GROWTH OF THE BLUE ROCKFISH *(SEBASTES MYSTINUS)*

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ABSTRACT

Weight-length and age-length data were obtained for samples of blue rockfish (*Sebastes mystinus*) taken off southern California.

For weight-length, $W = aL^b$, the value of a was found to be 2.043×10^{-5}; the value of b, 3.059.

The Von Bertalanffy curve was used for age length. It was determined that $L_\infty = 327.6$ mm, $k = 0.1428$, and $t_0 = -1.553$.

RESUMEN

Colecciones de *Sebastes mystinus* obtenidas en la región meridional de California, han proporcionado los datos básicos para establecer las relaciones entre peso y longitud, así como entre edad y longitud.

Para la relación peso y longitud, $W = aL^b$, se obtuvo el valor resultante 2.043×10^{-5}; siendo $b = 3.059$.

La curva de von Bertalanffy se utilizó para la relación edad y longitud. Así se ha determinado que $L_\infty = 327.6$mm, $k = 0.1428$, y $t_0 = -1.553$.

INTRODUCTION

The blue rockfish, *Sebastes mystinus*, is an important sport fish along the California coast, especially in central and northern California, where it was the most abundant species taken by hook-and-line fishermen in a 1957-61 survey (Miller and Geibel 1973). In the central California partyboat fishery, blue rockfish accounted for 27% of the total catch of all species and 31% of the rockfish catch.

The blue rockfish is less important in the southern California sport catch. In this area the sport fishery relies more on migratory surface species in summer and on rockfish during the winter when the other species are less available. In central California, although the blue rockfish are nonmigratory, the catch tends to be very low in the winter and high in the summer; Miller and Geibel (1973) attribute this to a seasonal change in feeding habits.

The purpose of this paper is to present growth data on blue rockfish off southern California. Such data are necessary to an understanding of the life history and population dynamics of the species. A secondary purpose is to compare and contrast these data with other published data on the blue rockfish.

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MATERIALS AND METHODS

Blue rockfish were caught on hook and line off southern California (Table 1). Standard length, fork length, total length, and weight were obtained for each fish. Otolith and scale samples were taken.

Scales were used for aging the blue rockfish because they appeared to be easier to read than otoliths and also because it is much more convenient to back-calculate lengths from scales. In addition, *Sebastes* species tend to exhibit nonisometric growth of otoliths. For a 130-mm fish the otolith equals 5.4% of standard length, whereas for a 330-mm fish it equals only 4.1% of standard length. This further complicates back-calculating lengths from otoliths.

There is no good way to verify isometric growth of rockfish scales relative to length. We assume that growth is isometric primarily because the scales and scale pockets are integral parts of the covering of the fish's body. One objection raised to back calculations of length from scale annuli is that the scales do not begin to form until the rockfish are about 15 mm long. However, when the scale does form, it forms as a plate and not as a point.

In many fishes, especially temperate freshwater species, the scale annuli are formed by a change in spacing of circuli. The circuli are more widely spaced when water temperatures, feeding, and metabolism are high, and more closely spaced when these factors are low.

In many species of saltwater fishes, annuli consist

TABLE 1
Blue rockfish Caught Off Southern California

			Standard length (mm)	
Locality	Date	Number	Mean	Range
Bird Rock (La Jolla)	1-25-78	4	165	156-179
San Nicolas Island	5-31-79	35	252	193-301
San Nicolas Island	9-07-79	20	231	190-290
Santa Barbara Island	5-31-79	11	220	172-283
San Clemente Island	9-06-78	9	221	147-308
San Clemente Island	5-29-79	1	235	
San Clemente Island	8-09-79	3	195	180-223
Osborne Bank	8-04-71	2	256	252-259
Tanner Bank	3-1-77	10	271	260-286
Tanner Bank	9-07-78	12	275	233-325
Cortes Bank	5-30-79	12	221	162-266
Cortes Bank	9-05-79	5	200	172-248
		124		147-325

of bands of broken circuli. These are especially noticeable in species with a marked fat cycle, such as the California sardine, *Sardinops sagax (S. caeruleus)*. The sardine gains weight during the summer and loses weight during the winter. A sardine taken in September might be 20% heavier than one of similar length taken in March.

The circuli on the scales of sardines are about equally spaced throughout the year. However, when the fish loses subcutaneous fat deposits during the winter, apparently the elastic skin tightens enough to exert pressure on the scale pockets. This causes an erosion and breaking of circuli around the edge of the scales. When the fish begins to gain weight and grow more rapidly in the spring, normal circuli are again laid down at the edge of the scale. All of the blue rockfish scales had checks caused by broken circuli.

Loss of scales can cause a change in scale-pocket tension on adjacent scales and result in false annuli being formed in the scales near the area of scale loss. These false annuli are often noticeably more or less prominent than the true annuli and also may be markedly asymmetrical, depending on their distance and direction from the area of scale loss. Sampling scales from several locations on both sides of the fish decreases the chance of obtaining scales with false annuli in similar positions relative to the scale center.

Rockfish scales tend to be deciduous. In some species it is almost impossible to find scales that are not regenerated, whereas in others only a small percentage of the scales are regenerated. Blue rockfish fall somewhere between the two extremes.

