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ESTIMATES OF REALIZED SURVIVAL FOR JUVENILE LOGGERHEAD SEA TURTLES (*CARETTA CARETTA*) IN THE UNITED STATES

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***Abstract.*—We used mark-recapture, live-resighting, and dead recovery data to estimate realized survival of juvenile Loggerhead Sea Turtles collected in North Carolina, USA, from 1998-2005. We estimated annual survival to be 0.83 when transients and emigration were accounted for in the analysis. Also, we found that movement out of the study area is best explained as permanent emigration, rather than random or temporary emigration. New modeling exercises may be required to incorporate revised survival estimates, allowing managers to make informed decisions on the long-term recovery of Loggerhead Sea Turtles.**

Key Words.—apparent survival; Barker model; *Caretta caretta;* Loggerhead; North Carolina; realized survival; sea turtle

INTRODUCTION

Sea turtles are long-lived, slow-growing animals that occupy various oceanic and coastal habitats during different portions of each life stage (Meylan and Ehrenfeld 2000), making population monitoring and assessment a difficult task. However, conservation managers must determine the population status and evaluate the effects of management practices on long-term population trends of sea turtles to provide for their recovery. Survival rates of sea turtles, especially the oceanic and neritic immature stages, can significantly influence long-term population growth rates (Crouse et al. 1987; Heppell et al. 2003), so it is critical that we get accurate estimates of this parameter for improving sea turtle stock assessments (Turtle Expert Working Group 2000).

Earlier investigators used catch-curve analyses of stranding data to estimate Loggerhead (*Caretta caretta*) Sea Turtle survival in the United States (Frazer 1987; National Marine Fisheries Service 2001). Unfortunately, these analyses could not incorporate information about the fates of individuals or provide variability estimates using this information. In addition, the assumption that cohort size was the same each year confounded these earlier estimates. More recently, Sasso et al. (2006) used Pradel's temporal symmetry approach within the program MARK (White and Burnham 1999) to analyze mark-recapture data of juvenile Loggerhead Sea Turtles from the inshore waters of Core Sound, North Carolina, United States collected during the summer months from 1998-2004. However, the abundance of transients within the study area complicated this model and incorporation of resighting data for turtles encountered outside of the study area was impossible. Both the catch-curve and mark-recapture analyses yielded only estimates of apparent survival, which confounds mortality and emigration, potentially underestimating the true survival rate. To provide the estimates of survival necessary to improve stock assessments and reduce uncertainty in population modeling efforts, we estimate realized survival, which does distinguish between mortality and permanent immigration,.

Barker et al. (2004) proposed an approach for obtaining realized survival that combines mark-recapture, live-resighting and dead recovery data, and incorporates distinctions between random, temporary, and permanent emigration. Herein, we applied the Barker model to the same 1998-2004 mark-recapture data presented in Sasso et al. (2006), and incorporated another year of data collected during 2005; as well as, live resighting and dead recovery data collected from 1998 to 2006. This is the first estimate of realized survival for juvenile Atlantic Loggerhead Sea Turtles from the US Atlantic Coast.

MATERIALS AND METHODS

To estimate realized survival, we analyzed data collected between June and August, from 1998 to 2006, during an on-going mark-recapture study of sea turtles in a study area of 18.68 km^2 in central Core Sound, North Carolina (Fig. 1) (for details see Sasso et al. 2006). Turtles ranged in size from 42.3 to 102.0 cm (mean = 63.9 ± 7.36 cm standard straight carapace length), and the majority were small neritic juveniles. We define juvenile as an individual

< 90 cm, which is the average size of putative first time nesters (NMFS 2001). Sasso et al. (2006) captured juveniles by sampling five to eight pound nets twice per week, double flipper tagged and PIT (passive integrated transponder) tagged each turtle, and then released them at their point of capture.

We obtained dead-recovery data from tag returns reported to the Cooperative Marine Turtle Tagging Program (CMTTP). The CMTTP is a centralized sea turtle tagging program maintained by the Archie Carr Center for Sea Turtle Research (ACCSTR) developed to distribute tags, manage tagging data, and facilitate exchange of tag information (Archie Carr Center for Sea Turtle Research. 2004. Cooperative Marine Turtle Tagging Program http://accstr.ufl.edu/cmttp.html. Last accessed 6 April 2007). We obtained live-sighting data from the CMTTP, other studies by the NMFS in North Carolina, and from other individuals and agencies working along the Atlantic coast of the United States.

