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GEOGRAPHIC VARIATION IN TOOTH MORPHOLOGY AND DENTINAL PATTERNS IN THE SPINNER DOLPHIN, *STENELLA LONGIROSTRIS*

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ABSTRACT

Sixteen tooth characters were analyzed in 277 specimens of spinner dolphins (*Stenella longirostris*) from the eastern tropical Pacific to determine whether the characters were associated with size of the animal, species-stock membership or geographic location. The tooth characters included 5 continuous measurements and 11 qualitative variables. Statistical analyses of the characters included two-way ANOVA tests which assessed continuous measurement variables for differences based on stock membership, latitude and longitude of collection or whether the animal was collected north or south of the equator. Principal component analyses combined factors of continuous variables with those of qualitative variables into components which were used as variables in further analyses. Discriminant analyses were performed using continuous variables alone and using principal components as potentially discriminating variables. Results showed that tooth differences were not associated with size but significant differences were found in some tooth variables with stock membership, incremental changes in latitude and whether the animal was collected north or south of the equator. A discriminant function, containing only tooth length, correctly classified 67% of northern and 78% of southern animals according to location of collection north or south of the equator.

Key words: spinner dolphin, *Stenella longirostris,* tooth characters, geographic variation.

A number of dolphin populations in the eastern tropical Pacific are caught incidentally by tuna seiners during fishing operations. One such species, the spinner dolphin, *Stenella longirostris,* includes a number of population stocks: the eastern spinner dolphin, northern and southern whitebelly spinner dolphin, Costa Rican spinner dolphin and Hawaiian spinner dolphin (Perrin *et al.* 1979, 1985). Stock membership is determined at sea by government observers using distinguishing criteria of snout and dorsal fin shape and overall body form. Another recognized category, 'unidentified,' are animals with an intergrade color pattern and which were collected where the ranges of the northern whitebelly spinner and the eastern spinner dolphin stocks overlap (Perrin and Henderson 1984).

In previous studies, researchers have used variability in color pattern, skull features and dorsal fin shape to characterize geographic variation in dolphins. Perrin (1972) described variations in color pattern in spinner dolphins and Perrin *et al.* (1979) studied variation in spotted dolphins (*S. attenuata*) and spinner dolphins north and south of the equator using skull features. Schnell *et al.* (1982) used skull features and total body length to study geographic variation in spotted and spinner dolphins and later (Schnell *et al.* 1985) found cranial morphometric differences between whitebelly and eastern spinner dolphin stocks compared from throughout the range. They also found strong cranial morphometric differences between samples of whitebelly spinner dolphins collected north or south of the equator. Tooth differences such as tooth width were found to be important by Douglas *et al.* (1984) who used multivariate analysis techniques on skull and tooth characters of spotted dolphins. They found a sharp demarcation between the characters of inshore and offshore populations, with tooth width as the most distinguishing variable. Walker (1981) also found tooth width the best character for distinguishing populations of *Tursiops truncatus.*

The purpose of this paper is to present results of statistical comparisons of morphometric and other morphological differences in teeth from different spinner dolphin populations. Comparisons were made to determine if these differences are associated with dolphin stock membership or geographic location.

Methods and Materials

The sample—In a separate study to estimate the age structures of the spinner dolphin populations in the eastern Pacific, teeth of female spinner dolphins were prepared and read to obtain age estimates (Myrick and Akin, in prep.). All samples were taken from the mid-portion of the lower-left jaw. Teeth in this region are uniform and least likely to be worn, broken or crowded.

Preparation technique was identical for all specimens. Preparation included decalcifying, sectioning, staining and mounting the sections on glass slides (Myrick *et al.* 1983). The 25-μm thick sections were taken longitudinally, from the tooth apex to the base, through the most central portion of the tooth. Stained central sections revealed all growth layers and other markings and patterns in the dentine as well as a readable portion of cementum. Age estimates of dolphins were obtained by counting units of associated layers or growth-layer-groups (GLGs, Myrick 1980) in the tooth sections. GLGs, deposited at the rate of one per year, provide an age estimate of the animal.

