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RELATIONSHIP OF OTOLITH LENGTH TO TOTAL LENGTH IN ROCKFISHES FROM NORTHERN AND CENTRAL CALIFORNIA

Knowing the relationship between otolith length and total length of a fish is useful for two reasons: 1) Fish size can be estimated from otolith lengths measured from otoliths encountered in predator stomachs, in core samples, archaeological sites, etc., and 2) the length of a fish can be verified when the age determined from the otolith lies outside expected values.

The otolith/total length relationship is useful in predator-prey and archeological studies if fish size can be extrapolated from otolith length. Otoliths are often the only part of a prey fish remaining in a predator's gut (Ainley et al. 1981; Treacy and Crawford 1981) or at cooking sites of archeological middens (Fitch 1972). Fish lengths could be estimated from otoliths found as remains of prey or in coastal archaeological excavations (Fitch and Brownell 1968). Existing keys (e.g., Morrow 1979) allow identification of fish species from otoliths. With these keys, personal reference collections, and the length relationships described in this paper, investigators will be able to verify species and size data collected in field sampling, and obtain more complete knowledge of prey species of marine mammals, birds, and fishes.

Large-scale surveys, such as the California cooperative survey (Sen 1984) that samples commercial rockfish landings in northern California, are prone to errors at several levels. Problems that may be encountered in collecting otoliths and measuring fish lengths include errors in recording lengths and the mixing up of otoliths. Some errors can be corrected by measuring the otolith and estimating the size of the fish it came from. Every effort should be made to eliminate erroneous data from the database before curves are constructed or cohort analysis is performed.

In this paper, I report the results of my investigation of the relationship between otolith length and total length for 30 rockfish species of the genus *Sebastes*. Linear regression statistics are presented for all fish of the species encountered.

Methods

Specimens were collected during a life history study on the rockfishes of northern and central California conducted at the Southwest Fisheries Center Tiburon Laboratory. Fish were sampled from the commercial trawl fishery, the commercial sport fishery, skiffs, and research cruises from 1977 to 1980. Specimens were identified to species, and then total lengths of frozen—then thawed—carcasses were measured on a meter board in millimeters (mm). Otoliths were measured to the nearest 0.1 mm with an ocular micrometer. The greatest length of the otolith was measured from the anterior tip to the most posterior projection (Kimura et al. 1979) (Fig. 1) as if the otolith were flat, without compensating for the curvature. Linear regressions were run on total length (y) versus otolith length (x) for 30 rockfish species. Outliers (± 3.0 standard deviations) from the line were assumed to result from measurement or recording errors and were discarded (2% of the observations).

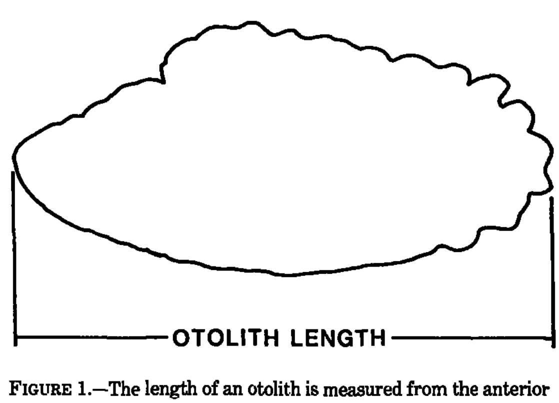

FIGURE 1.—The length of an otolith is measured from the anterior tip to the posterior projection.

Table 1 gives the sample size (N) and the minimum and maximum total lengths used in the analysis for each species and each sex. Table 2 shows estimates of y-intercept (a), slope (b), standard error of estimate ($S_{y.x}$), correlation coefficient (r), and F for each species and sex. Analysis of covariance was used to determine if separate lines for males and females significantly reduced the variance from a common line (Kleinbaum and Kupper 1978). Analysis of covariance was also used to test for significant differences in the relationship of otolith length to total length between the sexes at the $P = 0.05$ level and the $P = 0.01$ level (Table 2). The highest values of r and examination of scattergrams (Fig. 2) indicate that the length relationships are linear over the observed range of values. Limiting the application of these regressions to the ranges of observed values is advised.

Results and Discussion

Linear regressions were run on each sex in order to investigate possible sexual differences. In 17 of the 30 species investigated, the relationship between otolith length and fish length is significantly different between males and females (Table 2). Sexual size dimorphism has been observed in 11 of the 17 species in Table 2. These species (plus *S. alutus*) include most commercially and sport-caught rockfishes in the northeastern Pacific Ocean. The six species for which growth curves have yet to be con-

TABLE 1.—Sample sizes and size ranges used in the linear regressions of total length versus otolith length for *Sebastes*. Measurements are in millimeters.