We analyzed all forms of data from Loggerhead Sea Turtles using the Barker model (Barker 1997; Barker et al. 2004) in program MARK (White and Burnham 1999) to estimate realized annual survival rate where (Barker et al. 2004):

S_i – probability an animal alive at time i survives to time i+1
p_i – probability an animal is alive and available for capture at time *i* is captured at time *i*
r_i – probability an animal that dies between *i* and *i*+1 is found and reported
R_i – probability an animal alive at *i* and *i*+1 is resighted between *i* and *i*+1
R'_i – probability an animal alive at time *i* and dead by time *i*+1 without being reported dead is resighted alive between *i* and *i*+1
F_i – probability an animal alive and at risk of recapture at *i* is at risk of capture at *i*+1
F'_i – probability an animal alive and not at risk of capture at *i* is at risk of capture at *i*+1.

If one sets $F'_i = F_i$ for all *i*, then the random temporary emigration model is obtained where the probability of being at risk of capture at time *i*+1 does not depend on risk of capture at time *i*, and if $F'_i = 0$, the permanent emigration model is created where an animal leaves the 'at risk of capture' part of the population (Barker et al. 2004). Additionally, a model of Markovian temporary, or random, emigration (probability of being at risk of capture at time *i*+1 depends on risk of capture at time *i*) can be modeled. The random emigration model is specified by allowing F_i and F'_i to vary by time period or be time period independent, thereby addressing the issue of stochasticity.

A previous analysis of the mark-recapture data (Sasso et al. 2006) indicated that transients in this data set are important, and no evidence of temporary emigration exists. Also, time-independent estimates of apparent survival ranked as the best models of the data when transients were accounted for (Sasso et al. 2006). As such, we elected to test whether models that accounted for the transients in the survival estimates ranked highest by specifying survival as a two-age parameter with age one representing the period after first capture and age two representing annual survival for each interval between trapping periods two through seven for individuals captured at least twice and, therefore, considered residents.

We modeled survivorship as time-dependent (*t*), time-independent (.), or two-age as described (2age). We limited movement models to the permanent emigration and random emigration models, and all other parameters as time-dependent or time-independent. We ranked and selected models using the quasi-likelihood corrected form of Akaike's Information Criterion (QAICc) (Hurvich and Tsai 1989; Burnham and Anderson 1992, 1998; Anderson et al. 1998).

