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THE EFFECTS OF DIFFERENT OTOLITH AGEING TECHNIQUES ON ESTIMATES OF GROWTH AND MORTALITY FOR THE SPLITNOSE ROCKFISH, *SEBASTES DIPLOPROA,* AND CANARY ROCKFISH, *S. PINNIGER*

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Different ageing techniques affect not only the estimates of length at age but also estimates of population growth and mortality rates. This study considers these effects for the splitnose rockfish, *Sebastes diploproa,* and canary rockfish, *S. pinniger,* based on ages determined from the surfaces and sections of otoliths collected during a trawl survey off the west coast of North America in 1980. Estimates of growth based on surface rather than section ages were nearly identical for *S. diploproa* but were higher for *S. pinniger;* slightly different whole otolith ageing techniques are suspected of producing these interspecific differences. For both species, however, estimates of mortality were reduced by more than half when section rather than surface ages were used.

INTRODUCTION

Ages of fish are needed to estimate two vital parameters of exploited fish populations, namely growth and mortality rates. Many fish species typically are aged by interpreting rings on the otolith, as is the case for rockfishes (*Sebastes*) for which the otolith is the preferred ageing structure (Six and Horton 1977, Chilton and Beamish 1982). Various techniques have been developed to facilitate the detection and the interpretation of otolith patterns used in age determination (Chilton and Beamish 1982). Two methods to determine ages are counting the number of rings or annuli viewed on the exterior of the whole otolith (surface ages) or on a lateral cross section of the otolith (section ages). Section ages are often greater than surface ages for older specimens of many long-lived, slow-growing species (Beamish 1979a, 1979b, Boehlert and Yoklavich 1984), and recent evidence demonstrates that the section ages represent the true ages of fish (Bennett et al. 1982, Leaman and Nagtegaal 1987, Campana et al. in press).

Because present evidence supports the validity of section ages for older fish, important biological and management implications could result if many demersal fish stocks are underaged due to the more common surface ageing

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technique. Archibald et al. (1981) found that estimates of instantaneous mortality (*Z*) were reduced by as much as 50% when the otolith sections were used to age 10 species of rockfishes. Even for fishes that are not long lived, age length data without older fish affect the estimation of von Bertalanffy growth parameters (Hirschhorn 1974). Because population size, growth, and mortality are the basic data required for most production modeling, systematic bias in age determination may lead to serious errors in determining stock production estimates (Le Cren 1974). In the present study, we determine whether significant differences in the estimates of growth and mortality rates are affected by the method of otolith age determination for two species of *Sebastes*—the splitnose rockfish, *S. diploproa,* and canary rockfish, *S. pinniger.*

MATERIALS AND METHODS

Otoliths from *S. diploproa* and *S. pinniger* were collected during a 1980 trawl survey conducted off the west coast of North America (lat 36° 49′ to 50° 00′N). Gear, sampling design, and catch processing generally followed the procedures in Dark et al. (1983). Several differences in the collection and care of otoliths have been described by Boehlert and Yoklavich (1984). Otoliths used in the present study were initially collected for other work; therefore, fish comprising the age subsample were systematically chosen until a predetermined number for each size class was attained. When mortality rates were estimated in the present study, the original age subsample was applied to a simple random sample of length-frequency data to remove any potential sampling bias (Dark 1975) which may have been introduced during sample collection.

The length-frequency data were chosen for each species in the following manner. For *S. pinniger,* the limited length-frequency data from the 1980 survey were combined with length-frequency data collected in 1980 by the Washington Department of Fisheries and the Oregon Department of Fish and Wildlife. For *S. diploproa,* the length-frequency sample was restricted to fish from lat 40° 26′ to 48° 47′ N, where 76% of the fish in the age sample were collected. This was done because Boehlert and Kappenman (1980) detected increases in growth rate with latitude for *S. diploproa* when specimens were compared from this and two other geographic regions (i.e., lat 34°–37°, 37°–40°, 40°–48° N). Thus, all *S. diploproa* otoliths were analyzed as a single stock, even though 24% were collected south of 40° N, in order that the effects of using surface versus section ages could be evaluated with as large an age sample as possible. Resulting growth curves would most likely represent fish from the northernmost strata (40°–48° N) described by Boehlert and Kappenman (1980).

Ageing

Ages were determined from the same whole and sectioned left sagittal otolith of *S. diploproa* and *S. pinniger* by one of three readers from the same laboratory. The variability in ageing the otolith data set within and between readers is presented in Boehlert and Yoklavich (1984). Surface ages for both species were derived from whole otoliths by the method of Boehlert and Yoklavich (1984). The otolith was read from the focus to the dorsal edge or, in the case of older individuals, from the focus to the posterodorsal region (Figure 1A, 1B). Otoliths from many older specimens, particularly *S. diploproa,* possess posterior projections. Pairs of translucent and opaque bands in these regions were included in the counts for *S. diploproa* but not for *S. pinniger;* methodology for the latter species follows the general technique in Six and Horton (1977)