Three hundred fifty-one tooth specimens were non-randomly selected and examined for variation in tooth characters. (The sample was stored alphabetically by collector's name and was selected casually across the alphabet.) Because delphinid teeth increase in length for the first 3–4 yr (van Utrecht 1981), teeth with fewer than four GLGs were removed from the sample and not considered in this study.

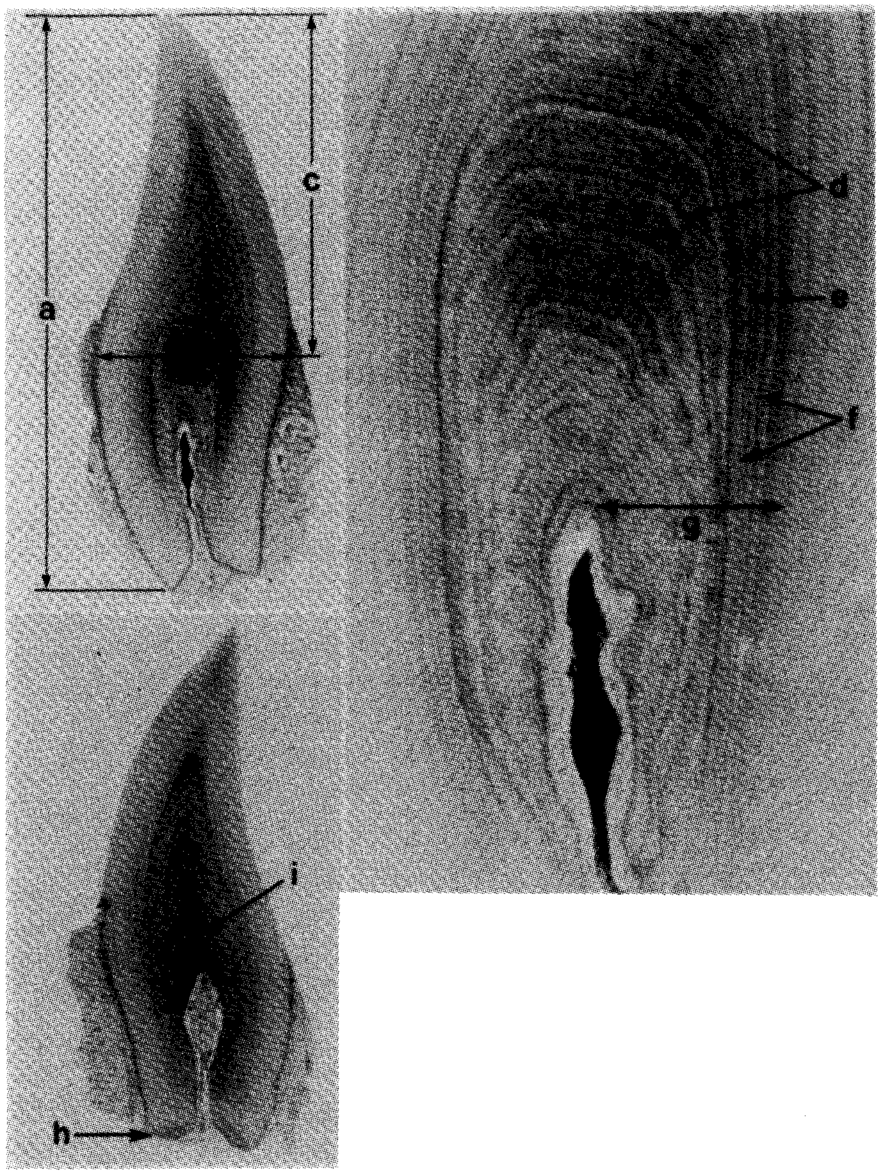

Figure 1. Recorded tooth variables. (a) tooth length, (b) width, (c) height of crown, (d) angular-shaped GLGs in crown, (e) paired lines, (f) crenulate lines, (g) GLG density, (h) truncated base and (i) triangular GLGs in crown.

