SOME MORPHOHOMETRIC RELATIONSHIPS IN THE WESTERN ATLANTIC LOGGERHEAD TURTLE, *CARETTA CARETTA*

By

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ABSTRACT

Morphometric relationships are described for western Atlantic loggerhead turtles, *Caretta caretta*, over a size range of 44-114 cm total carapace length (14-172 kg in weight). Regressions of length and width (measured over-the-curve and straight-line) showed good linear fits in all combinations. Regressions of length and width on weight were best fitted to a power function. Condition factor (C), based on the length-weight relationship for adult and subadult turtles, varied seasonally, with lowest factors during winter months and highest during warmer periods of faster growth.

Relative growth of loggerhead turtle carapace dimensions changed as animals matured and resulted in an ontogenetic change in the shape of the older animals. Growth in adult turtles was restricted primarily to the longitudinal axis.

Formulae for conversion of four possible length measurements were developed for both over-the-curve and straight-line techniques. These formulae provided a means to compare previously published size information, despite differences in measurement techniques.

The relationship of total tail length to total straight-line carapace length was found to be an accurate

indicator of sex in mature male turtles, and is assumed to be a good indicator of sex in adult female turtles as well. In subadult turtles, the tail measurement does not appear to be a usable indicator of sex.

INTRODUCTION

Sea turtle researchers commonly measure carapace dimensions as a routine part of their tagging projects (Gallagher et al., 1972; Kaufmann, 1975; Worth and Smith, 1976; Davis and Whiting, 1977; Fletemeyer, 1982; Bjorndal et al., 1983). Several researchers have also weighed turtles as part of their standard measurement procedures (Hughes, 1974; Ehrhart and Yoder, 1978; Ehrhart, 1979). These data have been used to describe length, width and weight relationships in nesting females, and to document size compositions within discrete nesting populations. While these studies contain valuable information on specific assemblages of adult females, they are not always directly comparable because different measurements were taken. Nesting studies have been limited in their applicability to sea turtle populations as a whole, because only adult females were measured.

Here we describe eleven morphometric relationships in western Atlantic loggerhead turtles captured with trawling gear. This method of sampling provided a means of capturing adult males and females, and subadult turtles over a broad range of lengths and weights. Our results are of particular value because, for the first time, subadults and adult male turtles are included in the catch with adult female turtles; morphometric relationships in the population as a whole could be described. Total tail length measurements were included in our analyses to test the use of this alleged sexually dimorphic characteristic as an indicator of sex in subadult and adult turtles.

A final analysis of the length-weight relationship was performed, and coefficient of condition (C) values were calculated. These values provide a convenient means of assessing the general well-being of individual turtles within populations.

MATERIALS AND METHODS

Data collection

Since 1978 the National Marine Fisheries Service (NMFS) has been conducting sea turtle tagging and research activities in U.S. coastal waters from North Carolina to Texas. The U.S. Army Corps of Engineers (COE) has cooperated in sea turtle capture and relocation efforts in the Port Canaveral shipping channel, Florida (Moulding, 1981) and in surveys of several navigation channels on the east coast of Florida (Butler, NMFS, Mississippi Laboratories, unpublished MS). All captured loggerheads (4505 animals) were incorporated into a single data base for our analyses.

Although sampling strategies varied according to individual project objectives, all employed trawling gear in the capture of sea turtles and all captured turtles were treated in the same manner. Straight-line (SL) measurements of carapace width (distance across the widest part of the shell perpendicular to the longitudinal body axis) and total carapace length (distance from the anteriormost edge of the 1^{st} and 2^{nd} marginals to the posteriormost edge of the 11^{th} and 12^{th} marginals) to the nearest 0.1 inch were taken with calipers (Fig. 1). When feasible, turtles were weighed with beam scales to the nearest pound. All turtles were visually sexed (based on a subjective evaluation of the tail length to carapace length relationship), tags were applied and the turtles released.

Additional carapace measurements were taken on 736 turtles to provide a means of comparing our results with studies in which different measurements were taken. These included standard carapace length, notched carapace length and minimum carapace length (Fig. 1), as described in Pritchard et al. (1983). Four lengths and width were measured both over-the-curve (OC) with flexible tape and straight-line (SL) with calipers on each of the 736 animals. Tail length to the nearest 0.1 inch was measured with flexible tapes in 387 instances. The tail was measured from the posterior margin of the plastron to the tip of the tail, with the tail held in as normal extension as possible.

All measurements were converted to metric units for calculations and presentations. Length measurements used in regressions were SL total carapace length unless otherwise noted.

