Variability in Reception Duration of Dual Satellite Tags on Sea Turtles Tracked in the Pacific Ocean [1]

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Abstract— Variability in satellite transmitter life has often been examined in terrestrial studies, however not in a marine setting. In this study, two transmitters per turtle were attached to loggerhead turtles (N=15), green turtles (N=2) and olive ridleys (N=3) to see if mortality could be determined and to examine variability between tags. Factors examined in this paper were reception duration or how long we received tag data, the habitat area where transmissions stopped, and the differences between reception duration. The results show that variation in transmission reception between identical transmitters ranged widely. Five of our 20 pairs (25%) had significant differences in duration between the tag pairs that could not be explained with normal tag variation; Four pairs had zero days difference in duration between the tag pair. Our data verifies that multiple factors need to be examined in order to determine the final outcome of tracking due to the variability in tags.

Introduction

Over the last three decades satellite tracking using the Argos system has become common in the study of movements of a great diversity of animals, such as falcons, wolves, caribou, penguins, seals, whales and all species of sea turtle (Hazen et al. 2012). Determining why transmissions from a transmitter are not being received, without recovering the animal or tag, is difficult, and retrieval of tags in the marine environment is rare. The behavior of the animal can also affect the performance of a satellite transmitter (Plotkin, 1998). For example, olive ridleys often float on the surface while resting, while other species rest on the bottom; the time spent at the surface positively affects the accuracy and number of transmissions received from the transmitter. Swimmer et al. (2002, 2013) as well as Chaloupka et al. (2006) brought up difficulties of determining mortality with singular satellite tags especially for turtles deployed after fisheries interaction. Initially, the objective of our study was to use dual transmitters to help determine mortality; however, the

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shortcoming of wide variability in tag duration became apparent early in the study. Our objective transitioned into using dual transmitters programmed with alternating on-off duty cycles to extend the length of time a turtle was tracked without sacrificing the amount of data we obtained. Using dual transmitters in this manner allowed us to have more positional data than just one transmitter with a longer duty cycle. The results of our study showed a high variation in transmitter reception.

Methods

STUDY AREA

Turtles were released during 2004 - 2009 in the western, central and eastern North Pacific as well as the South China Sea. (Fig. 1). Turtles were released in collaboration with researchers in Japan, Singapore, Mexico, and the United States. Some turtles were captive bred for research, while others were rescued animals that were rehabilitated and released in these various areas to promote awareness of turtle movements. In some cases the turtles were fisheries by-catch released with satellite tags. Previous satellite tracking of captive-reared, rehabilitated, and by-catch release animals show normal turtle behavior (Polovina et al. 2006; Kobayashi et al. 2011).

PROCEDURES

Argos satellite-linked transmitters were deployed on 20 sea turtles: 15 loggerhead turtles (*Caretta caretta*), two green turtles (*Chelonia mydas*), and three olive ridleys (*Lepidochelys olivacea*). Straight carapace length (SCL) was measured to the nearest 0.1 cm. A few days before deployment, all tags were tested for a 24-hr period to ensure that they transmitted properly. Forty Telonics, Inc. (Mesa, Arizona) model ST-24 tags, were attached in parallel pairs to each turtle's carapace by G. Balazs and M. Rice or under their direct supervision (Fig. 2). Turtles were handled humanely based on Institutional Animal Care and Use Committee standards (IACUC.org). The tag pairs were attached independently with polyester resin and fiberglass cloth, following the procedures of Balazs et al. (1996). Both tags on a turtle were programmed with a duty cycle that had the same hours on and off, but alternating so that when one transmitter was on the other was

