Chelonian Conservation and Biology, 1999, 3(3):501–504

Long-Term Trends in Size of Stranded Juvenile Loggerhead Sea Turtles (*Caretta caretta*)

C. ROBERT SHOOP[1,2], CAROL A. RUCKDESCHEL[2], AND ROBERT D. KENNEY[3]

[1]*Department of Biological Sciences, University of Rhode Island, Kingston, Rhode Island 02881 USA;* [2]*Cumberland Island Museum, P.O. Box 796, St. Marys, Georgia 31558 USA;* [3]*Graduate School of Oceanography, University of Rhode Island, Narragansett, Rhode Island 02882 USA [Fax: 401-874-6497; E-mail: rkenney@gsosun1.gso.uri.edu]*

In a stage-based population model for loggerhead sea turtles (*Caretta caretta*), Crouse et al. (1987) showed that survival of the pre-adult or large juvenile stage had the greatest effect on population growth, in part because of the prolonged time to sexual maturity. Since size is closely correlated with age in juvenile loggerheads (Zug et al., 1986; Parham and Zug, 1998), monitoring the juvenile size classes may allow prediction of changes in relative numbers of future nesting adults. Given the great mortality of sea turtles, especially juvenile loggerheads, along the Atlantic and Gulf of Mexico coasts during past decades (National Research Council, 1990), we sought to determine if there was any change or trend in the sizes of stranded, dead juvenile loggerheads found at a single location, Cumberland Island, Georgia. We tracked the sizes of stranded individual juveniles from a western North Atlantic population for 20 years and herein report significant long-term trends in size and speculate on possible reasons for the changes. The period of the study encompasses years both before and after the institution of required use of Turtle Excluder Devices (TEDs) in commercial shrimp trawl nets in 1991, making it possible to address the efficacy of TEDs using the Cumberland Island stranding data.

Very small juveniles are not usually found along the United States shore because hatchlings swim eastward to drifting *Sargassum* and become entrained in the North Atlantic gyre, and most spend their early years in the eastern Atlantic (Carr, 1987; Musick and Limpus, 1997). They apparently continue their journey near the Azores and Canary Islands and return to North American waters via the North Equatorial Current (Carr, 1987). Brongersma (1972) noted that the smallest size classes in the North Atlantic were seen along the European shore. Juveniles may be 8–10 years old at more than 40 cm in carapace length (Parham and Zug, 1998) by the time they join the near-shore foraging population along the eastern United States coast, and at any specific locality progeny from many nesting areas may be present. Each year, thousands of these juveniles, most apparently healthy prior to death, strand (wash up) on beaches from New England southward (National Research Council, 1990).

Methods. — From 1979 through 1998 we surveyed the ocean beach (ca. 27 km) of Cumberland Island, Georgia, USA, for stranded sea turtles at least weekly, often daily, and always in response to notification of a stranding. Frequent National Park Service patrols and visitor reports assured thorough coverage of the beach, so that we probably encountered most, if not all, stranded sea turtles. During necropsies, one of us (CAR) measured curved carapace length (CCL) to the nearest 0.5 cm from the cervical notch to the rearmost border of the last marginal (supracaudal) scute. An earlier experiment (Shoop and Ruckdeschel, 1986) established that the precision for repeated measurements on the same carapace for CAR was ± 0.5 cm, which was much lower than the ± 6.5 cm error range for the entire group of individuals tested. In order to maximize our precision we therefore excluded from length analysis all specimens with estimated carapace lengths (incomplete, falling apart, or dried and distorted carapaces), and those measured by other individuals.

Since some loggerheads begin to mature sexually upon reaching a CCL of about 85 cm (Dodd, 1988), we excluded turtles greater than that size for this study, and arbitrarily defined 10-cm size classes starting at 45.5 cm. Data were analyzed using Statistical Analysis System software (SAS for Windows version 6.12; SAS Institute, Cary, NC). Statistical analysis of the temporal trend in carapace length was conducted via quadratic least-squares regression using the SAS general linear models procedure (PROC GLM). The regression analysis used the individual CCL measurements vs. year of the study (with 1979 as year 1) as the independent variable. All other regressions were run using PROC GLM in linear mode. Graphical depictions of stranding frequencies and the regression analysis were done using options in PROC GCHART and GPLOT.