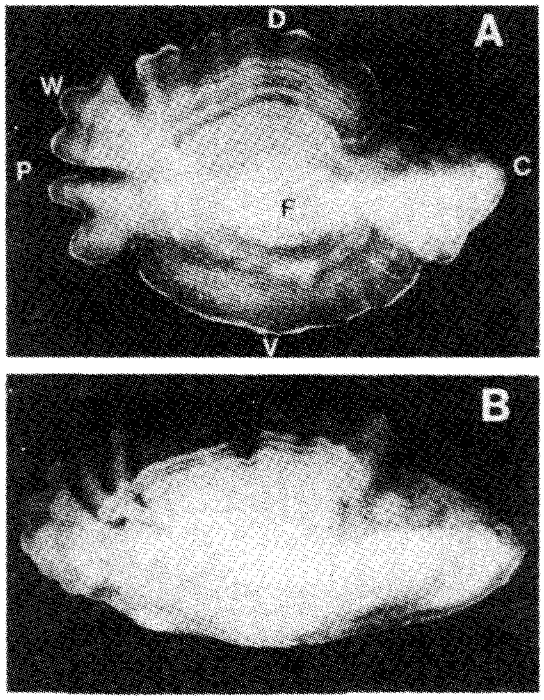

FIGURE 1. External surface of the whole otolith from (A) a 32 cm fork length (FL) female *Sebastes diploproa* with a surface age of 22 years and a section age of 25 years, and (B) a 52 cm FL male *S. pinniger* with a surface age of 18 years and a section age of 19 years. (C) anterior, (D) dorsal, (F) focus, (P) posterior, (V) ventral, (W) posterior projection.

Dorsoventral otolith sections (0.4 mm thick; Figure 2) were obtained with a double-bladed diamond saw; each section was mounted on a microscope slide and polished to remove surface artifacts (Nichy 1977, Boehlert 1985). The otolith section was read (30X or 100X) from the focus to the dorsal edge. For older individuals, the reader began counting toward the dorsal tip, then followed a distinct ring from the dorsal region of the section into the internal dorsal quadrant and continued counting towards the section edge (Figure 2).

In many species of rockfishes, surface and section ages tend to agree for younger individuals (Beamish 1979b, Shaw and Archibald 1981, Boehlert and Yoklavich 1984). For example, G. Boehlert and M. Yoklavich (unpub. data) systematically subsampled every fourth otolith pair from *S. diploproa* and every third otolith pair from *S. pinniger* used in this study and found mean differences between surface and section ages of ≤ 2 years for *S. diploproa* females aged ≤ 12 and males ≤ 17 years and *S. pinniger* females ≤ 7 and males ≤ 8 years. For this reason, we assigned a section age equal to the surface age for all remaining otoliths with surface ages less than or equal to the values listed above. Thus, an otolith from an *S. pinniger* male with a surface age of 6 years was given a section age of 6 years if the otolith had not been included earlier in the subsample. This procedure allowed an increased sample size.

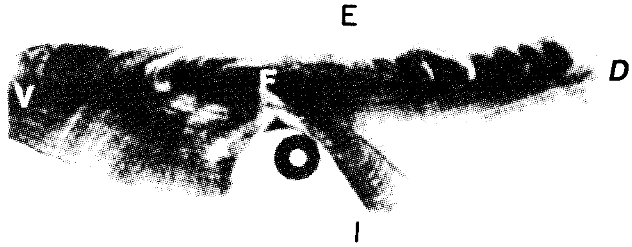

FIGURE 2. Dorsoventral cross section of the left otolith from a 31 cm fork length (FL) *Sebastes diploproa* with a surface age of 28 years and a section age of 39 years. (D) dorsal, (F) focus, (E) external surface, (I) internal surface, (V) ventral. Surface ages were determined by counting rings on the external side of the otolith from the focus towards the dorsal edge.

Mortality and Growth Rates

Total instantaneous mortality rates (Z) were estimated by calculating the slope of the descending right side of the age-frequency distribution (catch curve) by simple linear regression (Ricker 1975). Total instantaneous mortality rates were compared by using an F-test (Neter and Wasserman 1974).

Individual length at age data were fit to the von Bertalanffy growth model (Ricker 1975) by a nonlinear regression routine (Dixon 1981). Von Bertalanffy growth curves were compared by using the chi-square test for homogeneity of individual parameters (Rao 1973) and by the method developed by Gallucci and Quinn (1979) in which the von Bertalanffy growth function is reparameterized with the introduction of a new parameter (ω). Results of all statistical tests were considered significant at $P \leq 0.05$.

RESULTS

Sebastes pinniger

Otoliths were collected from a total of 363 female and 516 male *S. pinniger* specimens between latitudes 43° 11′ and 49° 16′ N. Females had maximum surface ages to 22 years and section ages to 34 years (Table 1). Differences between the two methods were greater for males; maximum surface and section ages were 25 and 60 years, respectively (Table 1).

Fitted growth curves for males based on each ageing method are more similar than growth curves for females. Estimates of L_∞ for both sexes based on surface ages significantly exceeded those based on section ages (by nearly 6 cm fork length (FL) for females and 4 cm FL for males, Figure 3). The difference in growth estimates between treatments apparently occurs beyond the region of the curve where statistical tests on ω are most powerful (Gulland 1983).