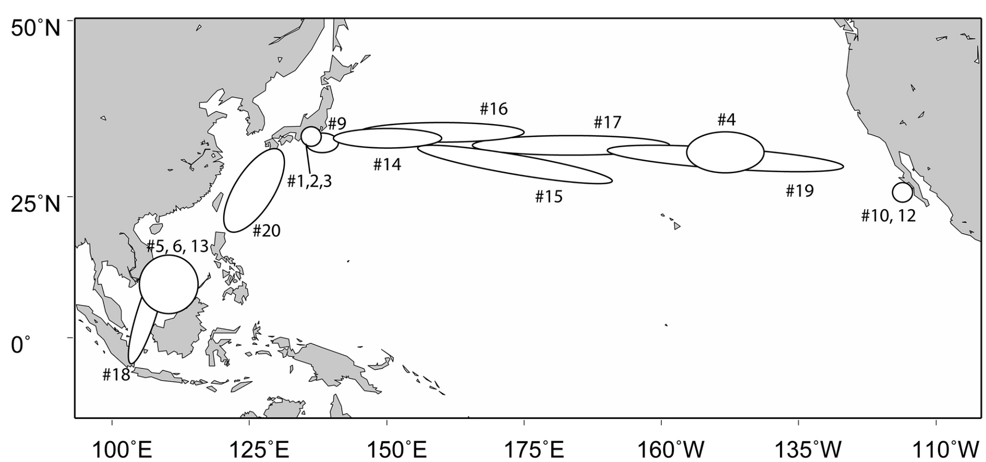

Figure 1. Distribution of dual tagged turtles in the North Pacific Ocean. Turtle numbers are connected to those in Table 1. Ovals show basic area covered by each turtle's track.

off. Thirteen turtles had paired tags with a duty cycle of 6 hrs on/48 hrs off, two turtles had paired tags with a 12 hrs on/48 hrs off duty cycle, and five turtles had paired tags with a 8 hrs on/72 hrs off duty cycle. Factory specifications note that transmitters have an expected 10% variation in operational life (transmitter duration) due to electronic component variations and tolerances that cause variation in current consumption among units. Tag repetition rates are programmed at 45 sec (± 5 sec) and introduce additional variation in the expected operational life. Different repetition rates were chosen for tags in each pair in order to minimize transmission overlap and interference between the tags. Data from transmitters were received by polar-orbiting NOAA satellites carrying Argos receivers, and processed using the Least-Squares filter by CLS America. Positional accuracy defined by Argos can be found at the CLS America website (http://www.clsamerica.com).

Reception duration is defined as how long a transmitter provided data and was determined from the date the transmitter was turned on to the last date the transmitter signals were received. All data were included, even transmissions that did not give positional data (e.g. the "Z???" data from Argos). The total number of transmissions was recorded for all tags, but only 5 tags were graphed because they had duration differences greater than one month.

The median of tags that stopped first and those that stopped second was calculated. A Wilcoxon signed-rank test for paired samples was done to test to see if there was a difference between median number of days transmitted in the tags that stopped first and those that stopped second. The null hypothesis was that there was no difference in median number of days transmitting and the alternative was that there was a difference. The Wilcoxon signed-rank test T values were calculated manually using Excel to determine differences and ranks based on equations given by Zar (1974). All differences that equaled 0 between the two tags were removed from analysis. The null hypothesis was rejected if either T+ or T- was less than or equal to the critical T value. Since our sample size was small (N=16), the critical value for T was determined from the table of critical T Values (Table B.12 in Zar 1974) and the z value (calculated for sample sizes of 100 or more) was not used.

The relationship between turtle size (SCL) and tag reception was examined with a simple correlation.

Figure 2. Example of dual tag attachment to a loggerhead turtle.

Results and Discussion

The data were not normally distributed, so a non-parametric Wilcoxon signed-rank test was performed on the data (N=16, T=0, T_{crit}= 29, p<0.001), indicating a significant difference between the number of days for tags that stopped first (median = 145 days) and tags that stopped second (median = 190 days) on the turtles. Reception duration of data ranged from 0 to 898 days for the 40 transmitters. The 20 dual-tagged turtles ranged in size from 35.3 to 91.2 cm straight carapace length (SCL, Table 1). A simple linear correlation between SCL and reception duration in this study is low (R^2 = 0.26), indicating size did not factor in reception duration; however, since this was a very small sample size (N=20), a larger sample may have shown otherwise. Potential reasons for transmitters stopping can be attributed to 1) mortality of the animal, 2) attachment failure, hence tag loss, 3) electronics failure or non-uniformity of electronics, and 4) non-uniformity of batteries or battery exhaustion (see Hays et al. 2007). Non-uniformity of batteries is a known issue with manufacturers and factory estimates of battery life (estimated tag duration) given to users are usually on the conservative side based on repetition rate, battery type, transmitter model, duty cycle, and how much data is being collected and transmitted. Attachment failure can happen more often in near shore environments due to a turtle's interaction with the bottom substrate. Our study included different species, many were released near shore, though most of the turtles were pelagic species (juvenile loggerheads and olive ridleys). Pelagic turtles are not as likely to interact with the bottom (e.g., coral reefs or rock outcroppings), but green turtles and benthic foraging loggerheads do interact with the bottom.

