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Use of Otolith Morphology for Separation of King Mackerel (*Scomberomorus cavalla*) and Spanish Mackerel (*Scomberomorus maculatus*)

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Shapes of otoliths (sagittae) of king and Spanish mackerel (*Scomberomorus cavalla* and *S. maculatus*) were compared using theta-rho analysis aided by digitized computer methods. Otoliths from three king mackerel groups [Yucatan (Mexico), northwest Florida, and North Carolina] and one Spanish mackerel group were examined. Seven analytical combinations of measurements were tested. Intraspecific separation was highest using two truss systems (66.7–70.0% and 57.7–77.5%) and interspecific separation was highest using length and width radii (91.7%).

The use of morphometric information is a well-established procedure for identification and classification of organisms and objects into various groups and relationships. Recent investigations have renewed interest in the use of morphology for separating groups of organisms. Diverse studies of fish (Winans, 1984), mammals (Thorington, 1972), invertebrates (Janson and Sundberg, 1983), and others, along with developments in computer technology, have led to fruition of the use of morphological methods.

The current study is a comparison of otolith (sagitta) shapes and their potential use as a tool for dividing king mackerel (*Scomberomorus cavalla*) into groups and separating it from Spanish mackerel (*Scomberomorus maculatus*). Shape analyses of various kinds have been used for grouping fish into various affiliations such as with stocks of herring (*Clupea harengus*) using otoliths by Messieh (1972), stocks of walleye (*Stizostedion vitreum*) using scales by Jarvis et al. (1978), and species of salmon (*Salmo salar*) and trout (*Salmo trutta*) using otoliths by L'Abée-Lund (1988). Recent reports have indicated that Fourier analysis of otolith shapes may be useful for stock separations. Bird et al. (1986) found this type of analysis to be promising for separation of juveniles of different races of herring (*Clupea harengus*) and that Atlantic and Alaskan adults had distinctively different otolith shapes. Colura and King (1989) reported differences between scale and otolith shapes of spotted sea trout (*Cynosion nebulosus*) and were able to correctly assign 64–74% of the fish to their area of collection. Castonguay et al. (1991) reported on Atlantic mackerel (*Scomber scombrus*) from the north Atlantic and North Sea areas. They reported temporal instability in shapes and found the method not to be useful for mackerel contingent discrimination. Additionally, nontraditional methods of examination from other disciplines such as geology [grain shape by Ehrlich and Weinberg (1970)] and paleontology [ostracod shapes by Benson (1967)] have influenced the current examination of mackerel otoliths.

METHODS AND MATERIALS

The methods used in the examination of mackerel otoliths are diverse and require several levels of combination for their integration and the resulting completion. The basic method of analysis uses theta-rho analysis (Benson, 1967). This method of analysis is a technique for recording the margins of an object (mackerel otolith) using polar coordinates and their conversion by X-Y transformation (Cartesian coordinates). Each point on the otolith margin is measured at a specific bearing (theta) and a radius (rho-distances from origin, i.e., otolith focus, to the point).

The measurements were made around the otolith margin with the focus as origin for 360° using 18° intervals, which results in 20 recorded points. All measurements were made on the right otolith's distal surface (concave side) with the 0° point on the posterior margin and the 180° point in the middle of the anterior margin. All measurements were recorded in counterclockwise rotation. Additional points were recorded, but these represented margin changes and did not necessarily occur at 18° intervals (Fig. 1). Twenty-five points were recorded. The polar coordinates (points) were converted to X-Y coordinates (Cartesian) with a sonic digitizer and a closed circuit television system. This system projected the image of the otolith at ×15 magnification onto a horizontal viewing screen where the image was measured. The resulting X-Y points were stored in a computer file for analysis. The digitization computer programs originated from G. Winans

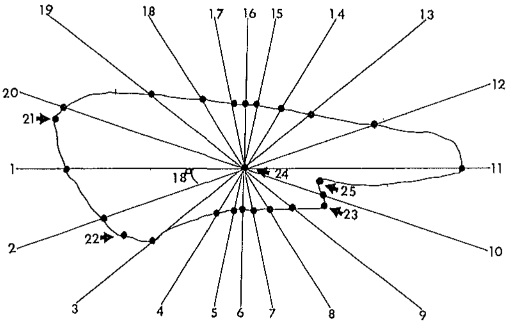

Fig. 1. Drawing showing theta-rho mapping of right mackerel otolith.

(NMFS, Seattle, WA) and were modified for the sonic digitizer.

The information generated by the above procedure was examined with a series of stepwise discrimination and spectral analysis programs that originated in BMDP-P7M and P1T (Dixson, 1983) and was modified for specific examinations. A multitude of combinations of points and distances were examined; however, some proved to be more useful than others [see Humphries et al. (1981), Strauss and Bookstein (1982), Winans (1984) and Kaesler and Waters (1972) for the various merits and demerits of these examinations]. Six stepwise discrimination sets and one spectral analysis were selected for this study.

