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ANNUAL SURVIVAL OF LOGGERHEAD SEA TURTLES (*CARETTA CARETTA*) NESTING IN PENINSULAR FLORIDA: A CAUSE FOR CONCERN

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***Abstract*.—To estimate annual survival rates of adult female Loggerhead Sea Turtles (*Caretta caretta*) in the Peninsular Florida subpopulation, we deployed pop-up archival transmitting tags on 30 Loggerhead turtles nesting at Juno Beach, Florida in 2009. We received data from 29 tags, which we used to estimate annual survival rates and assess the disposition of the animal at the time of tag release. A turtle could have survived the one-year deployment, could have died, or its fate may be unknown if a tag transmitted prematurely for no discernible cause. Annual survival was estimated to be 0.41 (0.20–0.65, 95% CI), but when assuming that all turtles whose fate was unknown had survived for one year survival was estimated to be 0.60 (0.40–0.78). These estimates are considerably lower than previous estimates for this subpopulation (range: 0.73–0.85) and raise concern for the recovery and conservation of the species.**

Key Words.—Atlantic Ocean; *Caretta caretta*; known fate; Loggerhead Sea Turtle; mortality; satellite tags

INTRODUCTION

The Loggerhead Sea Turtle (*Caretta caretta*) is listed as a threatened species under the U.S. Endangered Species Act (U.S. Department of Commerce 1978). Recently, the species was proposed by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service to be listed as nine distinct population segments (DPS) rather than a single global population (Conant et al. 2009; U.S. Department of Commerce 2010). Within the proposed Northwest Atlantic DPS, one of the largest populations in the world, five recovery units/subpopulations were identified (NMFS and USFWS 2008; Turtle Expert Working Group [TEWG] 2009): Northern U.S., Peninsular Florida, Northern Gulf of Mexico, Dry Tortugas, and Greater Caribbean (Quintana Roo, Mexico).

Nesting of Loggerhead Turtles declined 43% from 1998 to 2006 in peninsular Florida, the largest subpopulation (Witherington et al. 2009). While many hypotheses for the decline have been proposed, none have been shown to be conclusive (TEWG 2009; Witherington et al. 2009). Witherington et al. (2009) argued that the trend was best described by a decline in the annual number of adult females in the population. The Turtle Expert Working Group (2009) analyzed mark-recapture data for adult females in three subpopulations in the region. Annual adult female survival in the Northern subpopulation between 1973 and 2006 was relatively high at 0.81 (0.77–0.84, 95% CI) and was consistent with another recent estimate for 1991–2006 (0.85, 95% CI 0.78–0.93; Hedges 2007) and an earlier estimate 1964–1981 (0.81; Frazer 1983). The estimate for the Mexico subpopulation was similar, 0.85 (95% CI 081–0.88; TEWG 2009) for 1996–2006. However, the estimate for peninsular Florida was lower: 0.73 (95% CI 0.71–0.76; TEWG 2009) for 1982–2007.

The lower (0.73) survival rate reported for the subpopulation nesting in peninsular Florida (TEWG 2009) was not from a dedicated mark-recapture study and the interception rate was very low, leading the authors to question the accuracy of that estimate even though the confidence intervals were narrow (TEWG 2009). The purpose of our study was to use satellite tag technology to estimate annual survival for adult female Loggerhead Sea Turtles in the Peninsular Florida subpopulation. Conventional satellite tags have been used to estimate survival rates of sea turtles (Chaloupka et al. 2004; Hays et al. 2003), but those estimates are based on modeling time to transmission failure, rather than actual survival rates as the reason transmissions ceased is usually unknown and can result from actual mortality, battery failure, or the tag becoming detached from the turtle and sinking (conventional tags are generally non-buoyant). Pop-up archival transmitting (PAT) tags are an alternative that often provides greater insight into the fate of an individual because they are attached via a tether, are buoyant, are programmed to release from the tether if at a constant depth for an extended period, and can prematurely transmit data in

FIGURE 1. An adult female Loggerhead Turtle (*Caretta caretta*) with a PAT tag attached. (Photographed by Michael Patrick O'Neill)

the event the tag is no longer attached to a turtle (Sasso and Epperly 2007). These PAT tag features allow researchers to review behavior just prior to the tag releasing from the turtle and make it possible to assess fate.