In sampling rockfish scales it is often useful to include lateral-line scales in the sample in case no other unregenerated scales can be found. These scales are seldom deciduous, but there is a tubelike structure in the center of each scale that generally obscures the first annulus and makes the center of the scale difficult to locate. Fortunately, the blue rockfish generally had enough unregenerated regular scales so that it was not necessary to rely on lateral-line scales for most of the fish sampled.

The scales were mounted dry between two microscope slides and projected on a sheet of white paper at about 30× to 50× magnification. The scale center, annuli, and scale margin were marked for the six best scales for each fish. I obtained back-calculated lengths for each of the six scales and compared the readings to determine the age and average back-calculated lengths.

Annuli were considered valid if they appeared in the approximate same location in at least four of the six scales. The average value was obtained for each of the sets of readings to arrive at length at age for each fish.

LENGTH-WEIGHT RELATIONSHIP

Length and weight data were obtained from 98 blue rockfish ranging from 147 to 325 mm in standard length.

The usual formula describing a length-weight curve for fishes is $W = aL^b$. This may be obtained by transforming the straight line, $\log W = \log a + b \log L$, or directly by nonlinear methods (Marquardt's least squares) (Figure 1). The former should give the best least-squares fit to the logs of length and weight; the latter should give the best fit to the arithmetic curve. If the values of b are close to 3, the formula $W = aL^3$ may be used in which $a = K$; $(K = W/L^3)$.

The values of a and b for the three curves are:

nonlinear	$a = 2.04262 \times 10^{-5}$	$b = 3.05934$
log log	$a = 2.12486 \times 10^{-5}$	$b = 3.05240$
cubic	$a = 2.82587 \times 10^{-5}$	$b = 3.00000$

The calculated values of weight are the same between lengths 20 and 340 mm for the nonlinear and log log curves. The weights calculated from the cubic curve are slightly higher than those for the other two curves for lengths up to 240 mm, and slightly lower above 240 mm (Table 2).

The residuals from the nonlinear fit (Figure 2) increase with increasing length. An arithmetic standard error of estimate is useless for determining limits of weight divisions. There is no increase in residuals of log weight with log length. For the curve, $\log W = -4.67267 + 3.05240 \log L$, $Sy = 0.038498$. This value of S_y may be applied to the arithmetic curve as a

TABLE 2
Calculated Weights (grams) for Blue Rockfish

	Southern California		Monterey[a]		
Standard length (mm)	Male & female	Male & female	Female	Male	Male & female
20	0.20	0.23	0.37	0.22	0.73
40	1.65	1.81	2.60	1.72	4.27
60	5.69	6.10	8.11	5.77	12.0
80	13.7	14.5	18.2	13.6	24.8
100	27.1	28.3	34.1	26.6	43.7
120	47.2	48.8	56.8	45.8	69.3
140	75.5	77.5	87.6	72.6	103
160	111	116	127	108	144
180	163	165	177	154	194
200	224	226	238	211	253
220	300	301	311	280	322
240	391	391	397	363	402
260	500	497	498	462	492
280	627	620	613	576	594
300	774	763	744	708	708
320	942	926	892	858	834
340	1133	1111	1058	1029	972
Number of fish	98	98	147	58	278
Log a	−4.67267	−4.54885	−4.8346	−4.55299	−3.43180
b	3.05240	3.00000	2.80779	2.98849	2.53589

(a) Miller and Geibel 1973.