TABLE 1. Mean Fork Lengths at Age (FL in Centimeters) and Standard Deviation (SD) for Female and Male *Sebastes pinniger* Based on Surface and Section Ages. *N* Indicates the Number of Otoliths.

	Surface			*Section*		
Age	*N*	*FL*	*SD*	*N*	*FL*	*SD*
			Females			
1	—	—	—	—	—	—
2	4	15.50	0.58	3	15.67	0.58
3	—	—	—	1	15.00	—
4	3	30.00	4.36	3	30.00	4.36
5	4	31.75	0.50	2	32.00	—
6	11	37.27	3.55	8	36.38	3.50
7	6	37.67	1.86	5	36.80	3.70
8	18	41.28	2.70	9	41.00	7.63
9	13	44.08	4.52	16	43.50	3.20
10	18	46.11	3.43	20	46.10	3.65
11	37	49.27	2.91	28	46.71	4.47
12	64	49.92	2.69	50	49.50	3.70
13	57	52.23	2.49	47	50.64	3.59
14	38	53.97	2.83	34	52.53	2.26
15	33	54.48	2.58	18	52.22	3.14
16	23	55.52	2.13	21	53.90	3.06
17	14	56.00	1.84	16	54.06	2.64
18	15	57.00	1.60	13	55.46	2.96
19	2	59.50	2.12	15	54.80	2.51
20	2	61.50	3.54	11	55.00	1.73
21	—	—	—	6	53.83	2.64
22	1	59.00	—	4	54.75	1.71
23	—	—	—	8	56.38	2.39
24	—	—	—	5	57.20	2.49
25	—	—	—	5	56.60	2.19
26	—	—	—	5	57.40	6.07
27	—	—	—	4	57.00	4.83
28	—	—	—	1	50.00	—
29	—	—	—	3	58.33	1.15
30	—	—	—	1	58.00	—
31	—	—	—	—	—	—
32	—	—	—	—	—	—
33	—	—	—	—	—	—
34	—	—	—	1	50.00	—
			Males			
1	—	—	—	—	—	—
2	3	16.00	1.73	2	15.50	2.12
3	5	21.80	1.30	4	20.25	2.50
4	3	25.00	3.61	4	24.25	3.30
5	4	35.25	4.92	3	33.00	8.72
6	3	35.33	1.53	6	34.17	3.31
7	20	38.70	3.63	13	39.31	3.86
8	24	40.42	2.47	22	40.36	2.61
9	18	43.61	3.45	9	43.78	3.03
10	29	45.24	2.89	18	43.06	4.08
11	42	47.00	2.85	20	45.05	3.75
12	70	48.49	1.85	35	47.09	2.73
13	69	49.59	2.02	28	47.79	2.77
14	55	50.22	1.90	22	47.45	3.69
15	47	51.55	1.77	23	47.83	2.37
16	52	51.79	2.05	13	50.46	2.26
17	25	52.84	1.65	23	49.13	1.89
18	24	53.46	1.82	24	50.71	1.90
19	9	53.33	1.32	27	49.89	1.97
20	6	53.67	2.25	27	50.48	2.59
21	3	53.33	0.58	27	51.33	2.11
22	4	54.25	0.96	22	50.32	2.06
23	—	—	—	12	51.50	1.83
24	—	—	—	12	50.42	1.83
25	1	57.00	—	12	50.58	3.68

(Continued)

TABLE 1.—Continued

26.	—	—	—	14	52.07	2.23
27.	—	—	—	8	52.50	2.14
28.	—	—	—	7	52.14	2.34
29.	—	—	—	2	51.00	1.41
30.	—	—	—	5	52.60	1.82
31.	—	—	—	10	52.30	2.63
32.	—	—	—	3	51.67	0.58
33.	—	—	—	8	52.50	1.85
34.	—	—	—	3	54.00	1.00
35.	—	—	—	6	52.83	1.17
36.	—	—	—	3	54.33	4.62
37.	—	—	—	2	52.50	2.12
38.	—	—	—	10	52.80	1.99
39.	—	—	—	1	52.00	—
40.	—	—	—	6	52.67	1.86
41.	—	—	—	2	54.00	1.41
42.	—	—	—	2	53.50	0.71
43.	—	—	—	1	53.00	—
44.	—	—	—	1	52.00	—
45.	—	—	—	4	53.25	1.89
46.	—	—	—	1	50.00	—
47.	—	—	—	1	48.00	—
48.	—	—	—	1	52.00	—
49.	—	—	—	—	—	—
50.	—	—	—	2	52.00	1.41
51.	—	—	—	—	—	—
52.	—	—	—	1	53.00	—
53.	—	—	—	1	53.00	—
54.	—	—	—	—	—	—
55.	—	—	—	—	—	—
56.	—	—	—	1	56.00	—
57.	—	—	—	—	—	—
58.	—	—	—	—	—	—
59.	—	—	—	1	55.00	—
60.	—	—	—	1	56.00	—

Catch curves constructed from surface and section ages of *S. pinniger* clearly differed (Figure 4). Regardless of the ageing technique used, however, both sexes were fully recruited to the fishery by age 12. Estimates of *Z* derived from surface and section ages significantly differed for both sexes: *Z* values estimated from section ages were 61% less for females and 78% less for males than those calculated from surface ages (Table 2).