MATERIALS AND METHODS

We deployed thirty PAT tags (Mk10-PAT, Wildlife Computers, Inc., Redmond, Washington, USA) from 4 May to 16 May 2009 on nesting Loggerhead Sea Turtles at Juno Beach, Florida, USA, when the females were laying eggs (Table 1). We attached a PAT tag to a turtle using a 10-cm tether secured to an eyestrap, which, in turn, was secured with two bolts to bones underlying the postcentral scutes (Fig. 1; Epperly et al. 2007). We programmed PAT tags for a one year deployment and to record depth, temperature, and light level data. The tags were set to release prematurely if the tag remained at a constant depth (± 2 m with no outliers) for eight days. If the tag descended below 1,800 m, a device (RD-1800, Wildlife Computers, Inc., Redmond, Washington, USA) would sever the tether. Loggerheads are not known to dive this deep (Sakamoto et al. 1990) and descending to such a depth would indicate a dead and sinking turtle. Data from the PAT tags can provide insight into three possible fates: (1) survival for the one year deployment; (2) presumed death (e.g., remained at a constant depth for the programmed eight day premature release period, went below 1,800 m, or exhibited a change in dive behavior indicative of a compromised individual that gradually reduces diving over several days until the turtle is only floating at the surface); or (3) unknown fate (e.g., the turtle appeared to be diving normally but the tag became detached or popped-up for an unknown reason). Even when fate cannot be determined, we acquire the useful information that the turtle was alive until a known date. Transmission from a premature release begins after the tag ascends to the surface or had been at the surface for the specified eight days. In addition, the PAT tags were programmed to transmit on the first of each month to demonstrate that the tag was still attached to a living turtle. This check-in feature permitted us to know the fate of an animal for some portion of the year even if a tag did not transmit at the end of the full deployment.

Because the planned deployment was 12 months and annual survival was our parameter of interest, we created a 12 month survival record that accounted for the fate of an individual during each month for which we had data. If the realized deployment was < 12 months (e.g., premature releases or monthly check-in data only) and fate could not be determined, data were right censored. Right censored data remain in the analysis as individuals that are known to have survived until a certain time but their fate thereafter is unknown. We used these capture histories to estimate monthly and annual survival with the known fate model from program MARK (White and Burnham 1999). We ran two models in MARK, which included survival constant across time (survival was the same in each month) and survival by time period (survival varied by month). We used Akaike's Information Criterion adjusted for small sample sizes (AIC_c) to rank the models and determine which model best fit the data (Hurvich and Tsai 1989; Burnham and Anderson 1992, 1998). When comparing between models using AIC, a difference of < 2 in AIC values indicates no real difference, a difference between 2 and 7 indicates considerable support for a difference, and difference of > 7 indicates strong support for a difference between the models (Burnham and Anderson 1998).

RESULTS

First, we must acknowledge that there were problems with this particular batch of tags involving depth sensor drift of a magnitude not observed previously. After considerable discussion with the manufacturer, we do not believe that this problem would result in over or under estimation of survival. We elaborate on this problem in the discussion.

Of the 30 satellite transmitters that we deployed, one tag never transmitted; 14 transmitted at least once on the first day of the month as programmed, but did not pop-off prematurely and transmit, or transmit at the end of the 1-yr deployment; 15 tags popped-up prematurely; and one turtle was known to be alive at the end of the year, but her tag did not transmit at the end of its deployment, although it did check in once (Table 1). This turtle was found stranded dead in Virginia two months after the study concluded with the attachment intact and without the PAT tag, consistent with a

TABLE 1. Summary of *Caretta caretta* PAT tag data. We deployed 30 Mk10-PAT on nesting females at Juno Beach, Florida, USA from 4–16 May 2009. Tags were programmed for a one year deployment and an individual could have one of three fates based on the transmitted date: alive after one year, dead, or unknown (censored). If the deployment was < 12 months and fate could not be determined, data were right censored. Right censored data remain in the analysis as individuals that are known to have survived until a certain time but their fate thereafter is unknown.