Data analysis

Linear regression analyses were employed in all pairings of weights, SL and OC lengths, SL and OC widths and total tail lengths. Bartlett's three group method for Model II regression (Sokal and Rohlf, 1969) was used, because both x and y measurements were subject to error.

The condition factor (C) based on the length-weight relationship from our regressions was calculated using the formula:

$C = W_o/W$

W_o = observed weight

W = predicted weight.

Mean condition factors were computed by month for subadult and adult turtles.

All records in which tail length was measured in conjunction with carapace length (387 turtles) were analyzed with Biomedical Computer Programs (BMDP) stepwise discriminant analysis procedures (BMDP, 1979). The variables used in the analysis were total tail length, total carapace length and the product of these two variables.

In regressions where adult and subadult turtles were separated, 83 cm total (SL) carapace length was selected as the size where visual sexing of adults was possible. This was based primarily on verification of adult male sex identifications through serum testosterone levels (Owens, 1983), and the assumption that all males have developed secondary sexual dimorphic characteristics at this size. However, it may not reflect the size at sexual maturity, since females smaller than 83 cm have been observed nesting.

RESULTS

Regression analyses of the variables SL carapace width on SL carapace length, OC carapace width on OC carapace length and OC carapace length on SL carapace length were performed (Fig. 2). Because each regression had a coefficient of determination (r^2) greater than .90, the majority of the variation could be explained by a linear regression model.

A comparison of our equation for OC length on SL length (OC = 1.07SL + 0.36; 95% c.i. of B = 1.07 ± 0.008) with that of Frazer and Ehrhart (1983) based on the same analytical procedure (OC = 1.02SL + 5.24; 95% c.i. of B = 1.02 ± 0.034) indicated that the slopes were different at the 95% significance level. As differences in the two equations may have been related to turtle size composition within the sample, the same analysis was done using only adult turtles. The slope of the resultant equation (OC = 1.02SL + 4.85; 95% c.i. of B = 1.02 ± 0.036) was the same as that of Frazer and Ehrhart (1983). Their data base was composed mainly of measurements from adult females.

The fact that the regression equation for a sample composed of adult turtles had a different slope than that for subadults, suggested that carapace relationships may change as turtles mature. To test for differences in carapace relationships, we subdivided the data into groups of adult males, adult females and subadult turtles. Regression of SL carapace width on SL carapace length was performed on each set of animals (Fig. 3A). The slopes of regression equations in both adult male and female turtles were the same, but were significantly different from subadult turtles. For this reason, separate equations for adult turtles and subadult turtles were computed for the remaining cases (Figs. 3B and C).

These analyses indicated that growth in carapace width and OC carapace length (a measure of body depth) was slower in adult turtles than in subadults. Significant differences in the slopes of adult and subadult equations imply that growth in adult turtles was predominantly longitudinal. These findings are in agreement with Uchida (1967), who proposed that growth in loggerhead turtles follows a postero-anterior gradient with greatest growth capacity toward the posterior parts of the animal.

Regressions of weight on SL and OC carapace lengths and widths were best fitted to a power function through log-log transformations (Fig. 4). For both measurement techniques, the weight/length regressions produced higher coefficient of determination (r^2) values than weight/width, an indication that this relationship was the better predictor of the two. Untransformed data were plotted in Figure 4 to demonstrate the curvilinear relationship of length and width to weight. Our computations, however, were based on log-log transformed data using length and width as the predictor (X) and weight as the response variable (Y).

An examination of the r^2 values from regressions (Figs. 2,3 and 4), revealed that OC measurements were slightly superior to SL measurements as predictors. To test for significant differences in correlation coefficients, OC width on length was compared with SL width on length using Fisher's z transformation (Kleinbaum and Kupper, 1978). The correlation coefficient from OC width on length (0.976 r 0.978; 95% c.i.) was significantly higher than SL width on length (0.961 r 0.966; 95% c.i.). While we demonstrated statistically significant differences in this instance, our large sample size resulted in narrow confidence bands. From a practical standpoint, the differences in r^2 values were small; the slight improvement in OC measurements might only be evident in very large samples and be of limited importance in normal application.

The use of tail length as a field method for determining the sex of turtles was appraised with stepwise discriminant analysis techniques. These procedures evaluated how much each variable explained the differences in the sexes and presented the differences as a spatial relationship (Fig. 5). From this plot, it was evident that adult males were well differentiated from the other groups, and that adult females and subadults were separated primarily on the basis of carapace length. Character differences among the groups were sufficient to allow correct classification of 96.6 percent of the individuals.