	Males			Females		
		Total length			Total length	
Species of *Sebastes*	N	Minimum	Maximum	N	Minimum	Maximum
auriculatus	34	257	477	44	179	523
aurora	27	203	378	44	230	398
carnatus	100	112	289	103	109	279
caurinus	67	281	507	65	135	542
chlorostictus	73	155	450	101	162	458
chrysomelas	72	162	256	94	141	268
constellatus	54	186	422	45	177	430
crameri	42	206	445	47	134	505
diploproa	34	125	343	44	131	381
elongatus	25	188	326	73	135	378
entomelas	38	245	464	68	284	524
flavidus	163	254	504	221	232	539
goodei	26	227	385	52	227	556
hopkinsi	13	119	195	46	134	294
jordani	118	147	281	65	160	321
levis	14	267	773	15	237	900
maliger	13	317	481	21	226	478
melanops	120	334	534	89	197	607
melanostomus	34	250	442	46	297	538
miniatus	64	328	644	35	360	691
mystinus	141	248	480	63	213	375
nebulosus	25	270	391	23	257	500
ovalis	18	228	355	66	241	456
paucispinis	46	287	733	40	296	786
pinniger	92	249	585	81	251	622
rosaceus	72	212	426	75	203	310
ruberrimus	52	257	695	50	245	678
saxicola	29	141	240	73	159	358
semicinctus	15	125	150	16	128	182
serranoides	60	235	469	70	229	528

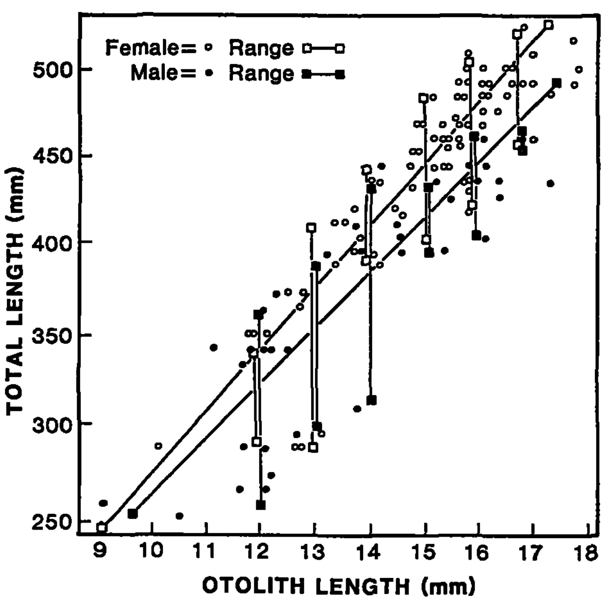

FIGURE 2.—Linear regression of total length on otolith length of widow rockfish, *Sebastes entomelas*. The range of values for males (•-•) and females (o-o) at each whole millimeter of otolith length.

TABLE 2.—Results of linear regressions of total length (y) versus otolith length (x) for *Sebastes*. Measurements are in millimeters. The F-test was run using the sums squared from the analysis of covariance comparing males and females; * - P = 0.05, ** - P = 0.01.

Species of *Sebastes*	Males				Females				
	r	a	b	$S_{y.x}$	r	a	b	$S_{y.x}$	F
crameri[1,2]	0.926	19.270	24.629	22.054	0.988	−43.418	29.440	16.067	4.676*
diploproa[3,2]	0.980	1.282	21.090	12.686	0.985	−22.120	23.717	13.390	6.601**
entomelas[1,2,4]	0.871	−23.039	28.853	33.896	0.880	−51.835	32.452	28.968	6.243**
flavidus[1,2,5,6]	0.923	30.400	23.546	14.771	0.947	−12.604	26.901	18.389	25.637**
goodei[7]	0.975	1.696	23.866	12.741	0.987	−56.831	29.347	16.321	14.842**
hopkinsi	0.868	20.734	20.172	9.567	0.951	−10.895	26.890	10.999	9.172**
maliger	0.840	79.427	21.359	25.533	0.965	−105.649	33.479	19.259	4.221*
melanops[5,6]	0.912	5.472	27.070	18.456	0.949	−124.076	35.784	19.480	25.338**
melanostomus	0.907	−21.094	25.187	21.777	0.918	−21.713	26.211	23.405	8.441**
miniatus	0.961	−42.615	28.385	23.399	0.971	−72.278	30.607	24.103	4.638*
mystinus[6,7]	0.910	−2.255	28.987	23.112	0.881	60.010	22.054	14.965	3.643**
ovalis	0.903	26.185	24.964	13.268	0.963	−27.207	31.859	14.144	21.995**
paucispinis[1,8]	0.893	−51.911	38.441	55.433	0.931	−102.932	43.993	56.501	5.965**
pinniger[1,2,5]	0.950	−61.508	27.663	25.655	0.967	−95.891	30.455	29.004	8.200**
saxicola[1]	0.928	−0.111	19.074	7.544	0.974	−19.565	22.495	12.797	11.412**
semicinctus	0.880	34.331	16.015	4.061	0.938	12.022	21.372	4.981	20.081**
serranoides[6,9]	0.967	−5.307	25.898	13.462	0.969	−63.475	30.445	20.668	10.318**