Results. — A total of 1148 juvenile loggerheads (CCL < 85 cm) was recorded, of which we excluded 188 specimens with unreliable length measurements. Thus, 960 juveniles were available for the length analysis. After initially high stranding rates in 1979 and 1980, annual numbers of stranded juveniles were lower, but fluctuated through the remaining years (Fig. 1). The very high stranding numbers in 1979 and 1980 corresponded to high shrimp landings in those two years; landings in 1979 and 1980 were greater than in any single year in the succeeding decade and were 49 and 29% higher, respectively, than the 1981–90 average (Georgia Dept. of Natural Resources statewide fishery landings data). There was no significant long-term trend in stranding numbers (slope = –2.08; $p = 0.192$) with all of the years included. If the 1979 and 1980 data are excluded, however, there is a small but statistically significant long-term increase in overall stranding rate of 1.67 turtles/yr (SE = 0.53; $p = 0.006$). Repeating the same analysis only for the years 1991 through 1998, when TED use might have been expected to result in a decrease in strandings, showed an even greater annual increase in stranding rates of 3.65 turtles/yr (SE = 1.46; $p = 0.046$).

The mean size of juvenile loggerheads stranded on Cumberland Island was lowest in 1991, when it was 60.25

cm (Table 1). Both the trend in annual mean sizes and the quadratic regression showed that stranded juveniles decreased in size through the 1980s, reached a minimum in the early 1990s, and then began to increase in the later 1990s (Table 1; Fig. 2). The quadratic regression resulted in the following equation:

$$CCL = 69.899 - 0.777 \text{ Year} + 0.0249 \text{ Year}^2 \; [r^2 = 0.073]$$

The declining trend was steepest in the earlier part of the study, before the institution of TED regulations. Including only data from 1979 through 1991 in a linear regression results in a decrease in size of 4.89 mm/yr (SE = 0.73; $p < 0.001$; $n = 643$). The mean CCL predicted by the quadratic regression for 1979 is 69.15 cm, slightly smaller than the actual mean value of 69.94 cm (Table 1). The predicted values reach a minimum between 1993 and 1994 (63.85 and 63.84, respectively). If the current increasing trend continues, mean carapace length should return to 1979 levels around 2008 or 2009 (predicted values of 69.00 and 69.74 cm, respectively).

Up to 1991 the annual proportions within the 10-cm size classes revealed a shift in relative abundance from larger to smaller juveniles (Table 1). After 1991 the size class 55.5 to 65 cm began increasing, except for 1993 and 1995. Percentages of the largest size class were uniformly low in the 1990s (0 to 6.3%) but in 1996 increased to 11.1%. The mean size of stranded juveniles in 1998 (64.4 cm) was still significantly smaller than in 1979 (69.9 cm; t-test: t = 4.74; df = 196; $p < 0.001$).

There were no significant trends in numbers of strandings per year for 1981 through 1991 within any of the four juvenile size classes. For 1991 through 1998 only, there were similarly no significant trends in the two smallest classes, but the 65.5–75 cm class significantly increased in strandings by 0.81 per year ($p = 0.039$, $n = 8$), and the 75.5–85 cm class increased by 0.60 per year ($p = 0.005$). For all years (1981–98, eliminating 1979 and 1980 because of potential bias), there was a significant trend only in the 55.5–65 cm class — an increase of 1.14 strandings per year ($p = 0.002$).