The variables—The remaining 277 specimens were analyzed using 16 tooth characters, including various continuous and qualitative variables (Figs. 1 and 2). The continuous variables, which were taken in micrometer units on each tooth, were length (a), measured as a vertical line from the apex to the base

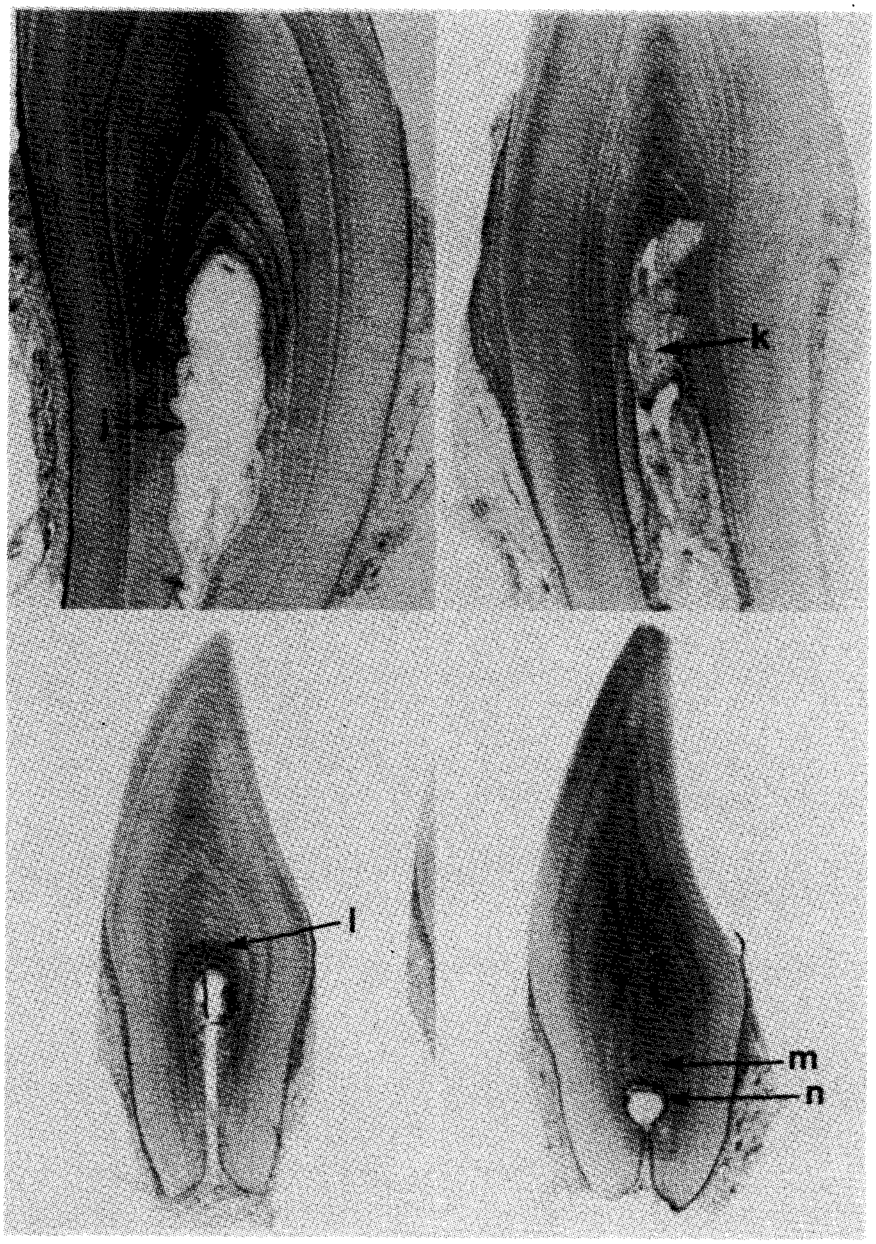

Figure 2. Additional variables noted. (j) crenulated pulp cavity margin, (k) globular 'pearls' in pulp cavity, (l) flat-topped pulp cavity, (m) curved GLGs in crown and (n) key-shaped pulp cavity.

Table 1. Results of two-way ANOVA tests comparing tooth measurement characters for a sample of spinner dolphin teeth. Comparisons were made by stock membership and geographic location.