[1]Westrheim and Harling 1975.
[2]Shaw and Archibald 1981.
[3]Boehlert and Kappenman 1980.
[4]Lenarz 1987.
[5]Six and Horton 1977.
[6]Wyllie Echeverria 1986.
[7]Miller and Geibel 1973.
[8]Wilkins 1980.
[9]Love and Westphal 1981.

structed may also show sexually size-dimorphic growth.

The 13 species with no difference noted between males and females consist primarily of two closely related taxonomic groups (Barsukov 1981). Few growth studies exist for these species. The first group of shallow, nearshore species is represented in this study by *S. auriculatus*, *S. carnatus*, *S. caurinus*, *S. chrysomelas*, and *S. nebulosus*. The growth curve for *S. chrysomelas* is the same for males and females (Zaitlan 1986). The second group is the subgenus *Sebastomus* (Chen 1971), represented in this study by *S. chlorostictus*, *S. constellatus*, and *S. rosaceus*. Growth curves exist for two members: *S. helvomaculatus* (Westrheim and Harling 1975) and *S. umbrosus* (Chen 1971), which do not show sexual size dimorphism. The indications are relationships of otolith length to total length reflect the age-at-length relationship between the sexes.

In food-habit studies, otoliths are often found but the sex and length of the fish are not known. Table 3 shows regressions for the combined sexes for those occasions when the sex is unknown or when the regressions were not significantly different between the sexes.

Data analysis for *S. entomelas* shows a potential to derive estimates of age from otolith lengths (Fig. 3). The calculated total lengths for males and females for each 1 mm increment in otolith length are overlaid on the age-length curve (from Lenarz 1987). These relationships are species-specific and

TABLE 3.—Results of linear regressions of total length (y) versus otolith length (x) for *Sebastes* for sexes combined. Measurements are in millimeters.

Species of *Sebastes*	r	a	b	$S_{y.x}$
auriculatus	0.968	−53.032	33.159	17.729
aurora	0.782	15.124	19.910	24.818
carnatus	0.945	−39.365	30.573	10.258
caurinus	0.906	5.099	30.234	26.291
chlorostictus	0.974	−18.537	24.113	14.898
chrysomelas	0.919	−21.780	28.609	9.020
constellatus	0.978	−37.484	25.266	13.123
crameri	0.971	−27.098	28.104	19.912
diploproa	0.980	−12.854	22.635	14.020
elongatus	0.974	−13.564	24.020	12.284
entomelas	0.898	−6.890	33.113	32.247
flavidus	0.938	−10.946	26.506	18.158
goodei	0.983	−57.996	29.129	17.819
hopkinsi	0.957	−30.546	28.868	12.168
jordani	0.985	−2.313	22.096	7.353
levis	0.973	−170.108	47.458	46.975
maliger	0.928	−53.107	29.967	23.862
melanops	0.930	−48.222	30.557	21.002
melanostomus	0.928	−47.070	27.362	23.590
miniatus	0.962	−56.738	29.365	24.516
mystinus	0.912	−18.175	29.765	23.204
nebulosus	0.891	32.970	25.181	16.131
ovalis	0.952	−53.472	33.562	17.179
paucispinis	0.903	−77.089	41.089	59.143
pinniger	0.957	−85.114	29.411	28.398
rosaceus	0.902	−83.484	22.533	10.908
ruberrimus	0.957	−76.233	31.328	31.206
saxicola	0.977	−32.765	23.399	12.663
semicinctus	0.924	−19.182	25.266	6.961
serranoides	0.965	−51.013	29.350	18.965

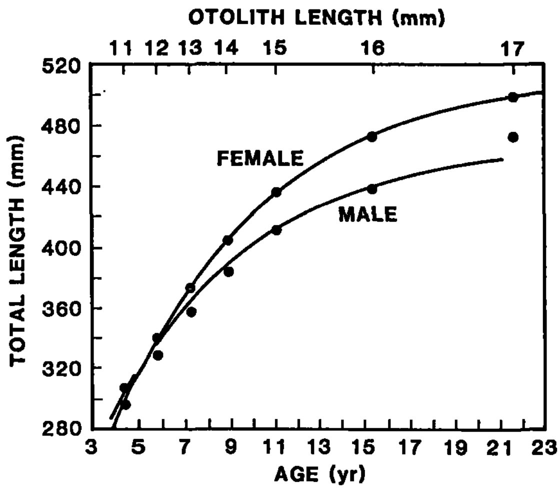

FIGURE 3.—Age-length curve for widow rockfish, *Sebastes entomelas* (from Lenarz 1987). The calculated total length from otolith length is overlaid on the curve to obtain an estimate of age.