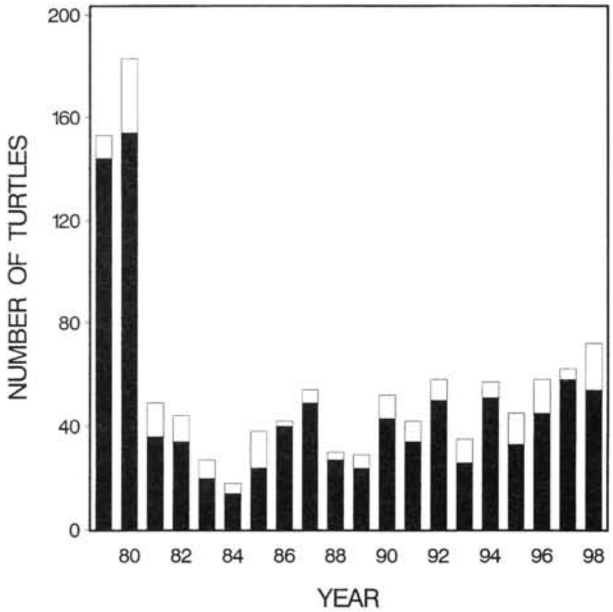

Figure 1. Numbers of juvenile loggerhead sea turtles (*Caretta caretta*) stranded on Cumberland Island, Georgia, USA, 1979–98. The solid bars show turtles measured by CAR and included in size analyses ($n = 960$); the open bars show those with only estimated lengths or measured by others ($n = 188$).

Table 1. Size-frequency distribution in 10-cm size classes (as number and percentage of turtles per size class each year), and mean size (with standard deviation) of stranded juvenile loggerhead sea turtles from Cumberland Island, Georgia, USA, 1979–98 ($n = 960$).

	Size Class (cm)					
Year	45.5-55.0	55.5-65.0	65.5-75.0	75.5-85.0	Mean (SD)	Total
1979	1/0.7%	38/26.4%	66/45.8%	39/27.1%	69.94(7.38)	144
1980	7/4.6%	53/34.4%	73/47.4%	21/13.6%	67.54(7.01)	154
1981	3/8.3%	16/44.4%	13/36.1%	4/11.1%	65.21(7.64)	36
1982	1/2.9%	11/32.4%	19/55.9%	3/8.8%	67.98(6.19)	34
1983	0/0.0%	7/35.0%	8/40.0%	5/25.0%	69.08(7.37)	20
1984	3/21.4%	5/35.7%	6/42.9%	0/0.0%	63.68(7.79)	14
1985	3/12.5%	7/29.2%	11/45.8%	3/12.5%	67.21(8.49)	24
1986	4/10.0%	17/42.5%	8/20.0%	11/27.5%	67.60(9.34)	40
1987	6/12.2%	20/40.8%	17/34.7%	6/12.2%	65.29(8.58)	49
1988	2/7.4%	10/37.0%	10/37.0%	5/18.5%	66.72(8.73)	27
1989	0/0.0%	11/45.8%	10/41.7%	3/12.5%	66.52(7.23)	24
1990	6/14.0%	20/46.5%	16/37.2%	1/2.3%	62.83(6.28)	43
1991	9/26.5%	17/50.0%	8/23.5%	0/0.0%	60.25(7.51)	34
1992	9/18.0%	27/54.0%	12/24.0%	2/4.0%	62.18(7.01)	50
1993	*5/19.2%	9/34.6%	11/42.3%	1/3.8%	63.56(8.88)	26
1994	*2/3.9%	31/60.8%	15/29.4%	3/5.9%	64.60(6.92)	51
1995	4/12.1%	12/36.4%	14/42.4%	3/9.1%	65.08(7.72)	33
1996	3/6.7%	26/57.8%	11/24.4%	5/11.1%	64.56(7.41)	45
1997	8/13.8%	30/51.7%	16/27.6%	4/6.9%	63.96(6.93)	58
1998	3/5.6%	32/59.3%	15/27.8%	4/7.4%	64.42(7.10)	54
79-91	45/7.0%	232/36.1%	265/41.2%	101/15.7%	66.98(7.88)	643
92-98	34/10.7%	167/52.7%	94/29.7%	22/6.9%	64.03(7.28)	317
Total	77/8.0%	399/41.6%	359/37.4%	123/12.8%	66.01(7.81)	960