In the case of Turtle #1 (Table 1), both tags had no transmissions received after release (0 days duration). In this case, one possible explanation is the electronic failure of both tags immediately after release. While tag failure does occur, the electronic failure of both tags would be a very rare event. Another possible explanation is the immediate loss of both tags; this would also be a rare event given the proven long-standing nature of our attachment technique (e.g. Polovina et al. 2006). A third explanation for receiving no data is that something happened to the turtle to cause a mortality before the first transmissions.

One turtle (#2, Table 1) was a confirmed mortality, with 0 days difference in reception between the two tags after 11 days of successful transmission and data reception. Turtle #2 was found dead in a net and both the turtle and tags were returned to researchers.

Two other tags had 0-day differences between the tags stopping. Both tags on turtle #3 stopped after 15 days of total transmissions in a near shore area. Turtle #4 was released after being captured as incidental by-catch in a longline fishery and both tags stopped after 106 days of transmissions. Both tags stopping with 0 days difference between the tags would be a rare outcome, as one would expect some variation between tags due to variances in electrical components and the repetition rate. Given this, Turtles #3 and #4 could be suspected as mortalities; however, since Turtle #3 was traveling through an area with a year-round local fishery, it is possible the turtle became a non-reported by-catch, and the limited data given by the tags does not allow for meaningful analysis with oceanographic data. Artisanal (local, non-commercial) fisheries have been documented off of Japan, Indonesia, Philippines, Baja Mexico, China and Taiwan (FAO, 1982; Rosales-Casián & González-Camacho, 2003). By-catch in fisheries is historically under reported due to many factors, one of which can be the fishermen's concerns of increased regulation based on the result of such reports (Alverson et al. 1994).

Table 1. Summary of data for 20 turtles deployed during 2004 – 2009 with two Telonics ST-24 satellite tags. Data include turtle species, Argos ID codes, size (straight carapace length, cm), days of reception, differences in reception duration, duty cycle, and rep. (repetition) rate of the tag. CC= *Caretta caretta*, CM = *Chelonia mydas*, LO = *Lepidochelys olivacea*

No.	Days Difference	Days Reception	ID Code	Distance Traveled (km)	Species	Size	Duty Cycle	Area Stopped	Rep Rate (sec)
1	0	0	52704	N/A	CC	44.7	6/48	Nearshore	43
		0	52696	N/A			6/48	Nearshore	48
2	0	12	50134	96	CC	46.7	6/48	Nearshore	46
		12	50137	96			6/48	Nearshore	44
3	0	15	4807	181	CC	42.5	6/48	Nearshore	45
		15	4802	181			6/48	Nearshore	49
4	0	106	52695	1,488	CC	40.6	8/72	Pelagic	47
		106	52697	1,488			8/72	Pelagic	49
5	1	27	68157	631	CM	91.2	8/72	Nearshore	47
		28	68152	649			8/72	Nearshore	42
6	2	31	68150	1,086	CM	69.6	8/72	Pelagic	45
		33	68156	1,254			8/72	Pelagic	46
7	2	240	29067	5,780	CC	41.1	6/48	Pelagic	48
		242	29060	6,700			6/48	Pelagic	46
8	3	435	42716	10,164	CC	39.7	6/48	Pelagic	46
		438	58846	10,116			6/48	Pelagic	44
9	4	278	22980	4,430	CC	47.0	6/48	Pelagic	48
		282	8552	4,580			6/48	Pelagic	46
10	5	58	42474	427	CC	87.5	6/48	Pelagic	45
		63	42477	472			6/48	Pelagic	44
11	6	132	25359	527	CC	46.4	6/48	Nearshore	46
		138	25313	739			6/48	Nearshore	43
12	8	58	42475	514	CC	91.5	6/48	Pelagic	46
		66	42479	620			6/48	Pelagic	43
13	15	50	68159	514	LO	61.1	8/72	Nearshore	49
		65	68155	481			8/72	Nearshore	45
14	18	293	57150	5,428	CC	35.3	6/48	Pelagic	42
		311	57151	5,620			6/48	Pelagic	45
15	45	317	22151	9,367	CC	39.2	12/48	Pelagic	45
		362	22208	10,649			12/48	Pelagic	44
16	45	853	50140	11,317	CC	37.8	6/48	Pelagic	46
		898	50141	12,533			6/48	Pelagic	45
17	74	381	50143	6,580	CC	38.4	6/48	Pelagic	44
		455	50142	7,539			6/48	Pelagic	46
18	129	163	68158	2,625	LO	59.0	8/72	Nearshore	48
		292	68153	2,803			8/72	Nearshore	43
19	192	321	52693	6,683	CC	37.5	6/48	Pelagic	45
		513	52694	8,657			6/48	Pelagic	46
20	347	158	52697	3,892	LO	56.0	12/48	Pelagic	48
		505	52699	11,675			12/48	Pelagic	43