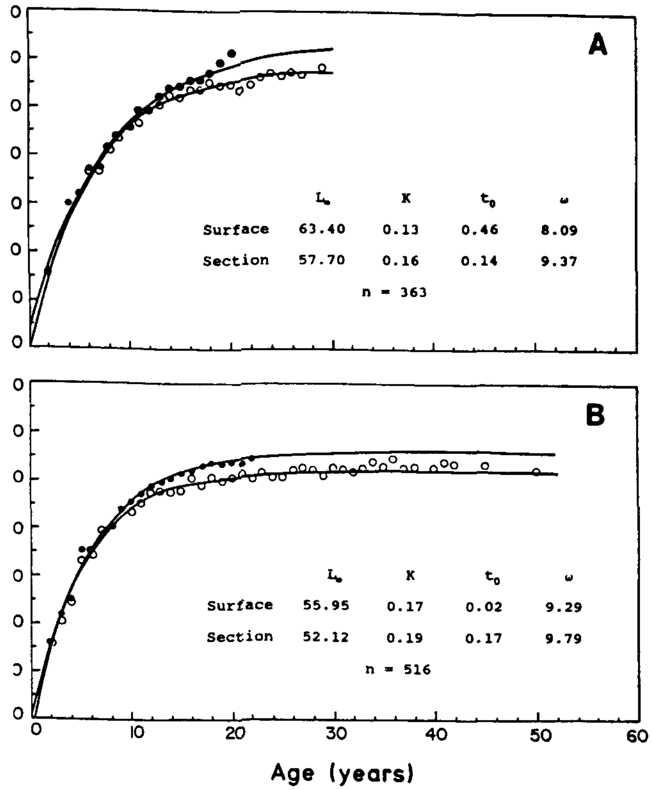

FIGURE 3. Fitted von Bertalanffy growth curves, parameter estimates (see text for explanation), and mean lengths at age based on surface (closed circles) and section ages (open circles) of otoliths from (A) female and (B) male *Sebastes pinniger*. Points representing single individuals are not shown. *N* indicates sample size.

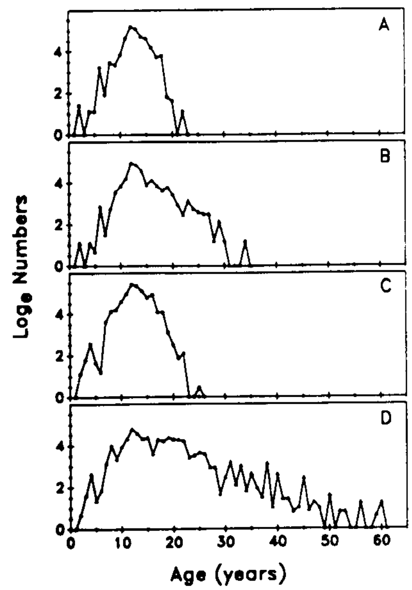

FIGURE 4. Catch curves based on (A, C) surface and (B, D) section ages of otoliths from (A, B) female and (C, D) male *Sebastes pinniger.*

Sebastes diploproa

Otoliths from 1,131 female and 922 male *S. diploproa* were collected between lat 36° 49′ and 48° 47′ N. Both sexes of *S. diploproa* reached much greater ages than those attained by *S. pinniger.* Female *S. diploproa* attained ages similar to males and had surface ages to 55 years and section ages to 81 years compared with 46 and 84 years, respectively, for males (Table 3). Growth curves of either sex based on surface and section ages were essentially identical, and parameter estimates and ω were not significantly different (Figure 5).

Catch curves constructed from surface and section ages of *S. diploproa* clearly differed (Figure 6). In all cases, particularly among females, substantial variation occurred between year classes, with a succession of weak year classes between ages 10 and 20. Therefore, Z was determined for fish older than 21 years. As with *S. pinniger,* significant differences were found between estimates of Z derived from surface and section ages for both sexes; estimates based on section ages were 55% less for females and 76% less for males than those based on surface ages (Table 2).

TABLE 2. Estimates of Total Instantaneous Mortality (*Z*) for *Sebastes pinniger* and *S. diplopro*a. Range Indicates Ages Over Which *Z* Was Determined.