* one individual < 45 cm

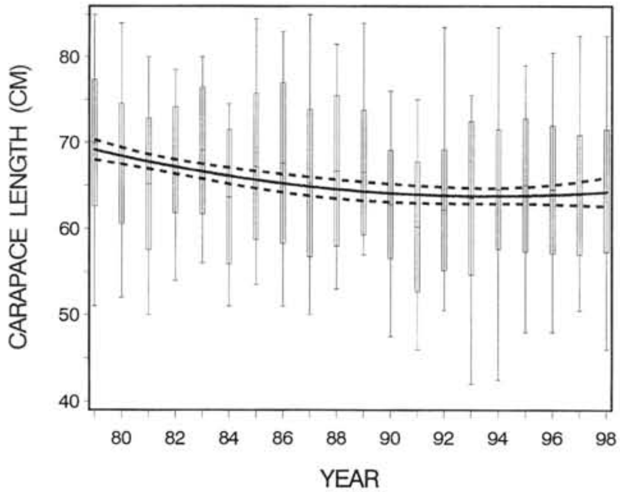

Figure 2. Distribution of curved carapace lengths of juvenile loggerhead sea turtles stranded on Cumberland Island, Georgia, USA, 1979–98 ($n = 960$). For each year the vertical line indicates the range, and the vertical box shows the mean ± 1 S.D. The solid line shows the quadratic regression of carapace length versus year (fit to the individual CCL data, which are not shown); the dashed lines are the 99% confidence limits on predicted mean length.

Discussion. — The stranded loggerheads on Cumberland Island likely represented many North Atlantic breeding populations (Bowen et al., 1993; Shoop et al., 1998), and their numbers do not necessarily indicate actual death rates since many variables govern the likelihood of a dead turtle washing up on shore. Epperly et al. (1996) estimated that only 7 to 13% of loggerheads killed in commercial fisheries stranded on shore during the winter in North Carolina. Westerly surface winds blow floating dead turtles out to sea where they are consumed by predators and scavengers or decay. Hence, our numbers probably represent only a fraction of the mortality in nearby waters.

Some unverified assumptions underlie our observations. We assume that the mortality we recorded represented the relative abundances of loggerhead size classes near shore, and that scavenger consumption of various sized carcasses was similar each year. During this study a shark gill-net fishery began operations off Cumberland Island and may have caused some mortality, although the fishery was active for only short periods of time. Because amounts and temporal aspects of mortality vary each year, and turtles grow at least some minimal amount each year, the size data incorporate increased variance because data collected through a year were pooled. Regardless of these caveats, the relatively large sample sizes and the use of measurements by a single investigator whose measurement variability (relative accuracy) was known reduce the measurement error, probably providing a true picture of the size structure of the Georgia near-shore, juvenile population, at least prior to TED requirements.

The enormous magnitude of sea turtle mortality along the Atlantic Coast results mainly from turtle interactions with commercial fisheries, primarily the shrimp trawling fishery (National Research Council, 1990). The very high numbers of strandings on Cumberland Island in 1979 and 1980, which mirror statewide stranding records for Georgia (M. Dodd, Georgia Dept. of Natural Resources, *pers. comm.*), correspond to high shrimp landings. The 1979–80 stranding levels are higher than can be attributed to differences in shrimping effort alone, and there are no comparable stranding data prior to 1979, therefore it is not possible to adequately assess the cause(s) of the high 1979–80 strandings, nor whether they were a long- or short-term phenomenon. The reversal in the long-term trend of declining size (i.e., the change in slope of the quadratic regression) of stranded juveniles in the early 1990s occurred after mandated use of turtle excluder devices (TEDs) in state waters began during summer months. That change, at the precise time TED use was required, seems more than coincidental. The fact that the slope reversal has continued supports the idea of a correlation between TED use and the size of stranded sea turtles. If, as suggested by preliminary results of an on-going study (S. Epperly, National Marine Fisheries Service, *pers. comm.*), TEDs are size-selective (e.g., for quick release of smaller juveniles but capture and subsequent mortality of larger juveniles), our stranding data from 1991 onward may reflect reduced mortality of smaller juveniles and continued mortality of larger juveniles rather than an increased proportion of larger juveniles in the population. Consequently, our assumption that strandings are representative of the relative abundances of size classes in the population may not be valid for data from 1991 and later. Alternatively, since the size range of juvenile recruits to the near-shore population is unknown, our observations may reflect a general decrease in the proportion of smaller (45.5 to 55 cm), new juvenile recruits from the pelagic population or an increase in recruitment of the 55.5 to 65 cm group.