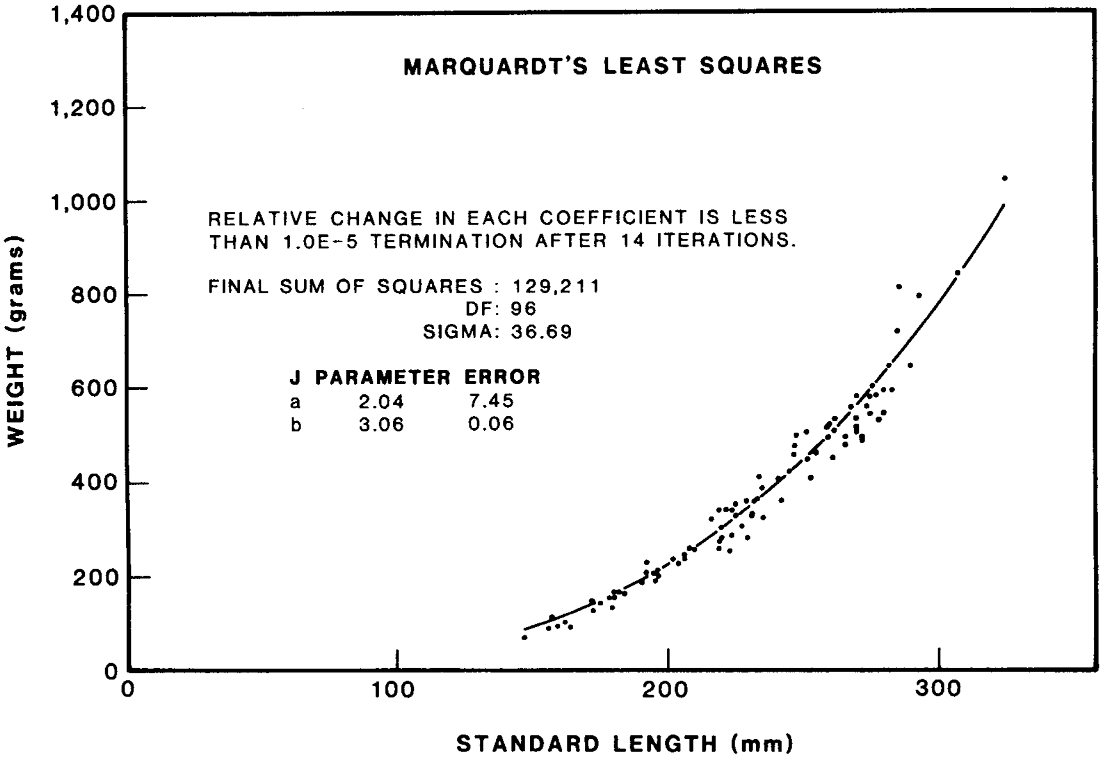

Figure 1. Length-weight curve ($L = 2.045W^{3.059}$) for blue rockfish taken off southern California.

percentage: S_y = +9.27%, −8.48%; $2S_y$ = +19.39%, −16.24%.

Miller and Geibel (1973) give length-weight formulas that they obtained for blue rockfish from the Monterey area. Their data were collected in total length in mm and weight in pounds. We have converted these formulas to standard length and grams for comparison ($SL = 0.8127\ TL$) (Table 2).

They also give length-weight curves for male fish, females, and sexes combined. The females do give a slightly higher curve, but this is probably fortuitous. When they added 73 apparently unsexed fish to get a combined curve, they obtained values higher than either the male- or female-only curves. However, the curves all agree well with that based on the data from this study (Figure 3).

AGE-LENGTH RELATIONSHIP

We were unable to get samples of young fish to obtain length-frequency data that could establish the ages of these fish. Wales (1952) and Miller and Geibel (1973) obtained samples of juvenile blue rockfish from the Monterey area; we have compared these with average observed lengths back-calculated from scales for younger blue rockfish from southern California (Table 3).

The data of Wales (who used fork length) and Miller and Geibel (who used total length) were converted to standard length by the formulas $SL = 0.8506\ FL$ ($\sigma = 0.0069$) and $SL = 0.8127\ TL$ ($\sigma = 0.0091$). These formulas were based on measurements from fish 147 mm SL and larger and may not be entirely applicable to the smaller fish. The agreement with Wales's data seems to be very good. Miller and Geibel's samples show little growth in the second year, but this may be because larger fish migrate out of the nursery area to deeper waters.

The Von Bertalanffy growth curve is widely used to describe fish growth. The equation takes the form:

$$L_t = L_\infty (1 - e^{-k(t - t_0)})$$

There are several methods of solving the equation. The values of L_∞, k and t_0 may be obtained from two simple equations of the $Y = a + bX$ type.

In the first equation X equals length at age t (L_t), and Y equals length at age $t + 1$ ($L_t + 1$) (Figure 4.)