Because our sex identifications were based on visual observations, it was not possible to establish the sex of individuals less than 83 cm total carapace length. Results of discriminant analyses indicated that the tail measurement taken in conjunction with the carapace length measurement is probably an acceptable technique for determining the sex of adult turtles. In subadult turtles, no sexual dimorphism in tail length was evident, nor were there indications that the sexes of subadult turtles could be discriminated on the basis of these variables.

Straight-line and over-the-curve measurements of standard, notched and minimum carapace lengths (Fig. 1) were regressed on total carapace length and conversion formulae were derived (Table 1). These conversion formulae are useful for comparisons between studies employing different measurements. An application of these formulae is illustrated in a comparison of several published reports on range and mean size of female loggerhead turtles encountered on U.S. nesting beaches (Table 2). Examination of size of females in separate nesting populations that were measured using three different measurements, indicated a range in means of 90.3 to 95.9 cm (5.6 cm difference). Converting these values to a single measurement (in this case total carapace length) reduced the range of means to 3.2 cm, i.e., 92.7 to 95.9 cm.

Mean condition factors by month for subadult and adult loggerhead turtles were computed and results are presented in Table 3. The condition factor (C) for all data ranged from 0.96 to 1.07.

Our results indicated that mean condition factors were similar over all seasons and sizes of turtles (Table 3); however, the highest values occurred during spring and summer months. Lowest values were in the fall and winter seasons when decreased feeding activity and growth were expected. The condition factor (C) best illustrates the seasonality of condition factors in subadult turtles; November to March conditions were lower than 1.0 and with the exception of June, April to October conditions were above 1.0.

DISCUSSION

Results of these investigations have made it possible to describe some relationships in body dimensions of loggerhead turtles. The large quantities of measurement data used in the analyses allow one to discern changes in some morphometric relationships with age, size or stage of sexual development, and to speculate on the significance of these changes to the growth and general biology of turtles.

The fact that carapace length, width and body depth relationships differed significantly in adult and subadult turtles indicated that carapace shape changed as turtles matured. These changes were probably gradual and do not reflect an abrupt change in the growth patterns. The observed statistical differences in the slopes of subadult and adult regressions were influenced by our large sample sizes. We speculate that growth in adult turtles may be restricted primarily to the longitudinal axis, while growth in subadults may have larger latitudinal and vertical components.

The regressions of weight on length and width indicated that the weight/length relationship was the better predictor of the two; the length measurement was less variable than the width measurement. This observation supports our contention that turtle growth may continue along the longitudinal axis in adults.

Carr (1952) noted that the shell of male loggerhead turtles appeared narrower or more gradually tapering than the female. In our regressions of SL width on SL length, we observed no differences in this relationship between adult males and females. Our analysis, however, does not preclude the possibility that the shells of males may be more gradually tapering than in females, since width was measured only at the widest point of the shell.

Our analyses of the tail length to carapace length relationship were inconclusive in subadult turtles; the gender of sexually mature males and females can be determined by tail lengths. As a field technique for sexing subadult turtles, however, our methods for measuring the tail are probably inadequate to provide the necessary resolution for accurate distinction between the sexes, even if differences in tail lengths occur in subadults of the two sexes.

An additional problem with the measurement of tail length from the posterior margin of the plastron to the tip of the tail is the occurrence of supernumerary scutes which protrude posteriorly between or behind the anals. Our measurements were performed from the posterior edge of these supernumerary scutes. Such a non-standard measurement contributes to error, and is another reason why the tail measurement employed is not an acceptable way for sexing subadult turtles.

Carapace length conversions described in this study make possible direct comparisons between studies employing different types of measurements. Our use of SL total carapace length in regressions was based on the fact that this was the standard method used in all NMFS projects. Pritchard et al.(1983) have recommended that standard SL carapace length be adopted as the most appropriate measurement for turtles. Our results indicate that any of these methods are satisfactory, but the use of a single measurement avoids confusion and unnecessary computations in comparing results.

Our purpose in computing condition factors among turtles was not to demonstrate differences in condition of groups of turtles at specific times, but to document the mean and standard errors of condition factors which were encountered over the course of our investigations. The groupings presented in Table 4 were selected arbitrarily and are useful for general trend comparisons only. The condition factor is influenced by sex, season, stage of maturity and size (Everhart et al., 1975), and our preliminary analyses may not have separated individuals sufficiently to discern differences in condition based on these variables.