Sex	Surface *Z*	Surface Range	Section *Z*	Section Range
		Sebastes pinniger		
Female	0.452	12–22	0.178	12–34
Male	0.405	12–25	0.089	12–60
		S. diploproa		
Female	0.109	25–48	0.049	22–71
Male	0.130	23–40	0.031	26–75

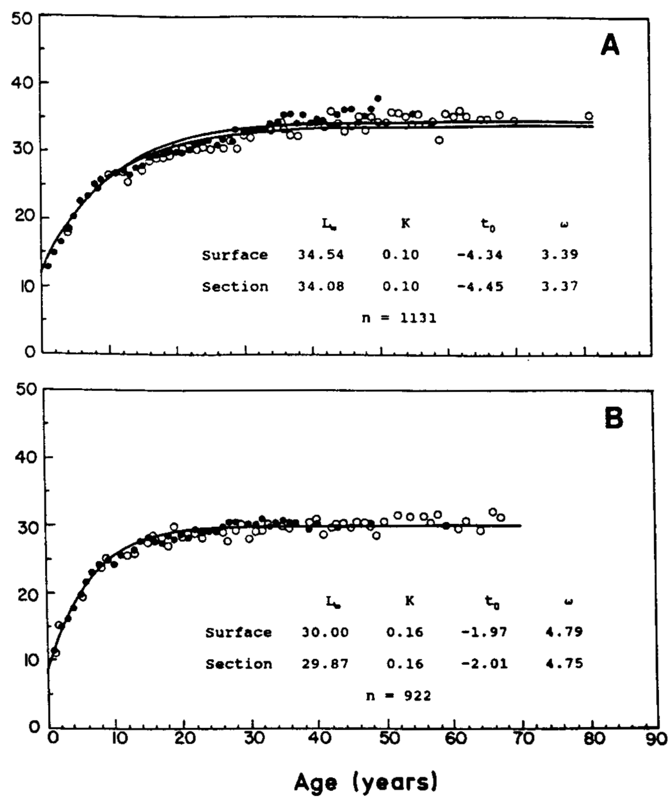

FIGURE 5. Fitted von Bertalanffy growth curves, parameter estimates (see text for explanation), and mean lengths at age based on surface (closed circles) and section ages (open circles) of otoliths from (A) female and (B) male *Sebastes diploproa*. Points representing single individuals are not shown. *N* indicates sample size.

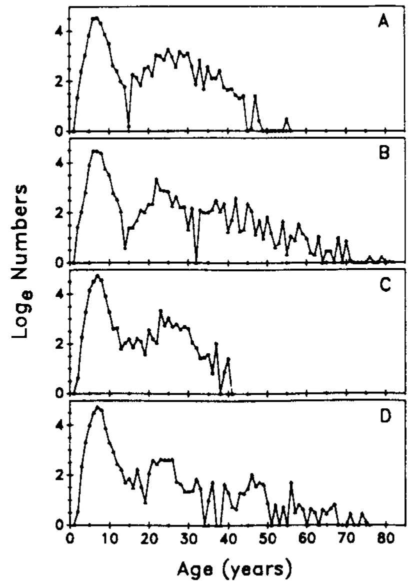

FIGURE 6. Catch curves based on (A, C) surface and (B, D) section ages of otoliths from (A, B) female and (C, D) male *Sebastes diploproa*.

DISCUSSION

Differences in Growth

The effects of changing the methodology of fish age determination can vary from a minor error to major differences. Estimates of maximum age in the genus *Sebastes* have changed markedly in recent years (Beamish 1979b; Bennett et al. 1982; Leaman and Nagtegaal 1987); thus, one would expect similarly remarkable differences in estimates of growth within a species. For *S. pinniger,* estimates of the L_∞ were significantly lower when section rather than surface ages were used although the increase in the growth completion rate (von Bertalanffy's k) for both sexes (Figure 3) was not significant. Therefore, when surface ages are used, errors in ageing incorrectly place older, larger individuals into younger age groups, thus inflating their mean lengths at age (Wilson 1985). This results in lower mean lengths at age for many of these section age groups relative to surface age groups, and a corresponding decrease in L_∞ based on section ages.

Another explanation to account for the differences between growth curves constructed from surface and section ages in *S. pinniger* is that a curve fitting problem occurs, particularly for females. Thus, L_∞ may be overestimated when data are available for only the ascending limb of the von Bertalanffy growth function (Knight 1968, Gallucci and Quinn 1979, Vaughan and Kanciruk 1982). Note that the estimate of L_∞ is typically greater than the maximum observed length in our study (Table 1, Figure 3). Because surface ages have a lower range than section ages and are more concentrated on the ascending limb of the growth curve, they may fail to adequately estimate the upper portion of the curve, which represents L_∞. For example, the large differences between estimates of L_∞ for female *S. pinniger* may occur because their surface ages are more concentrated on the ascending portion of the curve than are those of males (Table 1). This situation is analogous to fitting growth curves with incomplete representation of the range of ages (Hirschhorn 1974).