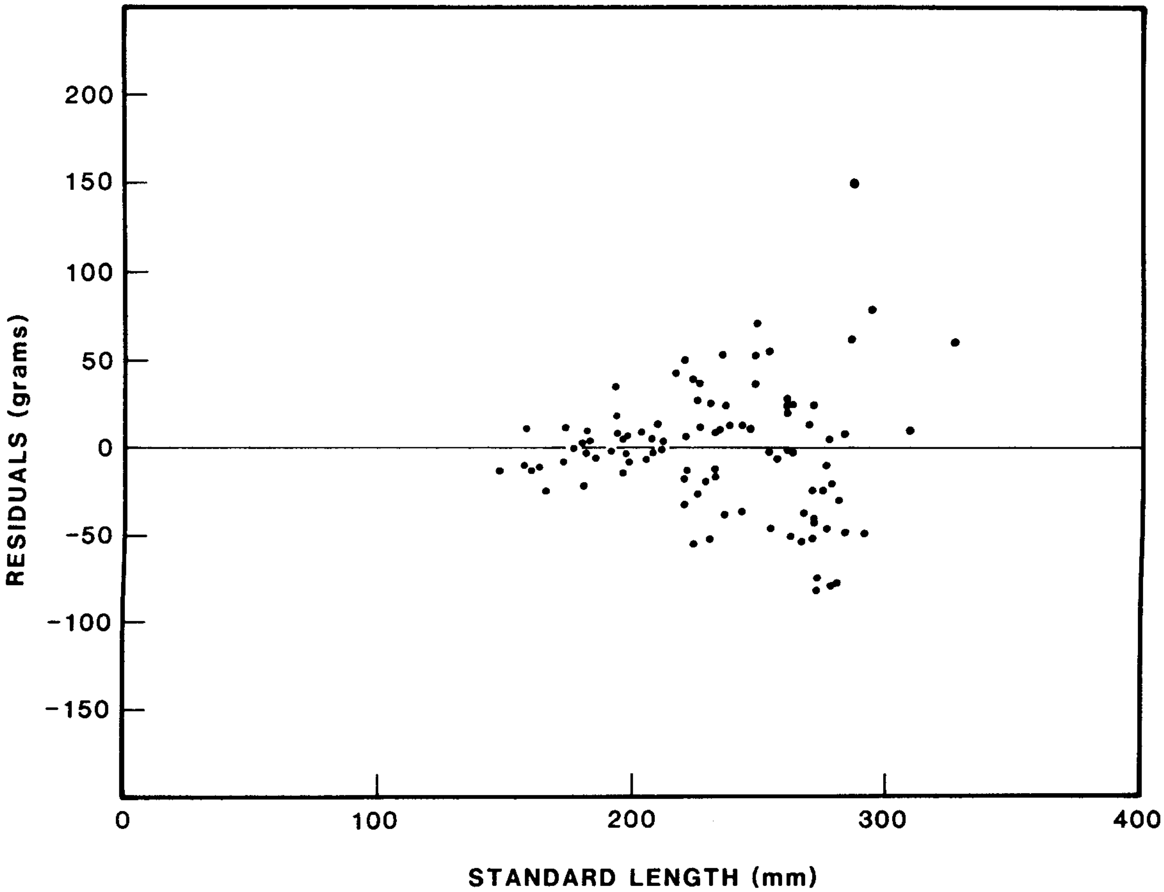

Figure 2. Residuals (L_o-L_c) of length-weight curve for southern California rockfish.

Length at infinity (L_∞) is assumed to be the point at which the computed line intersects the 45° diagonal from the origin. The value of k is obtained from $k = \log_e{}^{1/b}$. It is obvious from the angle at which the computed line intersects the diagonal that little variation around the line would take in a considerable range of lengths at age at infinity.

In the second equation X equals age, and Y equals $\log_e (L_\infty - L_t)$ (Figure 5). The value of t_0 (age at length zero) is obtained from $t_0 = a - \mathrm{Log}_e L_\infty / K$.

The second equation, when plotted, gives a good visual representation of the final age-length fit. Ricker (1958) suggests adjusting this equation to obtain a better fit by using trial values of L_∞, that is, iterating to get a better value of L_∞ for the Von Bertalanffy equation.

We have arbitrarily obtained two additional estimates of L_∞ by recalculating the first equation omitting the first pair of values (L_1 and L_2) from one equation and the second pair (L_2 and L_3) from the other. Both of these increase the value of L_∞. Length at infinity equals 313, 336, and 362 for the 12, 11, and 10 pairs of values, respectively.

Calculated values of length are closer to observed values for the second (336 mm) and third (362 mm) values of L_∞ than for the first (313) (Table 4). The sum of the squares of deviations of calculated length from observed length for the 12 pairs of values for the first value of L_∞ is 320; for the second, 128; and for the third, 284.

These equations can be used instead of the Von Bertalanffy equation to get the same calculated lengths and without the necessity of obtaining k and t_0. The equation $\log_e (L_\infty - L_t) = a + bt$ (in which t equals age) can be changed to $L_t = L_\infty - e^{(a + bt)}$, which also is easier to use than the Von Bertalanffy equation.

TABLE 3
Length-Frequency Data Used to Estimate Length at Age for Juvenile Blue Rockfish

Month	Age	Southern California	Monterey: Wales	Monterey: Miller and Geibel
April				41 (one fish)
June				57 mean
July			58-65 = Range	56 mean
Aug.				58 mean
Sept.				62 mean
Oct.				65 mean
Nov.				69 mean
Dec.				70 mean
Jan.				73 mean
Mar.	1	95		80 mean
Apr.				83 mean
May				88 mean
June			96-126 = Range (115 = mean)	
July				87 mean
Aug.				99 mean
Sept.				
March	2	133		
June			mean = 149	
March	3	163		
June			mean = 170	
March	4	181		

Monterey in 1929-30 (Wales 1952) and the 1964 year class in 1964-65 (Miller and Geibel 1973) compared with observed lengths back calculated from scales for southern California. All lengths are standard lengths in mm.

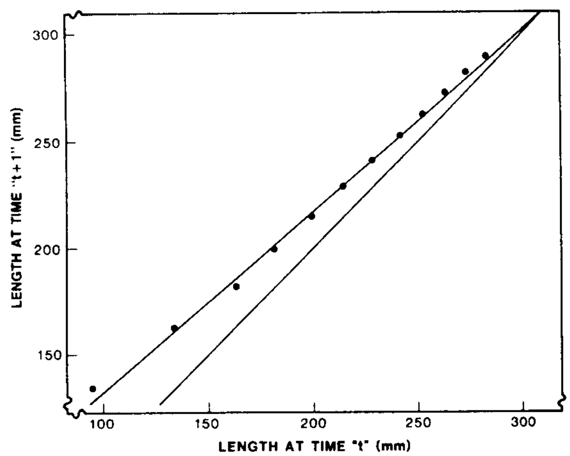

Figure 4. Plot of length at age plus one against length at age with the calculated regression line for blue rockfish.