Stranding rates of dead sea turtles on Cumberland Island did not show a decline with mandated TED use as reported for South Carolina by Crowder et al. (1995). In the Gulf of Mexico, Caillouet et al. (1996) showed that although there was a reduction in total strandings in 1990–93, there remained a statistical association between stranding rates and commercial fishing intensity. Renaud et al. (1997) reported more than an order of magnitude drop in incidental take of sea turtles in nets equipped with TEDs in the Gulf of Mexico and southern North Atlantic. It is important to stress that the relationship of stranding rate to population size is tenuous unless fishing effort, wind direction, water temperature, scavenger abundance, and other vagaries affecting stranding probabilities are quantified; consequently, caution is needed in relating stranding rates to actual mortality rates and thus population sizes.

Another potentially complicating factor involving assessment of TED effects on loggerhead population size structure is the observation (by M. Schwartz, Univ. of Rhode Island, *pers. comm.*) that green sea turtles held underwater for up to 40 minutes at 28°C may survive the immersion and appear to recover from the effects of anoxia, only to die hours later of what appears to be irreversible shock. If loggerheads respond in the same way after becoming at least partially anoxic before being released from a net, such response could help explain the continued mortality in spite of TED use. Additionally, if smaller turtles are less likely to suffer stress or become anoxic, or escape from the net faster than larger animals, perhaps the use of TEDs might selectively increase the likelihood of small juvenile survival, but not reduce mortality of larger juveniles. Another possible explanation for the continued mortality, or even slightly increasing mortality in the case of larger juveniles, is that turtle abundance has significantly increased at the same time that TED use has actually decreased the rate of mortality by about the same proportion. Other alternatives include increases in fishing effort while mortality rate is decreasing, disablement or removal of TEDs by shrimpers, deaths of turtles after frequent sequential captures and releases from nets with TEDs, increasing impact of other commercial fisheries, or the vagaries governing likelihood of washing on shore while comatose or dead. It is clear that sea turtle mortality still occurs in the shrimp fishery. In 1999, the numbers of turtle strandings in Georgia dropped precipitously with enforcement of regulations through boardings of shrimp trawlers by federal and state enforcement personnel (M. Dodd, Georgia Dept. of Natural Resources, *pers. comm.*).

Regardless of the causes for the observed changes, the mean size (64.4 cm CCL) of stranded loggerhead juveniles smaller than 85.5 cm was significantly smaller in 1998 than it was 19 years earlier (69.9 cm). These data suggest that the high mortality caused by commercial fishing is still having an effect on western North Atlantic loggerhead populations. Finally, while there was a leveling of the decline in size of stranded juveniles and an eventual upturn following mandated TED use, our data are insufficient to statistically confirm a cause-and-effect relationship between TED use requirements and the change in size trend.

Acknowledgments. — The Georgia Department of Natural Resources, National Park Service, U.S. Fish and Wildlife Service, Cumberland Island Museum, and University of Rhode Island provided support for this study. Numerous individuals notified us of strandings and aided in many ways. Sheryan Epperly provided an excellent and very helpful critique of the manuscript. We thank them all.

Literature Cited

BOWEN, B., AVISE, J.C., RICHARDSON, J.I., MEYLAN, A.B., MARGARITOULIS, D., AND HOPKINS-MURPHY, S.R. 1993. Population structure of loggerhead turtles (*Caretta caretta*) in the northwestern Atlantic Ocean and Mediterranean Sea. Conserv. Biol. 7:834-844.

BRONGERSMA, L.D. 1972. European Atlantic turtles. Zoologische Verhandelingen 121:1-317.

