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NOTE

COMPARISON OF STRAIGHT-LINE AND OVER-THE-CURVE MEASUREMENTS FOR GROWTH RATES OF GREEN TURTLES, *CHELONIA MYDAS*

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Knowledge of growth rates of wild green turtles, *Chelonia mydas,* are essential to our understanding of their demography and to our ability to evaluate management options for this endangered species. The few studies of growth rates in wild green turtles are divided between those based on straight-line (SL) and those based on over-the-curve (OC) measurements (see review in Bjorndal and Bolten, 1988). The need to compare SL and OC growth rates has been discussed (Limpus, 1985; Frazer and Ladner, 1986; Bjorndal and Bolten, 1988). To allow comparisons, we recorded SL and OC carapace measurements and calculated growth rates based on both types of measures for a population of immature green turtles in the southern Bahamas. Conversion equations were derived from these data.

METHODS

The study site on Great Inagua, Bahamas, is a tidal bay of approximately 20 km^2, which is a natural feeding area for green turtles. The area is a wildlife sanctuary of the Bahamas National Trust and is fenced to protect the turtles from hunting. The area is described in greater detail by Bjorndal and Bolten (1988).

Three trips from 1986–1988 yielded 335 captures of 236 turtles. Turtles were tagged, measured and released. Measurements taken were SL carapace length from anterior point of midline (nuchal notch) to posterior end of posterior marginal (SLCL), SL carapace length from anterior to posterior point of midline (nuchal notch to posterior notch) (SLCLm), SL carapace width at widest point (SLCW), OC carapace length from nuchal notch to posterior notch (OCCL) and OC carapace width at the same reference points as SLCW (OCCW). Sample sizes of the parameters vary because measurements were not included if the carapace was abnormal (e.g., chipped posterior marginals), and OCCW was not measured in 1988. The most appropriate comparison between SL and OC carapace length (CL) measures is between SLCLm and OCCL because they have the same morphological reference points. SLCL data are included because SLCL is considered the standard measure of CL (Pritchard et al., 1983).

Measurements were made with anthropometer calipers (GPM model 101) for SL and with a flexible, fiberglass measuring tape for OC. All measurements were taken to the nearest 0.1 cm. Every measurement was made by one of us (ABB) and recorded by the other (KAB) to avoid individual differences in measurement technique, a major source of error in growth data. We determined mean discrepancy for OCCL by measuring a group of 27 green turtles and then remeasuring them. Mean discrepancy was calculated as the mean of the absolute difference between the first and second measure of the 27 pairs of measurements. Mean discrepancy had already been determined for SL measurements (Bjorndal and Bolten, 1988).

Simple linear regressions were used with SL measures as independent variables and OC measures as dependent variables. Measurement error of the independent variable (SL measure) is significantly less than that of the dependent variable (OC measure, see below), thus that assumption of simple linear regression is met (Zar, 1984). All regressions also met the assumptions of homogeneous variance about the regression line and normal distribution of the residuals about the line. Significance of regression coefficients was tested according to Zar (1984). Unless otherwise stated, alpha = 0.05.

RESULTS AND DISCUSSION

OC growth rates were regressed against SL growth rates to determine if the regression coefficient is significantly greater than 1. For carapace lengths and width,

Table 1. Regressions of straight-line and over-the-curve carapace measurements. All F values are significant ($P < 0.0001$). See text for abbreviations. Two forms of the CW equation are presented to facilitate conversions

Equation	df	r^2	F
Carapace Length Conversions			
OCCL = −0.414 + 1.039 SLCL	326	0.997	99,283
OCCL = −0.028 + 1.051 SLCLm	328	0.998	145,796
Carapace Width Conversions			
log OCCW = −0.085 + 1.092 log SLCW			
or OCCW = 0.822 ($SLCW^{1.092}$)	205	0.986	14,346

the regression coefficients of growth rates are significantly greater than 1 (one-tailed test): for OCCL vs. SLCL $t = 1.882$, df = 93, $P < 0.05$; for OCCL vs. SLCLm $t = 4.911$, df = 95, $P < 0.0001$; for OCCW vs. SLCW $t = 3.126$, df = 26, $P < 0.0025$. Thus, OC growth rates are significantly greater than SL growth rates, and the two cannot be directly compared.

Comparison of OC and SL growth for small growth increments can be misleading because the two growth rates may be indistinguishable. For example, based on the regression coefficients presented in Table 1, the growth increment for CL must be at least 2 cm before the difference in growth of OC and SL will be detectable if measurements are recorded to ±0.1 cm.