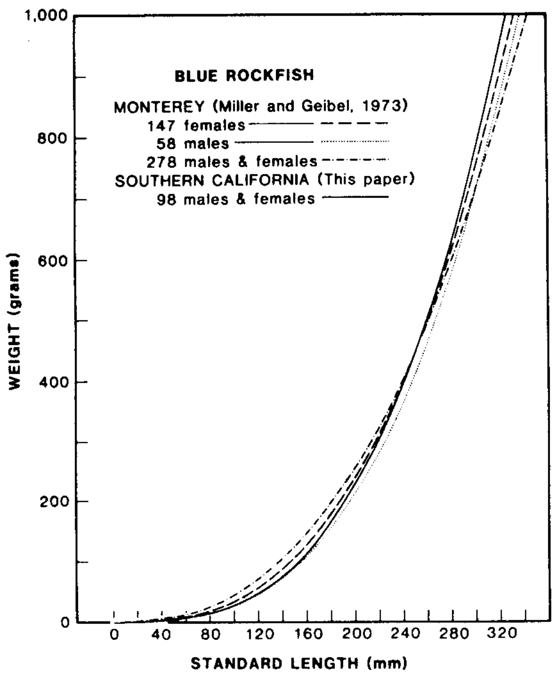

Figure 3. Comparison of blue rockfish length-weight curves, southern California and Monterey (Miller and Geibel 1973).

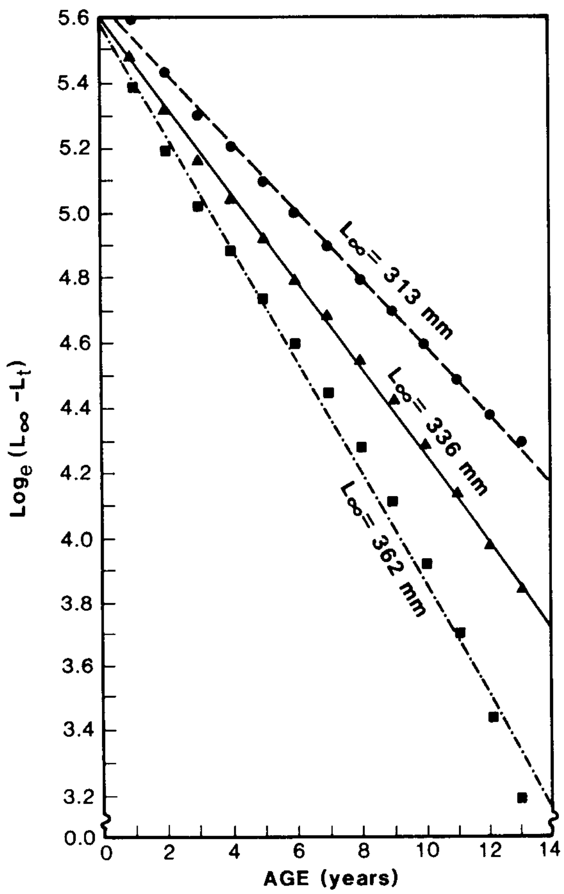

Figure 5. Plots of $\log_e (L_\infty - L_t)$ against age for blue rockfish.

In the Von Bertalanffy equation for the blue rockfish $k = 0.1316$ and $t_0 = -1.738$ for $L_\infty = 336$.

Tomlinson and Abramson (1961) give a method of fitting a Von Bertalanffy curve by least squares. Using this method, a value of 327.3 mm is obtained for L_∞; 0.1430 for k; and -1.5487 for t_0. The sum of d^2 is 118.

TABLE 4
Computed Values of Length at Age for Blue Rockfish: $L_t = L_\infty - e^{(a + bt)}$.

Age	Observed length	Calculated length $L_\infty = 313$	Calculated length $L_\infty = 336$	Calculated length $L_\infty = 362$
1	94.5	87.1	101.8	109.3
2	113.4	123.3	130.8	134.4
3	162.5	153.7	156.2	157.1
4	181.4	179.3	178.4	177.5
5	199.5	201.3	197.9	195.9
6	214.4	218.8	215.0	212.5
7	228.1	233.9	230.0	227.4
8	241.3	246.6	243.1	240.8
9	252.5	257.3	254.6	252.9
10	263.1	266.3	264.7	263.8
11	273.2	273.8	273.5	273.6
12	282.5	280.2	281.2	282.4
13	289.1	285.5	288.0	290.4
	a =	5.59644	5.58816	5.63799
	b =	−0.17437	−0.13225	−0.10488
	Σd^2 =	374.84	128.47	284.20

Using a Marquardt nonlinear least squares computer program to minimize the sum of d^2 by iteration from estimated values, 327.6 mm is obtained for the value of L_∞; 0.1428 for k; and -1.5535 for t_0 (Figure 6).

All of the above curves are based on average lengths at each age. A nonlinear least squares curve based on all length measurements at each age was also calculated (Figure 7). This weights the curve to those lengths for which there is most data. When back-calculated lengths are used, this means that the curve is weighted more heavily to the lengths at younger ages. It would appear that fewer older fish are more representative of their true size at age than lengths influenced by extrapolations of the more heavily weighted younger fish (Table 5). The value of L_∞ for the weighted curve is 313.0 mm; of k, 0.1600; and t_0, -1.3696.