Unexpected results of our study were the similarities in estimated growth parameters for *S. diploproa* based upon section and surface ages (Figure 5) despite the much higher maximum section ages (Table 3). This difference from *S. pinniger* is likely due to our surface ageing methodology. We suggest that the surface ageing technique for *S. diploproa* has changed over several years to provide older age estimates. Boehlert (1980), for example, used surface ages and observed only 0.5% of all specimens in excess of 25 years of age compared with 18.9% in the present study. Earlier surface ages for *S. diploproa* were assigned without rolling or tilting the otoliths, thus preventing the enumeration of additional annuli on the posterior "winglike" projections (Figure 1A). More recently, annuli located on posterior projection (present in older individuals of many species of *Sebastes)* have been included in surface age counts in order that surface ages more closely represent section ages (Chilton and Beamish 1982, Boehlert and Yoklavich 1984). In the present study, surface ages for *S. pinniger* were assigned using standard criteria for this species (Six and Horton 1977) without including these counts (which are typically less well developed on otoliths of *S. pinniger)*; the counts were included in assigning surface ages to *S. diploproa*. Thus, while maximum ages increased, counts including the posterior projection resulted in surface ages closer to section ages and minimized the higher mean length estimates for ages on the ascending arm of the growth curve as seen in the surface ages of *S. pinniger* (Figures 3, 5). Had the age estimates from Boehlert (1980) or the "other agency" readers in Boehlert and Yoklavich (1984) been used, it is likely that differences in growth parameters similar to those for *S. pinniger* would have been observed for *S. diploproa*.

TABLE 3. Mean Fork Lengths at Age (FL in Centimeters) and Standard Deviation (SD) for Female and Male *Sebastes diploproa* Based on Surface and Section Ages. *N* Indicates the Number of Otoliths.

	Surface			*Section*		
Age	*N*	*FL*	*SD*	*N*	*FL*	*SD*
			Females			
1	8	13.00	1.31	7	12.86	1.35
2	12	14.83	1.53	14	14.93	1.54
3	24	16.54	1.38	18	16.50	1.54
4	36	18.47	2.09	32	17.72	2.04
5	68	20.40	2.31	76	20.38	2.23
6	119	22.59	2.02	117	22.60	2.03
7	125	23.22	2.02	117	23.15	2.04
8	119	24.97	2.21	130	24.97	2.14
9	82	25.71	1.92	75	25.73	2.05
10	61	26.48	2.47	60	26.30	2.68
11	25	26.56	1.45	30	26.63	1.43
12	20	27.15	3.28	21	27.00	2.66
13	13	26.46	2.50	12	25.50	3.53
14	8	27.50	1.69	4	27.50	1.73
15	2	28.00	1.41	6	27.17	2.64
16	11	29.36	2.42	5	28.60	2.07
17	10	29.30	1.77	7	29.14	1.57
18	7	29.71	1.60	11	29.45	0.93

(Continued)

TABLE 3—Continued

19	13	30.15	1.68	7	29.57	2.15
20	15	30.13	1.06	11	30.36	1.80
21	10	30.00	2.45	11	30.36	1.75
22	21	30.71	1.55	27	30.81	1.49
23	18	31.33	1.88	19	30.37	1.67
24	17	31.53	2.37	15	30.80	0.94
25	25	31.80	1.91	17	30.59	1.37
26	18	31.33	1.97	9	31.22	1.99
27	14	32.21	2.46	14	30.79	2.12
28	23	32.22	2.19	9	31.89	2.15
29	20	33.30	1.81	9	30.56	2.01
30	21	33.19	1.57	3	32.67	1.53
31	14	33.07	2.40	8	32.25	1.75
32	9	33.33	3.16	1	37.00	—
33	17	33.47	2.15	9	33.44	2.30
34	7	34.29	2.56	7	33.43	1.72
35	17	34.53	2.53	9	34.22	2.17
36	15	35.53	1.60	9	33.56	1.51
37	12	35.58	1.73	12	32.58	1.73
38	15	34.47	2.50	7	32.57	1.90
39	10	35.50	1.90	13	33.77	2.86
40	6	34.33	1.86	4	34.25	2.36
41	8	35.00	2.14	8	34.38	2.39
42	5	34.60	2.51	5	33.87	2.00
43	4	34.00	1.41	7	36.00	1.15
44	7	35.57	1.13	4	34.50	1.29
45	2	36.50	0.71	11	33.09	1.97
46	4	36.50	1.00	11	35.33	3.30
47	5	34.80	1.64	6	33.29	2.73
48	2	35.50	0.71	7	33.29	2.43
49	2	36.50	0.71	3	35.33	0.58
50	2	38.00	1.41	10	34.50	2.68
51	—	—	—	4	34.50	1.91
52	—	—	—	4	36.00	1.41
53	—	—	—	5	36.00	1.22
54	—	—	—	8	35.37	2.45
55	3	36.00	1.00	2	34.50	2.12
56	—	—	—	6	35.83	1.94
57	—	—	—	4	34.25	3.10
58	—	—	—	6	34.67	2.34
59	—	—	—	3	32.00	2.65
60	—	—	—	5	35.80	1.92
61	—	—	—	2	35.50	0.71
62	—	—	—	3	36.33	2.08
63	—	—	—	4	35.50	1.29
64	—	—	—	—	—	—
65	—	—	—	2	35.50	1.41
66	—	—	—	2	35.00	1.41
67	—	—	—	—	—	—
68	—	—	—	4	35.75	1.71
69	—	—	—	1	38.00	—
70	—	—	—	3	34.67	2.08
71	—	—	—	1	35.00	—
72	—	—	—	1	30.00	—
73	—	—	—	—	—	—
74	—	—	—	—	—	—
75	—	—	—	1	39.00	—
76	—	—	—	1	34.00	—
77	—	—	—	—	—	—
78	—	—	—	1	36.00	—
79	—	—	—	1	34.00	—
80	—	—	—	1	36.00	—
81	—	—	—	2	35.50	3.54
			Males			
1	12	11.33	1.61	11	11.09	1.45
2	8	14.87	0.99	6	15.00	1.10