In half of the turtles (N=10), the difference in duration between the two tags was between 2-18 days. This variation in tag duration is within factory estimates due to variance in electronics and repetition rate. In four of these tags (Turtles #7, 8 , 9 and 14), battery exhaustion was considered the most likely cause of tag cessation, as the tags stopped between 240 – 438 days duration. These are times that were close to or within factory estimated durations of battery life, and all tags stopped in pelagic environments; hence, loss of the tag due to wear was unlikely.

In five of the turtles, the total reception duration of both tags was short – two months or less; however, the reason for the short-reception durations is not clear. Two of these turtles were residing in near shore areas (Turtle #5 and 13, Table 1), so one reason for the loss of transmissions may be due to tag loss or antenna damage if the turtles spent extended time in coral reef habitat. Green turtles (Turtle #5) and post-nesting female green or loggerhead turtles would more likely interact with the bottom in near shore environments, as they are mainly benthic foragers and rest on the bottom sometimes in caves. However, olive ridleys (Turtle #13) are mainly pelagic, so they would have little interaction with the bottom.

There were at least five examples of extreme variation between the cessation of tags, in which the variation could not be explained by typical variation in batteries and electronics (Fig. 3A-E). An additional exception was Turtle #18, which had 129 days difference between the final cessation of its two tags. The reason why the second tag stopped was most likely battery exhaustion. However, mortality was the most likely outcome for this turtle. Initially both tags on this turtle stopped within one day of each other near land. After a period of 40 days with no transmissions, one tag began transmitting again with positions on land for another 89 days – 230 km away from the initial end position, an indication that the tag was removed or the turtle's carapace with tag was discarded inland. In contrast, turtle #20 showed the first tag stopping at 158 days, and the second tag lasted another 347 days (Fig. 3E). While battery exhaustion likely caused the second tag to stop, the reason the first tag stopped is unknown, since the turtle was in a pelagic habitat for the entire track. However, since the first tag stopped well before both the second tag and the predicted battery life for each tag, either electronics non-conformity, or possibly tag loss could be the reason for cessation of the first tag. Four pairs of tag (#15 – Fig. 3A, 16 – Fig. 3B,17 – Fig. 3C and 19 – Fig. 3D) had total durations for both tags of over 300 days, but differences in repetition rate between tags do not fully explain the cessation differences between the paired tags since these differences were of 45 days or greater. However, when the number of transmissions per month were examined for these tags (Fig. 3A-E), the fluctuations in transmission reception and reduced numbers of transmissions in the months before cessation suggest an electronic component (e.g., battery failure or possibly moisture penetration into the package) might have contributed to early tag cessation. Fig. 3A, C, D and E show a dramatic end in transmissions for the first tag, suggesting a possible electronic component cause for the cessation of that tag. Fig. 3B shows a slow decline in transmission numbers over the months for the first tag to end this suggests more of a natural battery drain, and the extended duration of the tags also supports battery exhaustion as the cause of tag cessation.