The standard error of estimate for the weighted curve is 18.6 mm. However, the residuals (Figure 8)

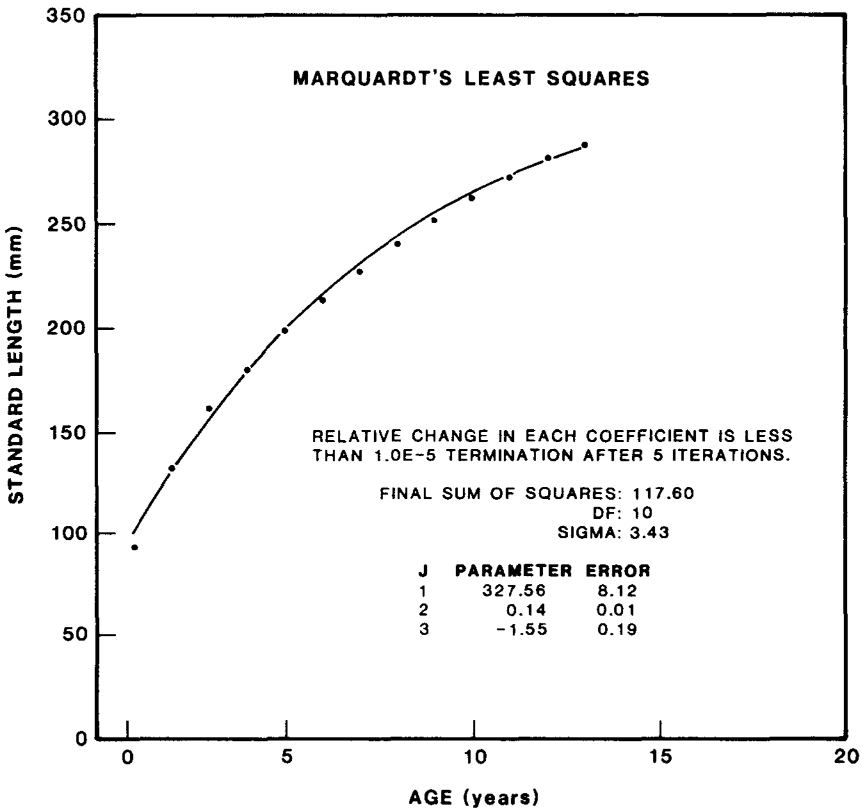

Figure 6. Von Bertalanffy length-age curve using mean lengths at age for blue rockfish.

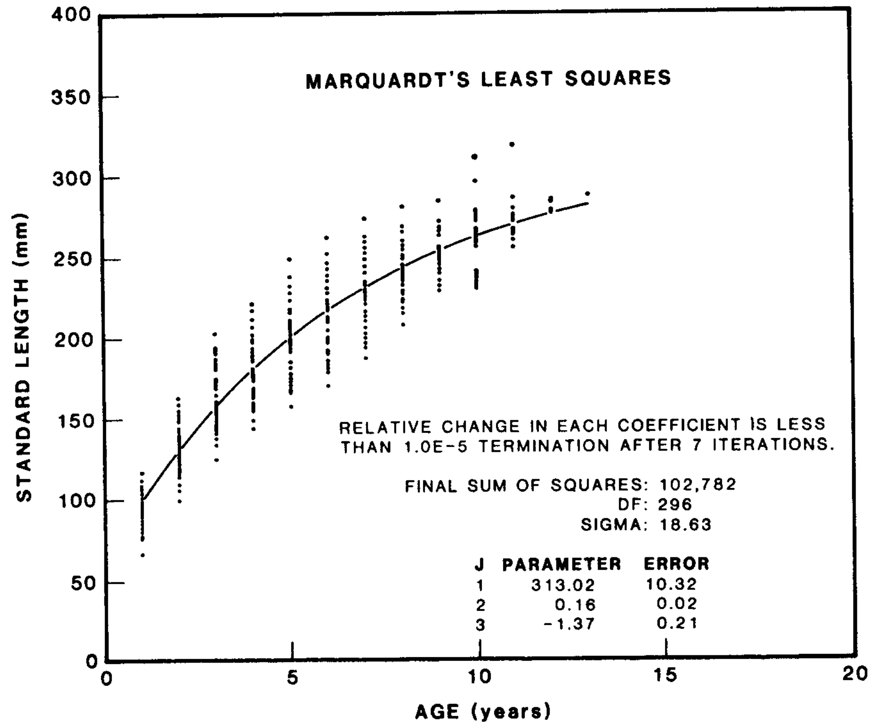

Figure 7. Von Bertalanffy length-age curve using sample of 299 age readings for blue rockfish (28 readings, age 1 through 10; 14 readings, age 11; 4 readings, age 12; 1 reading, age 13).