Equations to convert between OC and SL measurements can be generated from the OC and SL measurements for the range of body sizes measured in this study: OCCL = 26–77 cm, SLCL = 25–74 cm, SLCLm = 25–74 cm, OCCW = 26–61 cm, SLCW = 21–52 cm. Linear conversion equations can be used if there is a linear relationship between OC and SL measurements throughout the range of body size. To test whether the relationships are linear, the OC and SL measurements were log-transformed and regressed. The regression coefficients for OCCL vs. SLCL and OCCL vs. SLCLm were not significantly different from 1, indicating those relationships are linear. However, the regression coefficient of OCCW vs. SLCW is significantly different from 1 ($t = 10.121$, df = 205, $P < 0.0001$). As turtles increase in size, OCCW increases proportionally more rapidly than SLCW.

Therefore, CL measurements can be converted using linear equations with non-transformed data (Table 1). The CW conversion equation in Table 1 was generated from log-transformed data because the relationship between OCCW and SLCW is not linear. To compare OC and SL growth rates, measurements must first be converted using the equations in Table 1 and then growth rates calculated from these converted measurements. Theoretically, growth rates can be converted directly using the same equations as those used to convert measurements. However, using the equations in Table 1 to convert a 4-cm SL growth-increment would be equivalent to converting measurements for a 4-cm turtle—a size well out of the range of body sizes used to develop the conversion equations and thus an inappropriate extrapolation.

In comparing repeatability of measurements and coefficients of variation for growth rates for CL, CW and plastron length, Bjorndal and Bolten (1988) found that CL was the best linear measure of body size. But which CL measure is best? A significant, negative relationship exists between SLCL and SLCLm (regression of log-transformed data, $t = -2.150$, df = 326, $P < 0.05$). As green turtles grow, the posterior marginal notch, which is pronounced in young turtles, disappears,

Table 2. Precision of measurements expressed as discrepancy (mean ± standard deviation) between repeated measurements. See text for calculation and abbreviations. Sample size = N. Range of each body size parameter is given for the turtles measured. Means with different superscripts are significantly different (Mann-Whitney U, $P < 0.05$)

Parameter	N	Discrepancy (cm)	Range of turtle size (cm)
CL	26	$0.05^{a} \pm 0.06$	29.7–82.3
CLm	26	$0.06^{a} \pm 0.06$	29.1–81.8
OCCL	27	$0.11^{b} \pm 0.10$	32.3–70.1

so that SLCLm approaches SLCL in mature animals. Because the marginal points are susceptible to breakage and differential wear, SLCLm is the better measure.

SL measures are considered preferable to OC measures for sea turtle research (Pritchard et al., 1983) as well as for measurements of tortoises and freshwater turtles (Carr, 1952). In our study, both SLCL and SLCLm had significantly better precision (repeatability) than OCCL (Table 2). Limpus (1985) recorded SL measures to ±0.1 cm, but OC measures to ±0.5 cm. In addition, epibiotics can have a significant effect on the precision of OC measures. Green turtles usually have few epibiotics, but the carapaces of other sea turtle species are often heavily infested. For turtles growing at less than a few $\text{cm} \cdot \text{yr}^{-1}$, the growth or loss of epibiotics along the midline can have a significant effect on OC measures and on the calculation of growth rates.

Another consideration in selecting which parameter (SLCL, SLCLm or OCCL) to use to measure growth is the variation in growth rates based on the different measures. Coefficients of variation of growth rates measured in our study for SLCL, SLCLm and OCCL were 0.540, 0.512 and 0.570, respectively. The similar degree of variation among the parameters indicates that no parameter is better than the others in this regard.

Convenience would seem to be the only advantage of recording OC measurements. If OC measures are recorded, OCCL as described in this study should be used because it is the standard OC measure (Limpus, 1985) and because, if the tape leaves the carapace midline, much more variability is introduced.

A convention of adding 4 cm to SL carapace lengths of adult green turtles to estimate OC carapace lengths has been used (Hirth, 1980; Frazer and Ladner, 1986). To determine if this is a valid conversion, we solved the equations in Table 1 for those values of SLCL and SLCLm that yield values between 3.9 and 4.1 cm greater for OCCL (using ±0.1 as the acceptable precision for OCCL estimates). If our conversion equations hold for larger green turtles, adding 4 cm to SL measures to convert to OC measures is only accurate for turtles with SLCL between 111 and 116 cm or SLCLm between 77 and 81 cm.

The conversions reported here for SL and OC measures are based on one green turtle population and should be used with caution when comparing among populations. Conversions may differ for other populations of green turtles and will almost certainly differ for other species of sea turtles [see Frazer and Ehrhart (1983) for an equation for loggerheads, *Caretta caretta*]. Comparable equations need to be generated for other populations and species so that valid comparisons can be made.

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