Character	Stock	*F*-values		
		Long	Lat	NS
Length	3.14*	1.73	2.90*	7.39*
	P = (0.0451)	(0.1152)	(0.0146)	(0.0070)
Width	3.57*	0.42	0.76	0.23
	(0.0296)	(0.8655)	(0.5810)	(0.6300)
Crown height	0.85	1.70	1.90	3.87*
	(0.4278)	(0.12)	(0.0944)	(0.0500)
Width/length	1.62	1.13	2.18	4.89*
	(0.1995)	(0.343)	(0.0571)	(0.028)
Crown ht./length	7.06*	0.23	0.19	0.67
	(0.0010)	(0.9655)	(0.9661)	(0.4104)

* $P = <0.05$ indicates significant differences.

of the tooth; width (b), measured horizontally across the widest portion of the crown dentine excluding the cement; and height of crown (c), taken as a straight-line measurement from the apex to the neck (gum-line) of the tooth perpendicular to the width. The ratio of width to length and the proportion of height of crown to length were calculated. The density of 'lines' (g) (GLG boundaries and other prominent, narrow incremental layers in the dentine) was estimated by counting the number of lines intersected by a horizontal scale projected from the top of the pulp cavity, 20 micrometer units to the right.

Qualitative variables, reported as being present or absent, included GLG patterning of paired lines (e), which are a pair of lines parallel to each other and closer together than the next line on either side and which are within but not constituting the boundaries of a GLG and crenulate lines (f), which are GLGs that are wavy rather than smooth. GLG shape in the crown was recorded as triangular (i), curved (m) or angular (d). The occurrence of very wide GLGs at the base of the tooth (the first 3 or 4 GLGs) which are truncated giving the tooth an oblate appearance was noted (h). Qualitative characters of the pulp cavity recorded were presence of flat-topped (l) or key-shaped outlines (n), crenulate margins (f) or pearl-like globular deposition patterns (k).

The analyses—A sequence of statistical analyses was performed to evaluate the descriptive value of the variables chosen and to allow the inclusion of both continuous and qualitative characters in the comparison tests.

Because differences in tooth measurements can be a reflection of individual growth, I used body length, an indicator of growth, to test the measurements using one-way ANOVA (Program 1V of BMDP-81; Dixon 1981).

To determine if the measurement differences were characteristic of particular dolphin stocks or localities, two-way ANOVA (BMDP 2V) tests were performed on continuous variables. The categories compared were eastern spinner, whitebelly spinner and unidentified spinner dolphins. Collection localities were categorized by 10-degree increments in longitude, 5-degree increments in latitude and sites from either north or south of the equator.

Principal component analyses were used to evaluate overall variation and to allow inclusion of qualitative variables with the continuous variables. The three main principal components found incorporated a combination of all continuous measurement data with the four retained qualitative variables of line density, paired lines, crenulate lines and GLG shape.

Step-wise discriminant analyses (BMDP 7M) were performed to identify functions that would correctly classify specimens into groups of (1) previously-assigned species-stocks, (2) collection localities north or south of the equator, (3) latitude or (4) longitude.

Discriminant analyses were performed with a variety of variable combinations entering the calculations. Initially, all variables (continuous and qualitative) were entered, then only continuous variables were entered. Finally, principal components were entered as the potentially discriminating variables.

Results

The basic dentinal shapes and patterns appear distinctive but there is much variation and many degrees of differences. After quantifying and analyzing these differences statistically, however, the number of useful distinguishing characters was quickly reduced.

ANOVA tests, comparing differences in the measurement characters of length, width, crown height, width/length and crown height/length, showed no differences with body length but showed significant differences in some other comparisons (Table 1). Tooth length, width and crown height/length differed significantly ($P < 0.05$) between the species stocks. Tooth length differed by latitude, and tooth length, crown height and width/length differed between specimens from north or south of the equator. No significant differences were found in any measurement variable when compared for differences in longitude.

General characteristics of significant continuous variables are presented in Table 2, sections A, B and C. Examining tooth differences by stock membership indicated that the average whitebelly spinner tooth was longer and wider than the average eastern spinner dolphin tooth. Spinner dolphins collected south of the equator had longer teeth and greater crown height than northern spinner dolphins. Northern spinner dolphins had shorter, broader teeth as shown by the higher width/length ratios. Comparing spinner dolphin teeth by latitude, the average tooth length was greatest in animals collected from 5 degrees south to the equator.