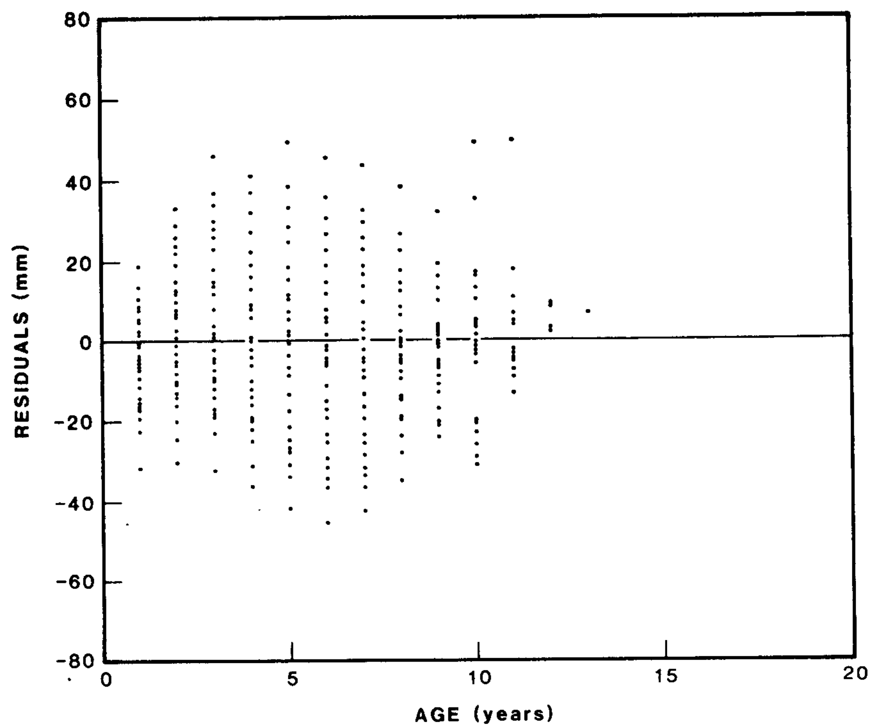

Figure 8. Residuals ($L_o - L_c$) of length-age curve for blue rockfish.

TABLE 5
Standard Lengths (mm) at Age for Various Calculations of the Von Bertalanffy Growth Curve Compared to Back-calculated Observed Length for Blue Rockfish

Age (years)	Observed length (mm)	Standard length (mm): Trial values of $L\infty$ Ricker (1958)			Least squares Tomlinson and Abramson (1961)	Marquardt Unweighted	Marquardt Weighted
1	95	87	102	109	100	100	99
2	133	123	131	134	130	130	130
3	163	154	156	157	157	157	157
4	181	179	178	178	179	179	180
5	200	201	198	196	199	199	200
6	214	219	215	213	216	216	216
7	228	234	230	227	231	231	231
8	241	247	243	241	244	244	243
9	253	257	255	253	255	255	253
10	263	266	265	264	265	265	262
11	273	274	274	274	273	273	270
12	283	280	281	282	280	280	276
13	289	286	288	290	286	286	282
	Length at Infinity =	313	336	362	327.3	327.6	313.0
	k =		−0.132		−0.1430	0.1428	0.1600
	t_0 =		−1.738		−1.549	−1.553	−1.370

increase in error to age six, followed by a decrease. If we calculate standard deviations for each age using the nonlinear curve value as a "mean" we obtain:

Age	σ	*Age*	σ
1	12.6	7	23.0
2	17.0	8	16.8
3	20.9	9	12.3
4	20.3	10	17.9
5	23.2	11	16.3
6	23.5	12	8.1

I have used the unweighted nonlinear curve values for further comparison with the data of Miller and Geibel (1973). They computed a Von Bertalanffy curve for their age-length data based on scale readings, but they do not give values for either the parameters of the curve or their age-length data. We have picked approximate values from their figured curve for combined sexes and have recomputed the age-length curve to compare with our data (Table 5, Figure 9). Their values are lower than ours for the first few years but eventually catch up.

The biggest difference is in the first year's growth in which the average back-calculated length attained by southern California fish is 95 mm, and by Miller and Geibel's Monterey fish only 75 mm. For the next 5 years the growth increments of the Monterey specimens are slightly greater until, at age seven, fish from both areas are approximately the same length.

We did not take any samples of mature blue rockfish during the winter and, therefore, could not delimit

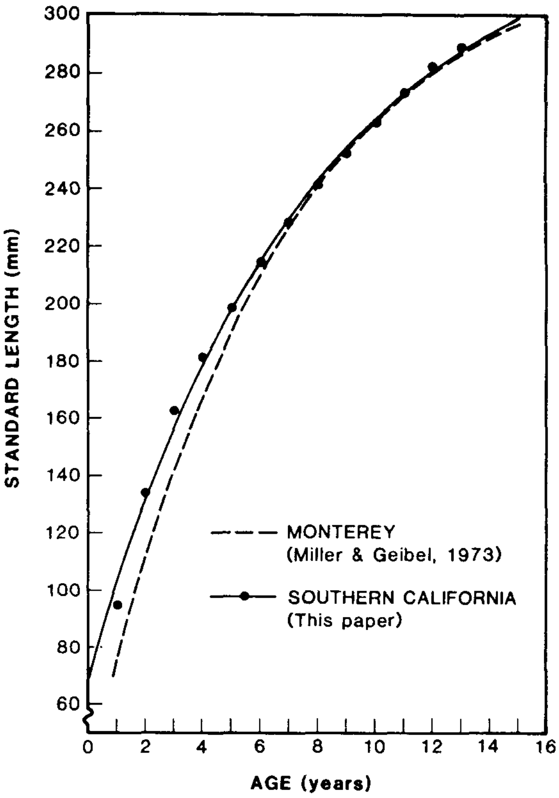

Figure 9. Comparison of length-age curves, blue rockfish, southern California and Monterey (Miller and Geibel 1973).

the spawning season off southern California. Wales (1952) states that spawning took place in the Monterey area in November, December, and January. Miller and Geibel (1973) found that annuli are formed in March and April. Because annuli do not form on the scales when the fish are only a few months old, the first annulus may be formed when the fish is one year and three months old and the second approximately a year later at age two years and three months. Thus the first "year" may be longer or shorter than a year for different species of fishes, depending on when annulus formation occurs in relation to the spawning season.