should be used within well-defined limits. The scattergram (Fig. 2) with the mean and range of total length found at each 1 mm otolith length increment indicates the ranges within which these data are useful. Some problems in relating otolith length to age include the increased range of fish lengths at older ages and the observed thickening-instead of lengthening of otoliths in *Sebastes* (Boehlert 1985).

These results may be used to estimate total length from an otolith length as shown in the following example. If the otoliths are from fish of unknown sex, the regression statistics from Table 3 would be used to estimate fish length. If the otoliths are from fish of known sex, Table 2 would be consulted. If a species appears in Table 2, the regression statistics for the appropriate sex would be used to estimate fish length. If a species does not appear in Table 2, Table 3 (with regression statistics for males and females combined) would be used. For instance, to estimate fish length from otolith length (OL) for male *S. auriculatus*, the regression statistics from Table 3 are used. An otolith 10.0 mm long gives an estimated total length of

$$TL = a + b\,(OL)$$
$$TL = -53.032 + 33.159(10.0)$$
$$TL = 279 \text{ mm}.$$

Tables have been constructed with the regression statistics presented here. The table for each species (and sex, where appropriate) represents otolith lengths measured in millimeters and the corresponding estimated total length. These tables are available on request from the author.

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CRATER WOUNDS ON NORTHERN ELEPHANT SEALS: THE COOKIECUTTER SHARK STRIKES AGAIN

A variety of wounds are observed on northern elephant seals, *Mirounga angustirostris*. We report a new type of wound observed on juveniles, primarily from the Mexican islands west of Baja California and rarely from off California. The form and shape of these wounds, and their similarity to wounds reported from other marine mammals, fishes, and squids, suggest that they were caused by a small, squaloid shark of the genus *Isistius*, commonly known as the cookiecutter or cigar shark.

The shape of wounds, their location on the victim's body, the time of the year that the wounds are received, and the age of the seal provide a good indication of the cause. During the breeding season, for example, suckling seal pups bear bite marks on the snout, head, and rump, these having been inflicted by adult females (Le Boeuf and Briggs 1977). Weaned pups and adult females bear fresh bite marks of varying severity caused by adult males biting their necks while attempting to mate with them, and breeding-age males inflict a variety of bite wounds on each other during fights to establish dominance (Le Boeuf and Reiter in press). During winter and spring, *Mirounga angustirostris* of both sexes and all ages exhibit fresh wounds inflicted by white sharks, *Carcharodon carcharias*. The shape and serrated edges of those wounds are easily distinguished from the smooth-edged and halfmoon-shaped wounds caused by boat propellers (Le Boeuf et al. 1982; Tricas and McCosker 1984).

The wounds that we discovered were round, hollowed-out craters, smooth edged at the margin, about the size of a tennis ball, and unlike any of the wounds described above. The similarity in appearance of these wounds to scars inflicted by *Isistius* upon cetaceans (Van Utrecht 1959) and fishes (Jones 1971) implicate the cookiecutter shark as the probable cause. The only reported eastern Pacific occurrence of an *Isistius* is that of an *I. brasiliensis* from off the Galapagos (Compagno 1984). However, we have examined additional eastern Pacific specimens of *I. brasiliensis*, including a specimen from off Isla de Guadalupe.

Background information. Northern elephant seals inhabit traditional island and mainland sites from mid-Baja California, Mexico, to central California. Their range at sea along the Pacific coast is from Isla Cedros, Mexico, to the southern Aleutians. Feeding occurs beyond the continental shelf in deep water (Le Boeuf et al. 1986). It is not known how far from shore they go to feed, but some animals have been seen as far as 3,000 miles away on Midway Island in the mid-Pacific (Condit and Le Boeuf 1984). Several islands are used regularly throughout the year (Guadalupe, San Benito, Cedros, and Coronoados in Mexico and San Miguel, San Nicolas, Año Nuevo, and the Farallones); the sex and age composition of each colony varies with time of year (Le Boeuf and Bonnell 1980). Late August or early September, when most of the observations reported in this paper were made, is the end of the molt period for adult and subadult males and the beginning of the fall haul-out for juveniles, 1-4 years old. Breeding-age males, observed on land at this time, are completing the annual molt, a process that takes