ASPECTS OF THE LIFE HISTORY OF TREEFISH, *SEBASTES SERRICEPS* (SEBASTIDAE)

MADHAVI A. COLTON AND RALPH J. LARSON
Department of Biology
San Francisco State University
1600 Holloway Avenue
San Francisco, California 94132
m.colton@zoology.unimelb.edu.au

ABSTRACT

In this paper, we report the reproductive seasonality, maturity, length-age and length-weight relationships, and the parameters for converting between total and standard lengths for *Sebastes serriceps* from the Southern California Bight. Our data indicate that the von Bertalanffy age-length parameters are L_∞ = 30.64 cm, k = 0.233, and t_0 = –1.167. Females were reproductively active between at least February and May, and ovaries were found to contain eyed larvae in March. Males were reproductively active between October and at least December. The oldest fish we collected was 25 years of age; the age at 50% maturity was 4 years for females and 3 years for males; and the total length at 50% maturity was 19.0 to 19.9 cm for both sexes. We found no evidence of sexual dimorphism in mean length, growth, or the length-weight relationship. These findings are consistent with the life history traits of ecologically similar species of *Sebastes*.

INTRODUCTION

More than 63 species of rockfish in the genus *Sebastes* (Sebastidae) inhabit the northeastern Pacific Ocean (Love et al. 1990). Members of this genus share characteristics such as viviparity, slow growth, and long life expectancy. Over fifty-five species of *Sebastes* have been reported within the Southern California Bight (Love et al. 1990), and the present study describes aspects of the life history of one species, the treefish (*Sebastes serriceps*).

Although the range of *Sebastes serriceps* extends from San Francisco, California, U.S.A., to Isla Cedros, Baja California, Mexico (Miller and Lea 1972), it is most common in the Southern California Bight (Jordan and Evermann 1898; Leet et al. 2001; Love et al. 2002) (fig. 1). *S. serriceps* is one of the larger benthic rockfishes, found inhabiting caves and crevices on rocky reefs usually shallower than 50 m (Miller and Lea 1972; Love et al. 2002), although it has been observed to 97 m on an oil platform (Love et al. 2000). The solitary adults are most likely territorial (Haaker 1978; Leet et al. 2001; Love et al. 2002), and are ambush predators that feed between dusk and dawn on benthic invertebrates and fishes (Hobson et al. 1981; Kosman et al. 2007).

Like other rockfish, *Sebastes serriceps* is viviparous. Females extrude preflexion, planktonic larvae, and pelagic juveniles may associate with drifting kelp mats (Hobday 2000; Love et al. 2002) before settling to adult habitat between June and August (Moser 1967; Boehlert 1977; Gunderson et al. 1980; Hobday 2000; Love et al. 2002). Prior to this study, information about the life history of *S. serriceps* was limited to observations of the maximum observed length (40.64 cm total length; Phillips 1957) and age (23 years; Love et al. 2002), and counts of ova in one individual (MacGregor 1970). MacGregor's study also provided minimal information about the seasonality of reproduction in *S. serriceps* given that the single gravid female was collected in March.

The goal of this study was to quantify aspects of the life history of *Sebastes serriceps*. Reproductive maturity and seasonality were investigated and length-age, length-weight and length-length relationships characterized. Because specimens were collected from several distinct regions within the Southern California Bight, the above relationships were compared between areas where possible. In addition, growth, longevity, and reproductive seasonality were compared between *S. serriceps* and ecologically and genetically similar species of rockfish.

METHODS

Between 1978 and 2005, 365 *Sebastes serriceps* specimens were collected from as far south as Ensenada, Baja California, Mexico (lat. 31°51'N; long. 116°37'W), and as far north as San Gregorio, California, U.S.A. (lat. 37°33'N; long. 122°40'W) (fig. 1). The majority of the specimens were collected from the Southern California Bight by SCUBA divers using pole spears between March 2003 and March 2005 (n = 321). Other specimens were collected by hook and line or gillnet. Specimens were put on ice immediately after capture, frozen within ten hours, and later thawed and processed. Sagittal otoliths were removed, cleaned, and stored dry. Whole specimens were weighed to 0.1 g, and their total and standard lengths measured to 1 mm. Gonads were removed and their weights recorded to 0.01 g, although for young fish this was not always possible. To maximize the accuracy of our length-weight, length-length, and length-