The morphometric relationships presented in this paper are descriptive of loggerhead turtles occurring in nearshore waters of North Carolina to Texas. All of the animals from different areas are treated as members of a single population, and no attempt has been made to separate discrete nesting assemblages. If we could assign subadults to specific nesting assemblages, it might be possible to identify animals of each population on the basis of subtle differences in some morphometric charactistics. To accomplish this, however, a method of identifying subadults from specific nesting populations must be developed.

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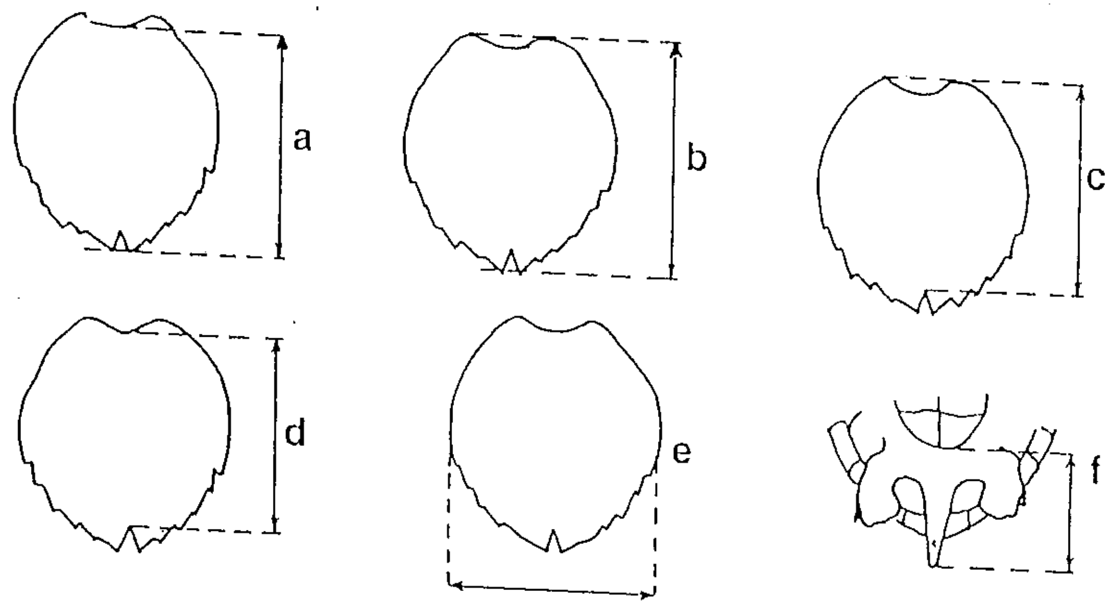
NOAA, NMFS, Mississippi Laboratories, P.O. Drawer 1207,
Pascagoula, MS 39567 and U.S. Army Corps of Engineers,
Jacksonville, FL



a. Standard carapace length - precentral scute to posterior margin of postcentrals
b. Total carapace length - shoulder to posterior margin of postcentrals
c. Notched carapace length - shoulder to notch between postcentrals
d. Minimum carapace length - precentral scute to notch
e. Carapace width - widest part of shell perpendicular to longitudinal body axis
f. Total tail length - posterior margin of plastron to tip of tail

Figure 1. Sea turtle carapace measurements and tail measurements used in analyses. Measurements conform to recommendations of Pritchard et al. (1983).