Three groups of king mackerel otoliths and one group of Spanish mackerel otoliths were examined. The initial collections were of 50 fish from each group that were "randomly" selected from a size range of 60–90 cm fork length (which represented 0+- to 1+-year-old king mackerel). Collection information and statistics are presented in Table 1.

Results and Discussion

The shape analysis of otoliths was performed on 129 fish from four collections. Their images were magnified ×15 with the previously reported system, wherein 1 mm on the otolith equaled 0.1546 ± 0.0106 ($\bar{x}$ ± 1 SD) units (calculated distance units between points). Points recorded by two independent examiners were not significantly different from each other (Sandler's A statistic, n = 200, A = 1.5367 > $P_{0.1}$ = 0.369).

Seven analytical combinations were used to examine the data; these were: (1) Stepwise discriminant analysis of length and width radii (L'Abée-Lund, 1988) (Table 2, Item 1). (2) Stepwise discriminant analysis of total length and width (Table 2, Item 2). (3) Stepwise discriminant analysis of maximum and minimum radii. These radii were not necessarily at 18° intervals (Table 2, Item 3). (4) Stepwise discriminant analysis of all 18° internal radii (Table 2, Item 4). (5) Stepwise discriminant analysis of truss distances (Winans, 1984) using margin and two connecting radii (Table 2, Item 5). (6) Stepwise discriminant analysis of truss distances of various types (Table 2, Item 6). (7) Spectral analysis of 18° radii means for each collection (Kaesler and Waters, 1972) (Table 2, Item 7).

Table 1. King and Spanish mackerel otoliths used for shape analysis.

Species and collection code[a]	Date	Location[b]	Size[c]	Age (yr)[d]	Number of fish[e]		
					Male	Female	Total
King mackerel							
YUC	Feb. 1988	Yucatan, Mexico	76.7 ± 6.0 (66–89)	0.7 ± 0.5 (0–1)	10	30	40
NWF	June–Sep. 1988	Panama City, FL	69.4 ± 3.0 (65–67)	0.9 ± 0.3 (0–1)	11	28	39
NC	Nov. 1987–July 1988	Beaufort–Wilmington, NC	69.3 ± 2.7 (66–73)	0.7 ± 0.5 (0–1)	7	19	26
Spanish mackerel							
SM	June–Oct. 1987	LA, MS, GA, AL, SC	65.6 ± 3.5 (61–74)	3.6 ± 0.7 (3–5)	0	24	24

[a] Various codes used in this report's text, figures, and tables.
[b] Postal abbreviations used for states.
[c] Expressed as $\bar{x}$ ± 1 SD. In parentheses is the size range. All measurements are fork length in centimeters.
[d] Expressed as $\bar{x}$ ± 1 SD. In parentheses is age range in years.
[e] Original collection size was 50. After examination some otoliths were rejected due to physical damage. Total number is number of "perfect" otoliths examined.

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TABLE 2. Results of analysis of otolith shape of king and Spanish mackerel using seven analytical combinations. Analytical combinations, variables, and abbreviations defined in text and in Table 1.

Item 1 Stepwise discriminant analysis using length and width radii.
Variables tested: 1124, 0124, 0624, 1624, 0111.
Variables used: 0124, 0624, 1624.

Classification (jackknifed):

Group	Percent correct	Number of cases classified into group YUC	NWF	NC	SM
YUC	72.5	29	3	4	4
NWF	61.5	5	24	8	2
NC	38.5	6	9	10	1
SM	91.7	0	2	0	22
Total	65.9	40	38	22	29

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	0124	32.5857	1	0.5611	32.586	3.00	125.00
2	0624	23.2248	2	0.3593	27.625	6.00	248.00
3	1624	13.7495	3	0.2690	23.795	9.00	299.50

Item 2 Stepwise discriminant analysis of total length and width.
Variables tested: 0111, 0616.
Variables used: 0111, 0616.

Classification (jackknifed):

Group	Percent correct	Number of cases classified into group YUC	NWF	NC	SM
YUC	77.5	31	5	1	3
NWF	38.5	5	15	15	4
NC	53.8	2	7	4	3
SM	87.5	1	1	1	21
Total	62.8	39	28	31	31

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	0111	35.7292	1	0.5384	35.729	3.00	125.00
2	0616	25.6492	2	0.3322	30.379	6.00	248.00

Item 3 Stepwise discriminant analysis of maximum and minimum radii (not necessarily at 18° intervals).
Variables tested: 0124, 1124, 2124, 2224, 1624, 0624, 2324, 2425.
Variables used: 0124, 0624, 2124, 1624, 2324.