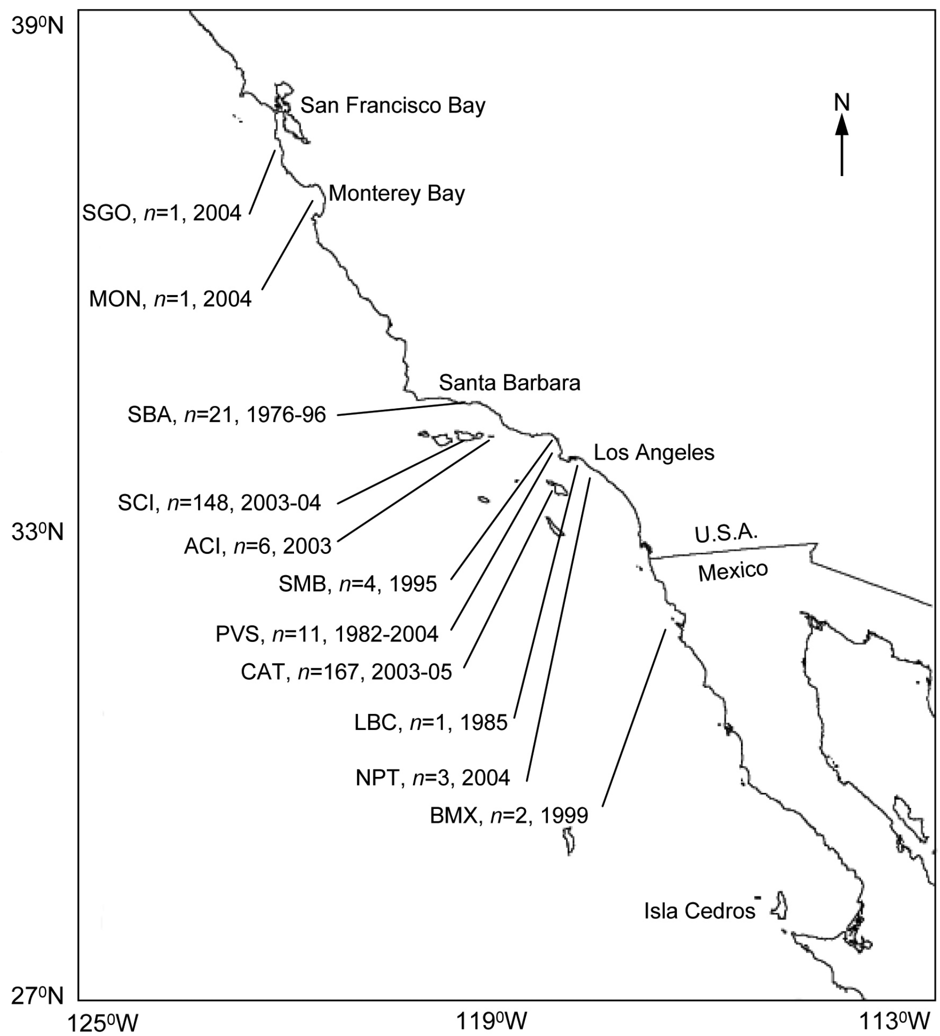

Figure 1. Collection sites with number of specimens and years in which collections were made. SGO = San Gregorio; MON = Monterey; SBA = Santa Barbara; SCI = Santa Cruz Island; ACI = Anacapa Island; SMB = Santa Monica Bay; PVS = Palos Verdes; CAT = Santa Catalina Island; LBC = Long Beach; NPT = Newport; and BMX = Ensenada, Baja California, Mexico.

age relationships, we included in our analyses 34 very young fish by recognizing that their total weight is approximately equal to their somatic weight; gonads of one-year-old specimens weighed at most 0.4% of their total weight. These specimens were assigned gender by grouping them based on month of capture, and randomly designating them male or female.

Age

Sagittal otoliths have been found to give the most consistent ages for several species of rockfish (Six and Horton 1977) and it has become standard practice to use them to age fishes (Love et al. 2002). In this study, we estimated the ages of *Sebastes serriceps* by counting the annuli on sagittae. March 1st was chosen as the birth date of *S. serriceps* as this corresponds to the presence of eyed larvae in ovaries (this paper).

Treefish sagittae are difficult to analyze because they grow thick and strongly curved, and contain many "false checks" (Kimura et al. 1979). This is particularly true of older specimens. In order to obtain the most accurate estimate of specimens' ages, we employed several methods to read treefish otoliths. As has been found for other species (Six and Horton 1979; Boehlert and Yoklavich 1984; Wilson and Boehlert 1990; Laidig et al. 2003), surface readings were only accurate for younger fish, here defined as fish less than six years old. Sagittae from older specimens, here defined as fish of at least six years of age, were treated separately. Every otolith, irrespective of age, was read at least three times before an age was determined. Readings were separated by at least one week and up to six months to ensure that the reader did not remember the ages previously assigned to the specimens.

The otoliths of younger specimens were placed in a black-bottom watch glass, immersed in water and examined using direct light at magnifications of 120× to 500×. Otoliths were tilted in order to view annuli on the outermost edge (Boehlert and Yoklavich 1984). An opaque zone followed by a translucent (hyaline) zone was considered to represent one year in the life of the specimen (Six and Horton 1977). The surfaces of otoliths from all younger fish were examined at least three times, and specimens with different ages for the second and third readings were read again. Of the specimens that had been read four times, those that had no single age in the majority were read a fifth time. Specimens that remained inconsistent after five reads were not included in the analysis ($n = 2$).