(Continued)

TABLE 3—Continued

Age	Surface			Section		
	N	*FL*	*SD*	*N*	*FL*	*SD*
3	27	16.15	2.16	27	16.48	2.08
4	47	17.70	1.92	48	17.63	2.05
5	86	19.98	2.02	79	19.77	2.25
6	100	21.87	1.86	101	21.71	1.96
7	128	23.23	1.82	124	23.16	1.83
8	114	24.32	1.91	119	24.12	2.11
9	62	24.69	2.05	61	24.90	1.79
10	30	24.23	2.16	32	24.28	2.25
11	15	25.53	3.20	21	25.52	3.12
12	16	25.81	1.83	14	25.57	1.70
13	7	26.43	1.72	11	25.82	2.96
14	8	27.63	2.07	6	27.67	2.42
15	9	28.22	0.83	8	27.63	1.30
16	7	27.57	1.27	5	28.40	1.67
17	11	27.64	1.43	10	28.50	1.27
18	9	28.56	1.51	6	27.17	1.17
19	5	28.00	1.22	3	29.67	1.15
20	13	28.92	1.12	9	28.67	1.41
21	9	28.44	1.67	14	28.64	1.08
22	9	29.56	2.13	12	28.92	1.24
23	29	28.93	2.20	14	28.32	1.50
24	16	29.44	1.71	13	29.31	1.18
25	20	29.15	1.31	14	29.43	1.40
26	15	29.73	1.10	15	29.13	0.99
27	17	30.41	1.84	6	27.67	3.88
28	13	30.46	1.39	6	29.50	0.84
29	16	29.94	1.18	5	30.20	1.10
30	16	30.19	2.48	4	28.25	2.50
31	9	30.11	1.90	4	29.25	0.96
32	6	31.00	0.89	6	29.33	1.75
33	4	29.75	2.22	5	30.00	0.71
34	5	30.40	0.55	1	30.00	—
35	5	30.80	0.84	2	30.00	2.83
36	3	30.33	1.15	6	29.83	0.98
37	7	30.43	1.27	1	30.00	—
38	1	30.00	—	1	26.00	—
39	2	29.50	3.54	4	30.25	2.63
40	4	30.50	1.29	4	30.75	1.71
41	1	31.00	—	2	28.50	0.71
42	—	—	—	2	29.50	2.12
43	—	—	—	3	30.00	2.00
44	—	—	—	4	30.25	0.50
45	—	—	—	5	29.80	0.84
46	1	31.00	—	8	30.50	1.51
47	—	—	—	5	30.20	1.92
48	—	—	—	6	29.83	2.86
49	—	—	—	6	28.67	1.63
50	—	—	—	2	30.50	2.12
51	—	—	—	1	31.00	—
52	—	—	—	2	31.50	0.71
53	—	—	—	1	30.00	—
54	—	—	—	3	31.33	2.52
55	—	—	—	1	30.00	—
56	—	—	—	6	31.50	0.84
57	—	—	—	2	30.50	0.71
58	—	—	—	2	31.50	0.71
59	—	—	—	2	30.00	—
60	—	—	—	1	30.00	—
61	—	—	—	2	29.50	2.12
62	—	—	—	2	30.50	0.71
63	—	—	—	1	29.00	—
64	—	—	—	2	29.50	0.71
65	—	—	—	1	32.00	—

(Continued)

TABLE 3—Continued

66	—	—	—	3	32.00	1.73
67	—	—	—	2	31.50	0.71
68	—	—	—	1	36.00	—
69	—	—	—	—	—	—
70	—	—	—	—	—	—
71	—	—	—	1	32.00	—
72	—	—	—	—	—	—
73	—	—	—	1	31.00	—
74	—	—	—	1	32.00	—
75	—	—	—	1	33.00	—
76	—	—	—	—	—	—
77	—	—	—	—	—	—
78	—	—	—	—	—	—
79	—	—	—	—	—	—
80	—	—	—	1	35.00	—
81	—	—	—	—	—	—
82	—	—	—	—	—	—
83	—	—	—	—	—	—
84	—	—	—	1	30.00	—

Mortality

The results of this study demonstrate that total mortality (*Z*) is significantly less when section rather than surface ages are used for slow-growing, long-lived fishes such as *S. pinniger* and *S. diploproa* (Table 2). As evident in the larger reduction in *Z* for males versus females, the problem is more pronounced in males, possibly because their slower growth increases the difficulty of assigning accurate surface ages. This may explain why *Z* is higher in male *S. diploproa* than in females when surface ages are used and lower when section ages are used. The absence of older *S. pinniger* females also contributed to the smaller decrease in *Z* when section ages were used.

This study has documented important differences in estimates of growth and mortality which result solely from differences in otolith ageing methodology. It is hoped that subsequent research will incorporate these estimates into various stock assessment models to evaluate the effect that these different otolith ageing techniques have on models designed to evaluate yield and production characteristics of long-lived, slow-growing fish stocks.