CAILLOUET, C.W. JR., SHAVER, D.J., TEAS, W.G., NANCE, J.M., REVERA, D.B., AND CANNON, A.C. 1996. Relationship between sea turtle stranding rates and shrimp fishing intensities in the northwestern Gulf of Mexico: 1986-1989 versus 1990-1993. Fish. Bull. 94(2):237-249.

CARR, A. 1987. New perspectives on the pelagic stage of sea turtle development. Conserv. Biol. 1(2):103-121.

CROUSE, D.T., CROWDER, L.B., AND CASWELL, H. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology 68:1412-1423.

CROWDER, L.B., HOPKINS-MURPHY, S.R., AND ROYLE, J.A. 1995. Effects of turtle excluder devices (TEDs) on loggerhead sea turtle strandings with implications for conservation. Copeia 1995(4):773-779.

EPPERLY, S.P., BRAUN, J., CHESTER, A.J., CROSS, F.R., MERRINER, J.V., TESTER, P.A., AND CHURCHILL, J.H. 1996. Beach strandings as an indicator of at-sea mortality of sea turtles. Bull. Mar. Sci. 59:289-297.

MUSICK, J.A., AND LIMPUS, C.J. 1997. Habitat utilization and migration of juvenile sea turtles. In Lutz, P.L., and Musick, J.A. (Eds.). The Biology of Sea Turtles. Boca Raton, FL: CRC Press, pp. 137-167.

NATIONAL RESEARCH COUNCIL. 1990. Decline of the Sea Turtles: Causes and Prevention. Washington: National Academy Press, 259 pp.

PARHAM, J.F., AND ZUG, G.R. 1998. Age and growth of loggerhead sea turtles (*Caretta caretta*) of coastal Georgia: an assessment of skeletochronological age-estimates. Bull. Mar. Sci. 61(2):287-304.

RENAUD, M.L., NANCE, J.M., SCOTT-DENTON, E., AND GITSCHLAG, G.R. 1997. Incidental capture of sea turtles in shrimp trawls with and without TEDs in U.S. Atlantic and Gulf waters. Chelonian Conservation and Biology 2:425-427.

SHOOP, C.R., AND RUCKDESCHEL, C.A. 1986. Sea turtle measurements. Marine Turtle Newsl. 36:10-12.

SHOOP, C.R., RUCKDESCHEL, C.A., AND KENNEY, R.D. 1998. Female-biased sex ratio of juvenile loggerhead sea turtles in Georgia. Chelonian Conservation and Biology 3:93-96.

ZUG, G. R., WYNN, A. H., AND RUCKDESCHEL, C. 1986. Age determination of loggerhead sea turtles, *Caretta caretta*, by incremental growth marks in the skeleton. Smithsonian Contrib. Zool. 427:1-34.

Received: 29 April 1998
Reviewed: 19 April 1999
Revised and Accepted: 15 October 1999

Chelonian Conservation and Biology, 1999, 3(3):504–507

Effects of Short-Term Water Temperature Variation on Food Consumption in Painted Turtles (*Chrysemys picta marginata*)

KRISTIE D. GIANOPULOS[1,2] AND JOHN W. ROWE[1]

[1]*Department of Biology, Daemen College, Amherst, New York 14226 USA;* [2]*Present Address: Department of Biology, University of South Florida, Tampa, Florida 33620 USA*

In ectotherms, the thermal environment influences food acquisition by affecting movement patterns, foraging activity and success, and digestive rates and efficiency (Parmenter, 1981; Huey, 1982), ultimately constraining individual growth rate, survival, and reproduction (Congdon, 1989). Variation in thermal environments appears to be an important determinant of life history variation (i.e., body size and reproductive output) in freshwater turtles (Congdon and Gibbons, 1983; Dunham and Gibbons, 1990). Temperature and digestive efficiency are positively related (Kepenis and McManus, 1974; Parmenter and Avery, 1990; Avery et al., 1993) and long-term (2 to 36 wks) acclimation to different temperatures can influence