Tag	Months-At-Large	Final Data Transmission	Fate
1	see footnote	see footnote	Alive[1]
2	3	No –monthly only	Censored
3	9	No –monthly only	Censored
4	6	No –monthly only	Censored
5	1	No –monthly only	Censored
6	7	No –monthly only	Censored
7	1	No –monthly only	Censored
8	6	No –monthly only	Censored
9	9	No –monthly only	Censored
10	3	No –monthly only	Censored
11	1	No –monthly only	Censored
12	1	No –monthly only	Censored
13	3	No –monthly only	Censored
14	3	No –monthly only	Censored
15	3	Yes –premature release	Dead –at depth
16	5	Yes –premature release	Dead –at depth
17	10	Yes –premature release	Dead –at depth
18	2	Yes –premature release	Dead –at depth
19	3	Yes –premature release	Dead –at depth
20	4	Yes –premature release	Dead –at depth
21	3	Yes –premature release	Dead –at depth
22	4	Yes –premature release	Dead –inland (Cuba)
23	3	Yes –premature release	Dead-Natural Mortality
24	3	Yes –premature release	Undetermined – Censored
25	3	Yes –premature release	Undetermined – Censored
26	3	Yes –premature release	Undetermined – Censored
27	4	Yes –premature release	Undetermined – Censored
28	5	Yes –premature release	Undetermined – Censored
29	4	Yes –premature release	Undetermined – Censored

[1]This tag did not transmit prematurely or at pop-off after one year but was known to be alive at the end of the one year as inferred from a subsequent sighting in July 2010.

successful pop-up or a broken pin in the base of the tag, but no transmissions.

Of the 15 premature tag releases, nine were determined to be turtle mortalities with seven tags remaining at depth constantly for eight days, and one transmitting well inland on the island of Cuba. The final tag showed evidence of ingestion as indicated by time at depth and an extended period of low light levels (we assume that both the tag and the turtle were preyed upon). The seven tags that remained at depth constantly were at depths ranging from 12.5 to 71 m. As noted, this group of satellite transmitters was problematic in that drift in the depth sensor greatly exceeded the tag manufacturing specifications (~5 m drift versus a specification tolerance of 0.5 m). Thus, we adjusted each day's readings by the difference in the shallowest depth recorded and zero depth (turtles must come to the surface to breathe).

One turtle apparently was intercepted while nesting during a subsequent emergence and the tag was removed. The tag was on the beach (a constant low pressure reading, elevated temperatures during daylight hours, a dry reading on the wet/dry sensor) for eight days before it began transmitting. Data from that turtle and the five other premature releases with an unknown cause were right censored. We also right censored data for tags that checked in during the year but did not transmit at the end of the deployment period. Of premature releases, one dead turtle was off the Florida Panhandle, one near southwest Florida, one in Cuba, one in the Bahamas, three near their nesting beach, one near the entrance to Chesapeake Bay, and one off the New Jersey Coast (Fig. 2). Premature releases of undetermined cause were located in southwest Florida, the Bahamas, and the east coast of Florida.

Our analysis of these data indicate that annual survival was 0.41 (95% CI 0.20–0.65) and best modeled as time invariant (AIC_c = 66.7 with an AIC_c weight of 0.97 versus AIC_c = 73.4 with an AIC_c weight = 0.03 for the time dependent model). The analysis run as a best case scenario assuming that all the censored turtles had survived for one year and also was best modeled as time

