track position.

Surfacing behavior data from day 91 until the tag stopped on day 111 suggest that the turtle may have been debilitated, dead or dying, because surface times and dive numbers varied greatly during this time (Fig. 2). The turtle surface behavior, dive durations and dive numbers were within normal ranges on day 94. However, near the end of the track, the turtle was showing frequent, extremely short dives with dive durations having a mean of 13 s. and no dives over 23 s. The increase in the number of LC2 and LC3 Argos positional data as well as GPS positions suggest that the turtle was spending an increasing amount of time at or near the surface, until surfacing data indicated that the turtle was floating (Table 1).

No adult hawksbills have been observed directly in the northwestern Hawaiian islands (NWHI). However, it is possible that the hawksbill in our study was transiting to a foraging ground at some unknown location within the NWHI or beyond. Van Houtan *et al*. (2012) noted recent observations of three hawksbills in the NWHI since 2003. These were juvenile turtles between 35-46 cm. carapace length, with two of the three observed from stranding reports: one turtle was entangled in marine debris, another was washed ashore after the Tohoku tsunami (Van Houtan *et al*. 2012). While the tag might have stopped due to transmitter failure, loss of tag, or battery exhaustion, (Hays *et al*. 2007), the end result of this tracking demonstrated abnormal diving behavior shedding light on a more likely outcome, that is, the fatality of the turtle possibly due to an extended forced submergence. However, if the turtle is ever sighted again, our provisional conclusion will need to be revised and/or refined with the possible recovery and examination of the satellite tag.

Acknowledgements. We thank the Hawai`i Wildlife Fund volunteers for their work monitoring nesting beaches and help attaching the satellite tag. We thank K. Van Houtan, N. Atkins, and two anonymous reviewers for their reviews, comments and suggestions. We thank Telonics, Inc. for their contributions. This study was done under permits USFWS TE829250-7 and DLNR-DAR 2012-23 72, and complied with all relevant regulations.

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