Classification (jackknifed):

Group	Percent correct	Number of cases classified into group YUC	NWF	NC	SM
YUC	75.0	30	4	3	1
NWF	56.4	4	22	12	1
NC	38.5	6	9	10	1
SM	91.7	0	2	0	22
Total	65.9	40	38	22	29

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	0124	32.5857	1	0.5611	32.586	3.00	125.00
2	0624	23.2248	2	0.3593	27.625	6.00	248.00
3	2124	17.4875	3	0.2519	25.365	9.00	299.50
4	1624	9.7038	4	0.2033	22.235	12.00	323.07
5	2324	5.0074	5	0.1809	19.126	15.00	334.43

TABLE 2. Continued.

Item 4 Stepwise discriminant analysis of all 18° interval radii.
Variables tested: 0124, 0224, 0324, 0424, 0524, 0624, 0724, 1024, 1124, 1224, 1324, 1424, 1524, 1624, 1724, 1824, 1924, 0824, 0924, 2024.
Variables used: 0124, 1124, 2224, 2124, 1524.

Classification (jackknifed):

		Number of cases classified into group			
Group	Percent correct	YUC	NWF	NC	SM
YUC	70.0	28	6	4	2
NWF	59.0	4	23	11	1
NC	65.4	3	6	17	0
SM	83.3	2	1	1	20
Total	68.2	37	36	33	23

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	0124	32.5857	1	0.5611	32.586	3.00	125.0
2	1124	30.3868	2	0.3234	31.349	6.00	248.00
3	2224	20.9392	3	0.2141	29.416	9.00	299.50
4	2124	6.8306	4	0.1833	24.202	12.00	323.07
5	1524	4.6966	5	0.1642	20.606	15.00	334.43

Item 5 Stepwise discriminant analysis of truss distances using margin and two connecting radii.
Variables tested: 1418, 1824, 1424, 0408, 1424, 0824, 1819, 1824, 1920, 1924, 2024, 0120, 2024, 0124, 0102, 0224, 0203, 0224, 0324, 0304, 0424, 0809, 0824, 0924, 0910, 1024, 1011, 1124, 1112, 1224, 1213, 1324, 1314, 1424.
Variables used: 0224, 1920, 0824, 1314, 0102.

Classification (jackknifed):

		Number of cases classified into group			
Group	Percent correct	YUC	NWF	NC	SM
YUC	70.0	28	6	5	1
NWF	66.7	4	26	9	0
NC	69.2	2	6	18	0
SM	83.3	2	1	1	20
Total	71.3	36	39	33	21

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	0224	32.5857	1	0.5611	32.586	3.00	125.00
2	1920	33.8530	2	0.3085	33.085	6.00	248.00
3	0824	19.7857	3	0.2078	30.190	9.00	299.50
4	1314	9.6270	4	0.1680	25.913	12.00	323.07
5	0102	4.2974	5	0.1518	21.838	15.00	334.43

Item 6 Stepwise discriminant analysis of truss distances of various types.
Variables tested: 0220, 2122, 0319, 1620, 0206, 0616, 1116, 0611, 0624, 2324, 1124, 0106, 0116.
Variables used: 2122, 0116, 0612, 2325.

Classification (jackknifed):

		Number of cases classified into group			
Group	Percent correct	YUC	NWF	NC	SM
YUC	77.5	31	4	4	1
NWF	59.0	5	23	10	1
NC	57.7	3	8	15	0
SM	83.3	2	1	1	20
Total	69.0	41	39	30	22

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TABLE 2. Continued.

Summary table:

Step number	Variable	F value to enter	No. of variables included	U statistic	Approximate F statistic	Degrees of freedom	
1	2122	43.0806	1	0.4917	43.810	3.00	125.00
2	0116	37.0530	2	0.2593	39.845	6.00	248.00
3	0612	8.8269	3	0.2133	29.506	9.00	299.50
4	2325	8.6170	4	0.1760	24.989	12.00	323.07

Item 7 Spectral analysis of 18° radii means for each collection.
Program used: BMDP P1T
Band width selected: 0.25
Shape: cosine
Coherence: 0.943 to 0.997
Phase: 0.079 to −0.038

The variables used in each analytical combination are reported as point distances (for example, 0111 is the distance between margin point 1 and margin point 11, which is also the distance from margin to margin along 0–180° axis).

The results of the various systems of discriminatory classifications indicate that a reasonably high level of separation may be obtainable with stepwise discriminant analysis of measurements from otoliths. The higher separation values were found using the two truss systems (Table 2, Items 5 and 6) for distinguishing king mackerel collections (66.7–70.0% and 57.7–77.5%) and using length and width radii (Table 2, Item 1) for distinguishing Spanish mackerel from king mackerel (91.7%). The latter interspecific results are similar to the results found by L'Abée-Lund (1988), who used otolith length and width radii for separating Atlantic salmon and brown trout (92.2–96.0%).

The spectral analysis (Table 2, Item 7) indicated that the differences between the various collections were not extreme (coherence 0.943 to 0.997) at any of the examined frequencies (harmonics).

The overall conclusion that is apparent from the current examination of otolith morphometrics is that this technique may be useful for interspecific separation. However, for intraspecific separation the technique should be used in addition to other methods.

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