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LITERATURE CITED

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977–1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048, 57 p.

Beamish, R. J. 1979a. Differences in the age of Pacific hake (*Merluccius productus*) using whole otoliths and sections of otoliths. J. Fish. Res. Board Can., 36: 141–151.

Beamish, R. J. 1979b. New information on the longevity of Pacific ocean perch (*Sebastes alutus*). J. Fish. Res. Board Can., 36: 1395–1400.

Bennett, J. T., G. W. Boehlert, and K. K. Turekian. 1982. Confirmation of longevity in *Sebastes diploproa* (Pisces: Scorpaenidae) from ^{210}Pb/^{226}Ra measurements in otoliths. Mar. Biol. (Berl.), 71: 209–215.

Boehlert, G. W. 1980. Size composition, age composition, and growth of canary rockfish, *Sebastes pinniger*, and splitnose rockfish, *S. diploproa*, from the 1977 rockfish survey. Mar. Fish. Rev., 42(3–4): 57–63.

Boehlert, G. W. 1985. Using objective criteria and multiple regression models for age determination in fishes. Fish. Bull., 83: 103–117.

Boehlert, G. W., and R. F. Kappenman. 1980. Variation of growth with latitude in two species of rockfish (*Sebastes pinniger* and *S. diploproa*) from the northeast Pacific Ocean. Mar. Ecol. Prog. Ser., 3: 1–10.

Boehlert, G. W., and M. M. Yoklavich. 1984. Variability in age estimates in *Sebastes* as a function of methodology, different readers, and different laboratories. Calif. Fish and Game, 70(4): 210–224.

Campana, S. E., K. C. T. Zwanenburg, and J. N. Smith. In press. ^{210}Pb/^{226}Ra determination of longevity in redfish. Can. J. Fish. Aquat. Sci.

Chilton, D. E., and R. J. Beamish. 1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Can. Spec. Publ. Fish. Aquat. Sci. 60, 102 p.

Dark, T. A. 1975. Age and growth of Pacific hake, *Merluccius productus*. Fish. Bull., 73: 336–355.

Dark, T. A., M. E. Wilkins, and K. Edwards. 1983. Bottom trawl survey of canary rockfish (*Sebastes pinniger*), yellowtail rockfish (*S. flavidus*), bocaccio (*S. paucispinis*), and chilipepper (*S. goodei*) off Washington —California, 1980. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-48, 40 p.

Dixon, W. J. 1981. BMDP statistical software. Univ. Calif. Press, Berkeley, 726 p.

Gallucci, V. F., and T. J. Quinn II. 1979. Reparameterizing, fitting, and testing a simple growth model. Trans. Am. Fish. Soc., 108: 14–25.

Gulland, J. A. 1983. Fish stock assessment. A manual of basic methods. John Wiley and Sons, New York, 223 p.

Hirschhorn, G. 1974. The effect of different age ranges on estimated Bertalanffy growth parameters in three fishes and one mollusk of the northeastern Pacific Ocean. Pages 192–199 *In* T. B. Bagenal (ed.) The ageing of fish. Unwin Brothers, Surrey, Engl.

Knight, W. 1968. Asymptotic growth: An example of nonsense disguised as mathematics. J. Fish. Res. Board Can., 25: 1303–1307.

Leaman, B. M., and D. A. Nagtegaal. 1987. Age validation and revised natural mortality rate for yellow tail rockfish. Trans. Am. Fish. Soc., 116: 171–175.

Le Cren, E. D. 1974. The effects of errors in ageing in production studies. Pages 221–224 *In* T. B. Bagenal (ed.) The ageing in fish. Unwin Brothers, Surrey, Engl.

Neter, J., and W. Wasserman. 1974. Applied linear statistical models. Regression, analysis of variance, and experimental designs. Richard D. Irwin, Inc., Homewood, Ill.

Nichy, F. 1977. Thin-sectioning fish ear bones. Fish age determination aids pollution control research. Sea Technol., Feb., p. 27.

Rao, C. R. 1973. Linear statistical inference and its implications. 2nd ed. John Wiley and Sons, New York, 625 p.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Shaw, W., and C. P. Archibald. 1981. Length and age data of rockfishes collected from B.C. coastal waters during 1977, 1978, and 1979. Can. Data Rep. Fish. Aquat. Sci. 289, 119 p.

Six, L. D. and H. F. Horton. 1977. Analysis of age determination methods for yellow tail rockfish, canary rockfish, and black rockfish off Oregon. Fish. Bull., 75: 405–414.

Vaughan, D. S., and P. Kanciruk. 1982. An empirical comparison of estimation procedures for the von Bertalanffy growth equation. J. Cons. Cons. Int. Explor. Mer, 40: 211–219.

Wilson, C. D. 1985. The effects of different otolith ageing techniques on estimates of growth and mortality for two species of rockfishes, *Sebastes pinniger* and *Sebastes diploproa*. M.S. Thesis, Oregon State Univ., Corvallis, 107 p.

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