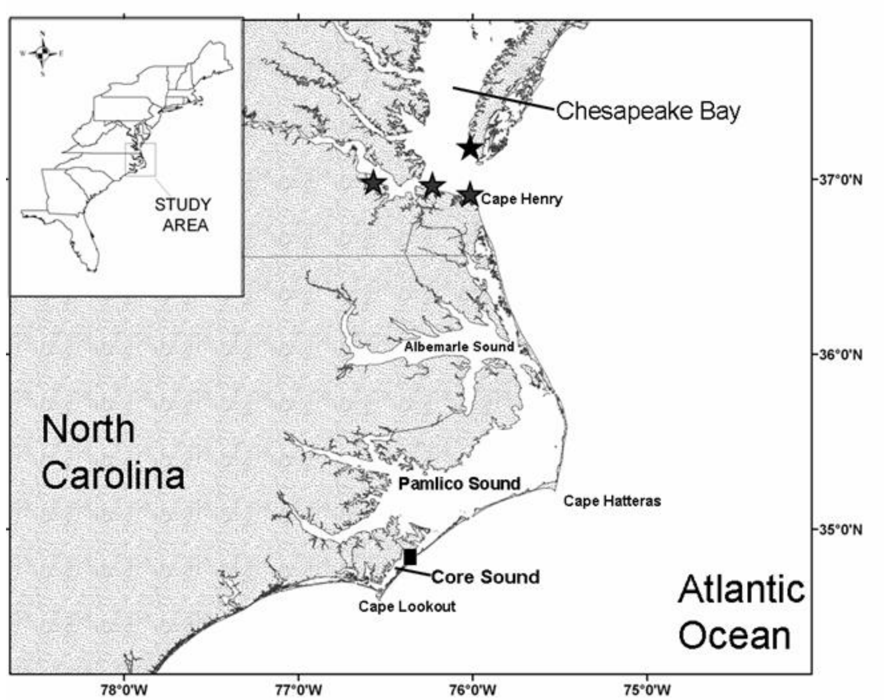

FIGURE 1. Study area from which live sighting and dead recovery data came. Stars represent dead turtles recovered outside North Carolina, USA. Box in Core Sound encompasses the area in which pound nets were sampled.

TABLE 1. Summary of Models from Program MARK where S_i – probability an animal alive at time i survives to time i+1; p_i – probability an animal is alive and available for capture at time *i* is captured at time *i*; r_i – probability an animal that dies between *i* and *i*+1 is found and reported; R_i – probability an animal alive at *i* and *i*+1 is resighted between *i* and *i*+1; R'_i – probability an animal alive at time *i* and dead by time *i*+1 without being reported dead is resighted alive between *i* and *i*+1; F_i – probability an animal alive and at risk of recapture at *i* is at risk of capture at *i*+1; F'_i – probability an animal alive and not at risk of capture at *i* is at risk of capture at *i*+1.

Model	QAICc	ΔQAICc	QAICc Weights	Model Likelihood	Number of Parameters
S(2age) *p*(*t*) *r*(*t*) *R*(*t*) *R'*(.) *F*(.) *F'*(.) = 0	1681.12	0.00	0.37	1.00	27
S(2age) *p*(*t*) *r*(.) *R*(*t*) *R'*(.) *F*(.) *F'*(.) = 0	1681.21	0.09	0.35	0.96	20
S(2age) *p*(*t*) *r*(*t*) *R*(.) *R'*(.) *F*(*t*) *F'*(.) = 0	1682.78	1.66	0.16	0.44	20
S(2age) *p*(*t*) *r*(.) *R*(.) *R'*(.) *F*(.) *F'*(.) = 0	1683.25	2.13	0.13	0.35	13
S(*t*) *p*(*t*) *r*(*t*) *R*(*t*) *R'*(*t*) *F*(*t*) *F'*(*t*)	1749.86	68.73	0.00	0.00	48

We then used a parametric bootstrap approach in program MARK to determine the goodness-of-fit (GoF) of the best model as determined by QAICc values and QAICc model weights. A probability > 0.05 indicated an acceptable fit. We adjusted these models to account for overdispersion with ĉ (a variance inflation factor) calculated as the observed ĉ from the original data divided by the mean ĉ from the bootstrap simulations in Program MARK (Burnham et al. 1987). Only survival and capture probability are reported here as they are the parameters of interest. We used the model averaging routine in Program MARK to get the final estimates.

RESULTS

There were 746 individual tagged Loggerhead Sea Turtles with 100 live recaptures or resightings and 35 dead recoveries. All dead recoveries were from North Carolina with the exception of three from Virginia and one from Maryland (Fig. 1). The two-age survival models that accounted for transients ranked highest, with the time dependent and time independent survival models not supported (Table 1). The permanent emigration model of movement appears to best fit the data as our analysis ranked the random emigration models poorly. The global model [*S*(*t*) *p*(*t*) *r*(*t*) *R*(*t*) *R'*(*t*) *F*(*t*) *F'*(*t*)], which did not account for transients, was a poor model for the data (weight = 0; Δ_{QAIC} = 68.73; Table 1).

The best model (*S*(2age) *p*(*t*) *r*(*t*) *R*(*t*) *R'*(.) *F*(.) *F'*(.) = 0) was appropriate for the data based on the bootstrap procedure (*P* = 0.37). Models were adjusted by the estimated ĉ of 1.16. The model averaged parameter estimates from the top four models (Table 1), estimated realized survival to be 0.37 (95% CI 0.29-0.47) for age 1 (transients and residents) and 0.83 (95% CI 0.74-0.89) for age 2 (residents) (Table 2). Estimates of probability of capture ranged from 0.07 (95% CI 0.03-0.17) to 0.42 (0.25-0.61) (Table 2).