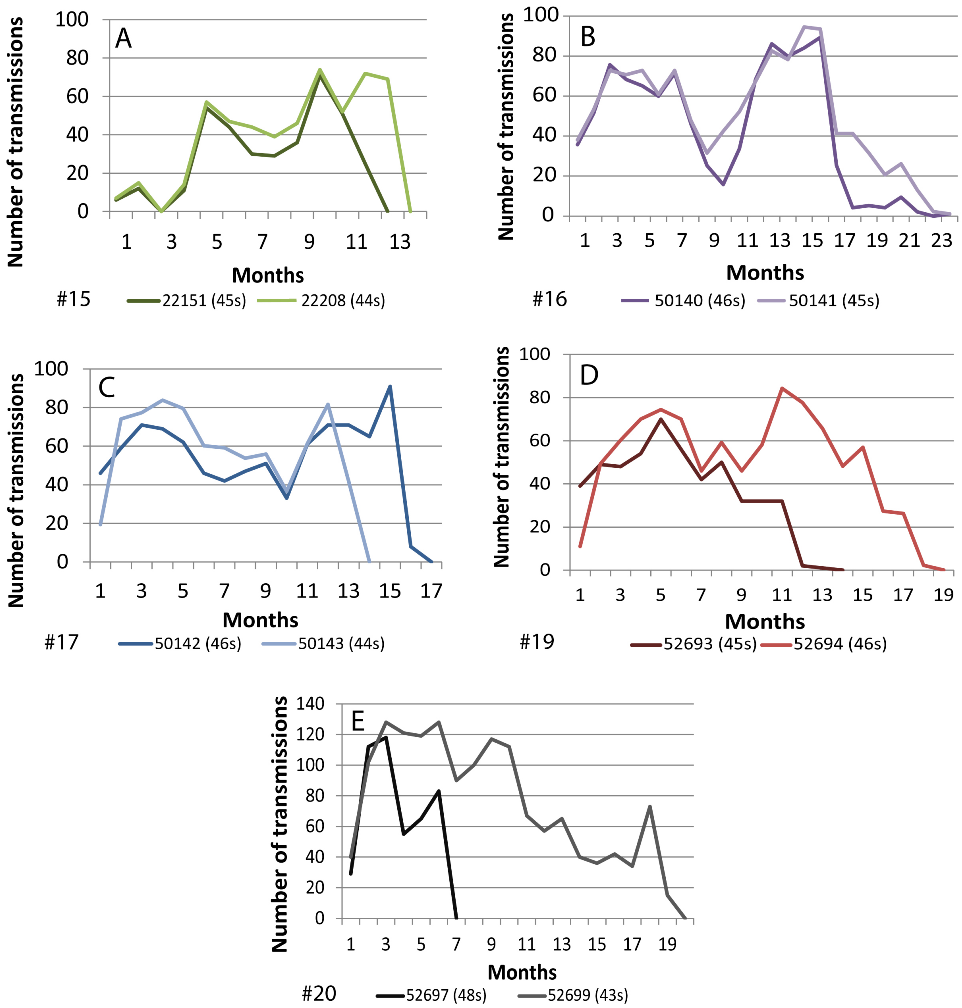

Figure 3A-E. Number of transmissions by month for five turtles that have over 30 days difference in tag duration between the two tags on each turtle. Turtle number on each graph is connected to the numbers assigned to the turtle in Table 1. Legends indicate which tag ID goes with each color on the graphic.

While putting two tags on a turtle, with an offset duty cycle, can increase the duration of a track without sacrificing the quantity of data collected, it does not help determine mortality and in some cases the additional drag could be detrimental if the turtle is not healthy (Jones et al. 2013). Overall, our study indicates that the variation in reception duration for a tag can be large and verifies that mortality cannot be determined using tag duration alone. In our study, we determined a likely mortality based on high quality positions transmitting on land for an extended time. Therefore, it is important to look at other data such as sea surface temperature, proximity to land and known local fisheries, speed of travel, currents and other oceanographic features - and when available, other data from the tags, which can include parameters such as percent time spent underwater, dive depths, duration of dives and temperature. Examining all of these variables will aid researchers to better determine the final outcome of sea turtles from satellite tag tracking. Our study provides a unique and useful contribution to the body of published information on satellite tag variability.

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