This phenomenon is more marked in some species. Sardines in the northern part of their range tended to spawn later than those off southern California and northern Mexico, and showed apparent slow growth (i.e., a shorter first year) in length at age one back-calculated from scales. However, they grew much faster than the more southerly populations of sardines in subsequent years and soon outgrew them.

Actually, although the blue rockfish probably have a long first "year", their first year's growth appears to be less than a year's growth compared with the best-fitting curves that we computed. However, 9 of 10 species of rockfish show negative deviations of observed values from Von Bertalanffy curves for the first year in Phillips's (1964) data (Table 6).

Considering the possible variation that one might expect, the pattern of deviations in Phillips's data is noteworthy. From the second to fifth year the observed values tend to be higher than computed values; from the sixth to eleventh year they tend to be lower; and from the twelfth on, higher (Table 6). For the blue rockfish the pattern is remarkably similar.

One possible explanation of this is that male rockfish of many if not all species tend to be slower growing and shorter lived than females. For the first few years the fish grow more rapidly, and there is less difference in growth rates between the two sexes (plus deviations) until sexual maturity is reached. Then, for several years, the slower growth of the males causes the curve to dip (minus deviations). The increasing higher mortality of the slower-growing males in the later years gradually increases the proportion of faster-growing females in the population causing a final rise in the curve (plus deviations).

CONCLUSIONS

The length-weight data for blue rockfish from southern California show nearly isometric growth. Therefore the formula $W = KL^3$ may be used instead of $W = aL^b$.

The length-weight curve for southern California blue rockfish was close to the curves obtained by Miller and Geibel (1973) for samples from Monterey.

Several modifications of the Von Bertalanffy growth curve were used to describe the age-length relationship. Growth of southern California blue rockfish appeared to be more rapid than for Monterey samples for the first few years. This was caused by the smaller length at age one calculated for Monterey fish. Growth increments were actually greater for the following 5 years until they caught up with southern California fish.

There was a tendency toward a slight "S" shape to the curve of observed values of age length, which caused it to not quite fit the Von Bertalanffy curve. This tendency appears to hold true for other species of rockfishes also, and may be caused by differences in growth rates and mortality between male and female rockfish.

Conversions to standard length from fork length and total length (in millimeters) are: $SL = .8506FL$ and $SL = .8127TL$.

TABLE 6

Deviations of Observed Total Length from Von Bertalanffy Curve for Ten Species of Rockfish (Phillips 1964) Compared to Deviations (Standard Length) of Blue Rockfish from Southern California

Species of rockfish	Deviation at age													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bocaccio	−4.4	+4.0	+4.4	+1.2	−3.0	−6.5	−2.4	+0.5	+2.4	+0.5	+2.4	+4.4	+3.2	+6.3
Chilipepper	−4.7	+2.7	+6.4	+5.3	−0.3	−5.8	−8.4	−7.1	−1.7	+2.2	+3.9	+6.0	+11.1	+16.8
Yellowtail	−1.0	−1.2	+1.0	+3.2	+3.7	+0.5	−3.5	−4.0	−5.8	−6.4	−4.5	+0.8	+5.8	+11.5
Dark blotched	+1.4	−1.6	−1.8	−0.4	+0.5	+2.8	+4.9	+0.1	−3.3	−4.8	−4.7	−2.4	−0.3	+9.3
Splitnose	−1.0	+1.4	+1.5	−0.3	−1.4	−0.3	+0.7	+0.3	−1.0	−1.2	+1.3	+0.4	+0.8	+1.5
Canary	−0.3	−1.8	0.0	+2.2	+2.2	+1.3	+0.8	−1.7	−4.7	−3.5	−1.7	−1.4	+7.1	+9.5
Vermilion	−4.5	+1.0	+4.5	+2.6	+3.0	−0.8	−3.2	−1.5	−0.9	−2.7	−5.2	−2.7	+2.8	+0.1
Widow	−0.1	−1.2	+0.2	+6.0	−0.1	−7.0	−6.4	−4.5	−1.4	+0.3	+2.6	+6.3	+8.7	+17.6
Stripetail	−2.9	+2.7	+2.2	+1.9	−0.9	−0.5	−0.4	−3.1	−4.7	−2.5	−0.9	0.0	+1.0	+2.9
Shortbelly	−0.1	+0.5	+0.8	0.0	−1.4	−2.2	−0.8	+3.0	+3.2	+3.3	—	—	—	—
Mean deviation	−1.8	+0.7	+1.9	+2.2	+0.2	−1.9	−1.9	−1.8	−1.8	−1.5	−0.8	+1.3	+4.5	+8.4
Blue rockfish	−7.3	+2.6	+6.3	+3.0	+1.6	−0.6	−1.9	−1.8	−2.1	−1.6	−0.3	+1.3	+1.1	—

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