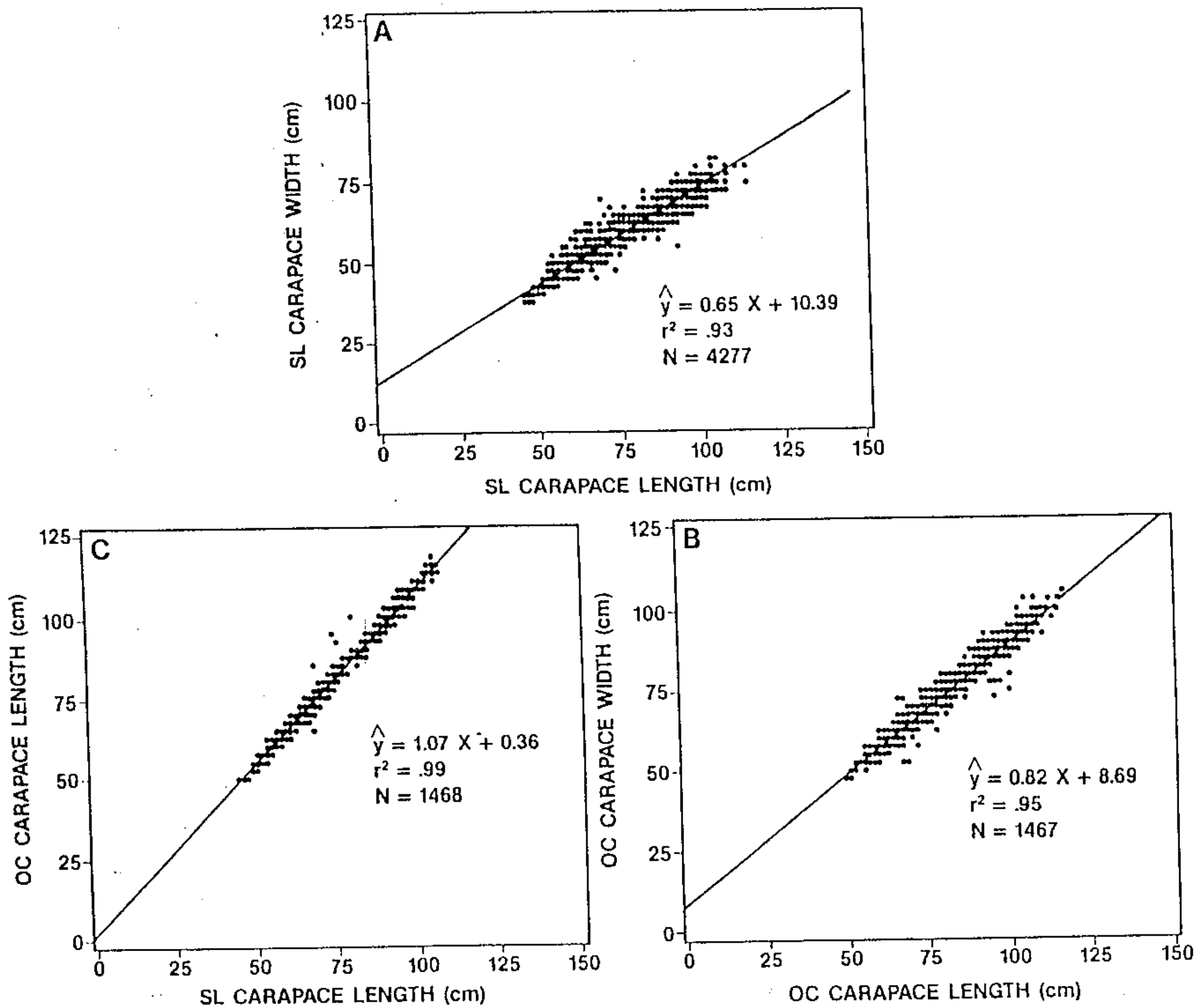


Fig. 2.—Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (*Caretta caretta*).