DISCUSSION

Prior analyses of data collected for this study demonstrated that transients represented a significant component of the population (Sasso et al. 2006). So, it was not surprising that the best models for the data were those accounting for transients and modeled movement as permanent emigration. We seldom encounter adult Loggerhead Sea Turtles in pound nets in this region. This suggests that large juveniles may emigrate from the area as they mature. Our estimate of annual realized survival of juvenile Loggerhead Sea Turtles [0.83 (0.74-0.89)] is an improvement over apparent survival (Sasso et al. 2006) [0.81 (0.69-0.93)], because realized survival accounts for emigration and reduces the confidence interval around the estimate. However, the difference between the two point estimates is minimal given that we predicted transients would cause the estimate of apparent survival to be lower than realized survival.

Francis and Cooke (1993) noted a large difference between apparent and realized survival of snow geese when rates of emigration are high (i.e., transients), and mortality and permanent emigration are confounded. Although our analysis distinguished between mortality and emigration, we may have underestimated realized survival as only 135 (18%) of the 749 individuals we tagged were recaptured, resighted, or recovered dead. Despite the high capture effort maintained within the study area, the large number of transients in the study population combined with the lack of other in-water studies, results in a low probability that turtles would be sighted and/or reported.

Earlier estimates of apparent survival for juvenile Loggerhead Sea Turtles in the United States were 0.68 and 0.70 (Frazer 1987) and 0.893 (NMFS 2001). However, investigators derived these estimates from catch-curve

TABLE 2. Parameter estimates averaged from the four best models. Survival Age 1 represents the interval immediately following first capture and includes transients and residents. Survival Age 2 represents individuals captured at least twice and considered residents. p_i represents the probability of capture for individuals at risk of capture in each of the periods from *i* = 2 to *i* = 8.

Parameter	Estimate (95% CI)
Survival Age 1*	0.37 (0.29-0.47)
Survival Age 2**	0.83 (0.74-0.89)
p_2	0.22 (0.10-0.44)
p_3	0.42 (0.25-0.61)
p_4	0.26 (0.15-0.43)
p_5	0.17 (0.09-0.30)
p_6	0.21 (0.12-0.35)
p_7	0.07 (0.03-0.17)
p_8	0.12 (0.05-0.24)

*transients and residents
**residents only

analyses of strandings data. Consequently, they should be viewed with caution because they assume equal cohort sizes for each year, incorporate no information about the observed fate of individuals, and provide no estimate of variability. Additionally, both Frazer (1987) and NMFS (2001) provided survival estimates from the period when turtle excluder devices (TEDs) were not required for shrimp trawlers. The use of TEDs since 1990 should have improved survival rates accordingly (Crowder et al. 1994).

Our estimate of realized survival (0.83) is higher than Frazer (1987) and lower than NMFS (2001). This suggests that the estimates of Frazer (1987) were closer to the realized survival rates when TEDs were not required and that the NMFS (2001) value may overestimate juvenile Loggerhead Sea Turtle survival in the United States. Despite the effectiveness of TEDs at reducing strandings (Crowder et al. 1995), mortality of large neritic stage loggerheads continued to be extremely high (Epperly and Teas 2002) resulting in additional federal TED regulations (National Marine Fisheries Service 2003). Thus, use of TEDs may not have increased survival rates as much as suggested by the NMFS (2001) analysis. Alternatively, we may have underestimated realized survival for reasons stated above.

If survival is lower than the 0.893 estimate used for population models by NMFS (2001), then we may need new modeling exercises that incorporate the revised survival estimates so that managers can make informed decisions regarding the long-term recovery of Loggerhead Sea Turtles. In any case, our confidence interval for survival of 0.74 to 0.89 is useful to provide biologically realistic bounds for juvenile Loggerhead Sea Turtle survival in a stochastic population model. The discrepancy between recent estimates of survival and those obtained previously using different methods, suggests that collaborative in-water tagging studies should be conducted in other areas along the United States Atlantic coast to provide additional data that can be used to estimate survival and other population parameters.

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