Step-wise discriminant analysis, performed with various combinations of input variables, correctly classified the same percentages of specimens when all variables (qualitative and continuous) were entered and when only continuous variables were entered. This suggests that the qualitative variables chosen, while possibly being locally distinctive, do not add more power to the discriminating functions than the use of measurements alone.

Discriminant analysis was most successful in separating specimens as to whether they were collected north or south of the equator. Separation of stocks or

Table 2. Means, standard deviations and ranges of tooth variables found to be significant in two-way ANOVA analyses.

	Stock	$\bar{x}$	SD	Range
A. Comparison of variables by dolphin stock membership				
Length	Eastern	294.1	31.4	220–391
	Whitebelly	316.1	35.5	214–392
	Unidentified	305	21.2	271–346
Width	Eastern	82.4	7.7	60–100
	Whitebelly	86.5	6.9	63–101
	Unidentified	81.5	8.5	66–95
Crown ht/ length*	Eastern	0.944	0.05	0.819–1.06
	Whitebelly	0.906	0.05	0.698–1.03
	Unidentified	0.937	0.04	0.864–1.02
B. Comparison of variables by group from north or south of the equator				
Length	Northern spinner	302.7	34.2	214–392
	Southern spinner	329.3	25.6	275–380
Crown height	Northern spinner	192.8	22.3	100–250
	Southern spinner	203.8	16.6	150–235
Width/length	Northern spinner	0.281	0.04	0.184–0.446
	Southern spinner	0.260	0.02	0.226–0.293
C. Comparisons of tooth variables by latitude: all dolphin stocks				
	Latitude	$\bar{x}$	SD	Range
Length	≥ −5 degrees	323.5	18.1	290–346
	0	334.5	27.6	275–380
	5	315	33.6	214–382
	10	303.9	31.5	214–392
	15	294.3	36.2	220–391
	20	293	12.2	285–307

* Data converted by an arcsine transformation.

separation by longitude or latitude of collection was marginally successful (44 to 71% correctly classified).

A single variable, tooth length (L) was the most important character in the discriminant analysis. Specimens of all stocks combined (67.44% of northern and 75.9% of southern) were correctly classified as having been collected north or south of the equator with a discriminating function of tooth length; for northern specimens, the classification function is $Z1 = .27488L - 42.37716$ and for southern, $Z2 = .30184L - 50.95422$. (To use this function, calculate the scores $Z1$ and $Z2$. The specimen goes into the group for which the classification function is largest.) The largest percentage of correct classifications was within four degrees north of the equator.

Discussion

Teeth of spinner dolphins from the eastern Pacific showed more variation in tooth morphometrics than in pattern or pulp cavity characters. Pattern and pulp cavity characters may be distinctive enough that they might be useful as identifying characteristics of a population. However, sample sizes were not large enough to demonstrate this in this study.

Although tooth morphometrics were shown by ANOVA tests to differ with stock designation, there is overlap of the variable ranges, and separation was incomplete.

Variation in tooth morphology was strongly associated with incremental increases in latitude for northern and southern spinner dolphins. There is evidence for geographic variation in tooth length between northern and southern spinner dolphin populations when combining eastern spinner dolphin and northern and southern whitebelly spinner dolphin stocks. Similarly, northern and southern whitebelly spinner dolphins show variation in tooth length when tested alone.

Perrin *et al.* (1979), utilizing skull features and color pattern, found that the southern whitebelly spinner dolphins were clearly different from the northern whitebelly spinner dolphins. Schnell *et al.* (1985) compared variation in cranial characters of whitebelly spinner dolphins and found differences between northern and southern populations. He also found cranial differences between the northern and southern spinner dolphin with eastern spinner, northern and southern whitebelly spinner stocks combined (Schnell *et al.* 1985). Results in this study are similar; differences are latitudinal, north and south of the equator, whether all spinner dolphin stocks or whitebelly spinner dolphins only are compared.

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