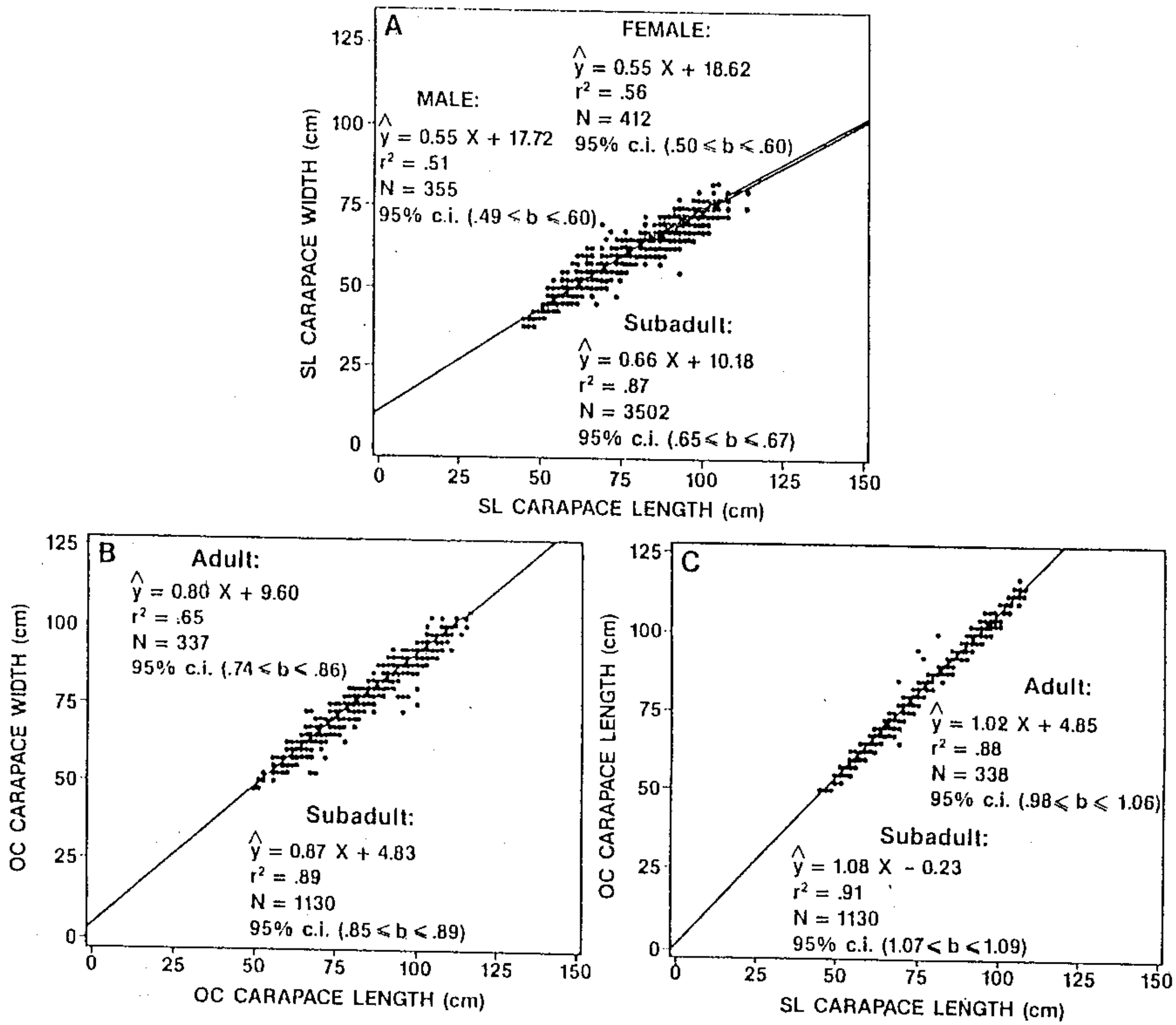


Fig. 3.—Regressions of SL carapace width on SL carapace length (A), OC carapace width on OC carapace length (B) and OC carapace length on SL carapace length (C) in loggerhead turtles (*Caretta caretta*). Adult and subadult regressions computed separately.