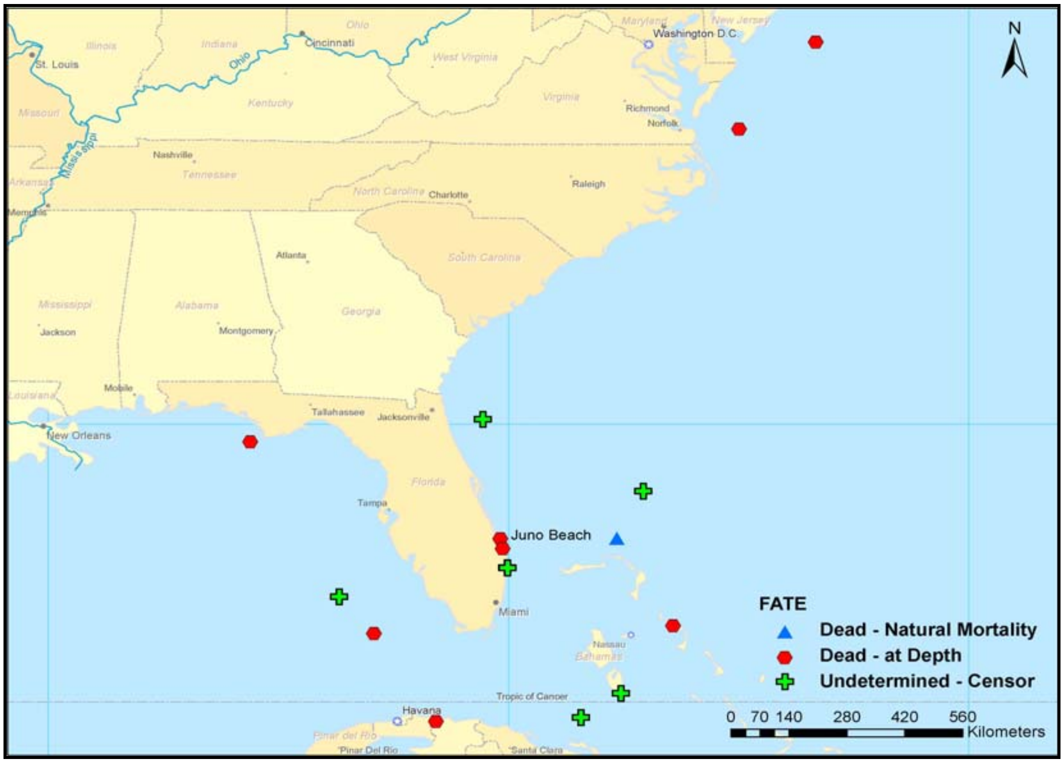

FIGURE 2. Location of premature releases of PAT Tags from Loggerhead Turtles (*Caretta caretta*). Red marks are mortalities, blue is a natural mortality, and green are unknown cause premature releases (right censored data). Monthly transmissions of tags that did not transmit prematurely or after one year did not provide location data.

invariant (AIC_c = 77.1, AIC_c weight = 0.91; AIC_c = 81.6, AIC_c weight = 0.09 for the time dependent model) with an estimate of 0.60 (95% CI 0.40–0.78).

DISCUSSION

We do not believe that any of the depth sensors completely failed, which would have resulted in false constant depth readings and triggered premature release of the transmitters. The drift was unidirectional and consistently indicated deeper depth use than possible (turtles did not appear to return to the surface according to data). After extensive discussions with the manufacturer, we concluded that while sensor drift may cause problems with some analyses (e.g., dive behavior), it did not affect our ability to determine the fate of the animals. Depth drift has been observed by the manufacturer in other tags and, although it limits fine scale depth use interpretation, the sensor was still functioning and turtles were diving. Equally troubling was the failure of one tag to ever transmit and 13 failing to transmit at the end of the deployment period or releasing prematurely. Hence, we ran analyses in two ways, in one case right censoring the data for those with unknown fates (S = 0.41) and in the other, assuming all tags that checked in but were not premature releases survived the one year (S = 0.60). In both cases, the estimated survival rate was sufficiently low to cause concern for the conservation of this population. We do not believe that there is mortality associated with this tagging method because we have monitored captive animals for a year (Epperly et al. 2007) and have used this method in other studies, including on small juveniles, that resulted in higher survival estimates than realized in this study (Sasso and Epperly 2007; National Marine Fisheries Service, unpubl. data).

In addition to the low survival rate, we note that mortality occurred over a wide area, in the Gulf of Mexico, the U.S. Atlantic coast, and the northern Caribbean. Loggerheads are a long-lived, late-maturing species and adult survival must necessarily be high for long-term population maintenance (Crouse et al. 1987). Estimates of annual survival for other populations of Loggerheads in the region are 0.81 (Frazer 1983), 0.81 (95% CI = 0.77–0.84, TEWG 2009), 0.85 (95% CI = 0.81–0.88, TEWG 2009) and 0.85 (95% CI = 0.78–0.93, Hedges 2007). For the Peninsular Florida subpopulation, of which Juno Beach is a part, the prior estimate was 0.73 (95% CI = 0.71–0.76, TEWG 2009).

Loggerhead Turtles have existed for millions of years, but during this study it appears that the largest nesting subpopulation in the Atlantic basin experienced unsustainable mortality levels. Previous population projection models for Northwest Atlantic Loggerheads have used high estimates for adult female survival ranging from 0.8091 to 0.85 (TEWG 2009). Our lower estimate, if correct, would greatly alter the outlook for this subpopulation and for the entire Western North Atlantic population, as it would generate an entirely different population trajectory, one of rapid decline. Our study needs to be replicated and expanded geographically to verify these results or determine if this one year was unrepresentative of the average year. If our results are representative of actual survival rates, more effective conservation measures may need to be implemented to sustain this Loggerhead Turtle population.

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