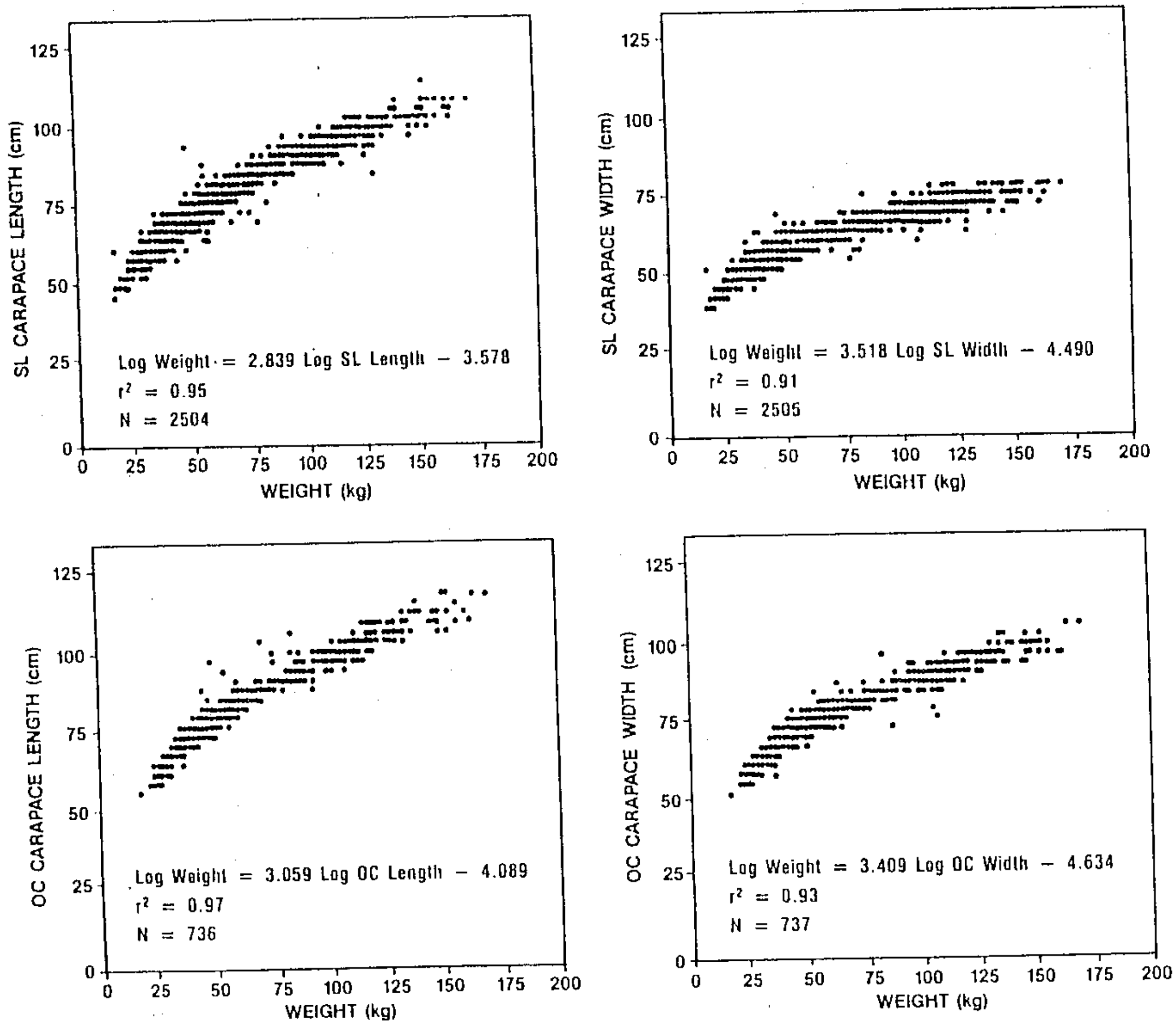


Fig. 4.—Regressions of straight-line (SL) and over-curve (OC) length and width on weight. Log-log transformed formulae are presented.

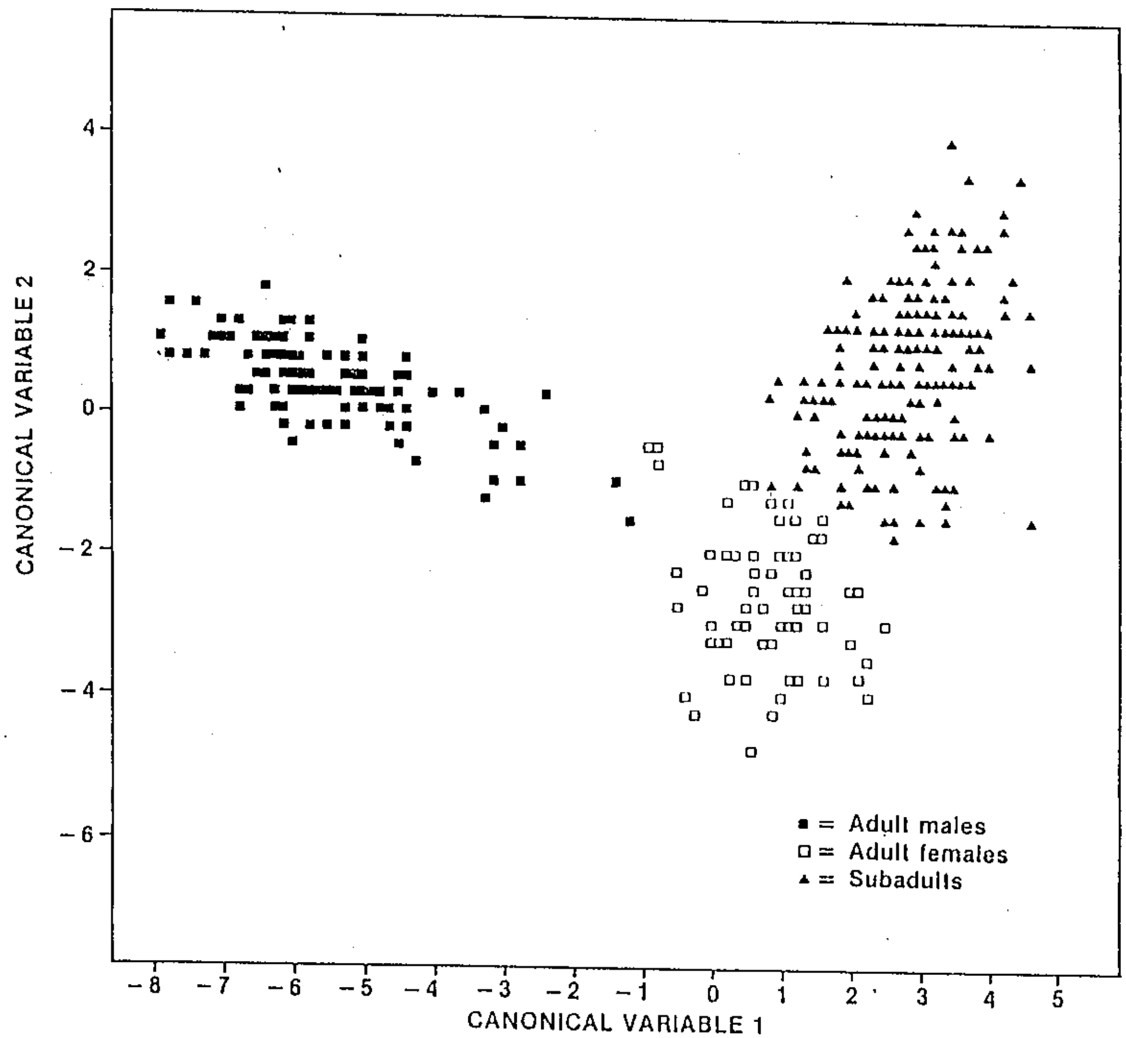


Figure 5. Positions of male, female, and subadult loggerhead turtles, Caretta caretta, in discriminant space defined by two discriminant functions.

Table 1. Conversion formulae for comparisons between different measurement techniques in loggerhead turtles, *Caretta caretta*.

Measurement calculated	Formula based on length (b)	r^2	N
SL length (a)	0.9964 SL length (b) - 0.775	0.99	722
OC length (a)	0.9891 OC length (b) - 0.066	0.99	713
OC length (b)	1.0700 SL length (b) + 0.360	0.99	1468
SL length (c)	0.9875 SL length (b) - 0.271	0.99	722
OC length (c)	0.9680 OC length (b) + 1.277	0.99	712
SL length (d)	0.9774 SL length (b) - 0.809	0.99	722
OC length (d)	0.9516 OC length (b) + 1.380	0.99	714

a = Standard carapace length
b = Total carapace length
c = Notched carapace length
d = Minimum carapace length
OC = Over-the-curve measurement
SL = Straight-line measurement

Table 2. Comparisons of mean size of nesting female loggerhead turtles, *Caretta caretta*, of the western Atlantic as reported in the literature.

PUBLICATION AND STUDY LOCATION	NUMBER OF TURTLES	MEAN	MEASUREMENT	MEAN CONVERTED TO TOTAL CARAPACE LENGTH (b)
Ehrhart (1979), Kennedy Space Center, FL	1224	92.5	a	93.6
Ehrhart & Yoder (1978), Merritt Island, FL	194	91.7	a	92.8
Baldwin & Lofton (1959), South Carolina	18	92.7	b	92.7
Caldwell et al. (1959), Jekyll Island, GA	110	95.9	b	95.9
Bjorndal et al. (1983), Melbourne Beach, FL	661	92.0	d	95.0
Gallagher et al. (1972), Hutchinson Is., FL	164	92.5	d	95.5
Worth & Smith (1976), Hutchinson Is., FL	260	90.3	d	93.2

Table 3. Coefficient of condition (C) in subadult and adult loggerhead turtles, *Caretta caretta*.

SUBADULTS (<83 CM. TOTAL CARAPACE LENGTH)

Month	Number (N)	Condition Factor (C)	Standard error of the mean (s.e.)
Jan.	79	0.99	0.010
Feb.	181	0.98	0.007
Mar.	276	0.96	0.005
Apr.	32	1.05	0.013
May	47	1.03	0.011
June	44	0.99	0.015
July	99	1.03	0.011
Aug.	196	1.03	0.006
Sept.	231	1.02	0.008
Oct.	280	1.01	0.007
Nov.	478	0.99	0.004
Dec.	73	0.97	0.010
Total	2016	1.00	0.002

ADULTS (>83 CM. TOTAL CARAPACE LENGTH)

Month	Number (N)	Condition Factor (C)	Standard error of the mean (s.e.)
Jan.	2	0.96	0.098
Feb.	57	1.05	0.012
Mar.	72	1.02	0.013
Apr.	74	1.06	0.008
May	68	1.07	0.011
June	34	1.03	0.015
July	36	1.06	0.023
Aug.	28	1.03	0.014
Sept.	22	1.04	0.016
Oct.	35	1.00	0.019
Nov.	53	1.02	0.012
Dec.	7	1.00	0.046
Total	488	1.04	0.004
TOTALS	2504	1.00	0.004