Two techniques are commonly employed for analyzing otoliths from older specimens: break and burn (MacLellan 1997) and sectioning (e.g., Love and Johnson 1998). Sectioning is more precise, particularly when the otoliths are thick and strongly curved, and was therefore selected as the more appropriate method for this study. We took transverse sections of otoliths from older specimens and from a representative sample of younger fish ($n_{total} = 218$). The sectioned otoliths from younger samples of known age (i.e., specimens which had been read as the same age multiple times) were used to calibrate the sectioned otolith reading method. These specimens were examined by a reader who knew the age of the specimen and used this information to separate true annuli from "false checks" (Kimura et al. 1979). This ensured that the two methods were comparable.

Otolith sections were embedded in clear resin on a waxed paper tag and sliced using a Buehler Isomet low-speed saw. A dorso-ventral transverse section through the nucleus was cut from each otolith using two diamond-edge blades separated to 0.06 cm by plastic shims. Sections were affixed to slides using Cytoseal, ground, polished, brushed with mineral oil, and read twice using a compound microscope at 240× magnification. Digital photographs of otolith sections were taken using a Nikon Eclipse E600 microscope connected to a Spot RT Slider digital camera and imported using Spot Advanced (ver. 4.0.1). These photographs were imported into Microsoft PowerPoint (2003) and viewed beneath a grid that had been calibrated to 2.5 mm × 2.5 mm using a photograph of a stage micrometer taken with the same equipment. This allowed the reader to take measurements of the otolith and annuli. The total length of the transverse section, the length of the nucleus, and the total length across the nucleus from the inside curve of each hyaline ring were measured. From these data, frequency diagrams were constructed and means computed for measurements at each age. These measurements were used to aid the identification of annuli associated with early years (Boehlert and Yoklavich 1984). Identifying these early annuli improved the accuracy of the readings of sagittae from older specimens. The sagittae of younger specimens of known age were again used to validate that the sectioned otoliths were read in a method consistent with whole otoliths.

All sectioned otoliths from older fish were read at least once using the calibrated grid. Those specimens that had the same age estimate for the first three reads (twice using a compound microscope and once with the grid) were deemed that age. Those specimens for which the ages were inconsistent were read up to four times using the grid. Specimens that had four readings with a range of four were read a fifth time. Otoliths that remained inconsistent were not included in the analysis ($n = 6$).

Several researchers have validated the deposition of one hyaline band per year on an otolith by examining the edges of otoliths collected over the course of a year (e.g., Kimura et al. 1979; Pearson et al. 1991; Laidig et al. 2003). To validate that a single opaque band was deposited annually on treefish otoliths, the edges of whole otoliths from younger fish ($n = 189$) were examined at 240× magnification using a dissecting microscope. After examining the dorsal edge, the otolith was classified as either having a translucent or opaque outer band. If the edge was half opaque and half translucent, the ventral edge was also examined. Whenever possible, both otoliths were inspected. As a secondary validation, age-length frequencies were plotted for different locations and examined to see if clear age modes were apparent.

Mortality

A nonlinear catch curve of abundance against age was constructed using FISHPARM (Prager et al. 1989). Mortality was estimated from the equation:

$$N_t = N_o(e^{-Zt}) \qquad (1)$$

where N_t = population size at age t (years);
N_o = the theoretical population size at age 0; and
Z = instantaneous rate of mortality.

Sexual Dimorphism

We examined the effect of gender on the length-weight, length-length, and length-age relationships. Details of these analyses can be found in their respective sections below. We also examined whether the mean total length of females ($n = 162$) was different from the mean total length of males ($n = 148$) using an independent samples t-test and data pooled from Santa Catalina, Santa Cruz, and Anacapa islands. It was easier to identify small female fish than small males because immature ovaries are easier to locate than testes. To account for this bias, small specimens were included and assigned genders according to the methods outlined above.

TABLE 1
Independent Variables Used to Explore the Length-weight Relationship of *Sebastes serriceps*.

Independent Variable	Categories	*n*	Description
Location	CAT	180	Santa Catalina Island
	SBA	17	Santa Barbara
	SCB	16	Long Beach, Newport, Palos Verdes, Santa Monica Bay
	SCI	160	Santa Cruz Island and Anacapa Island
Time	FMA	125	February, March, April
	MJJ	92	May, June, July
	ASOND	154	August, September, October, November, December
Gender	M	156	Male
	F	177	Female

Length-weight Relationship

The relationship between length and somatic weight, calculated as total body weight less gonad weight, was fitted using the allometry equation in FISHPARM (Prager et al. 1989):

$$W = aL^b \tag{2}$$

where W = somatic weight (g);
L = total length (cm); and
a and b = constants.

To examine whether gender, location, and time of year had an effect on the length-weight relationship, a multiple linear regression was performed (SPSS ver. 11.5) (n = 333). The dependent variable was $\log_{10}$(somatic weight), and the independent variables were $\log_{10}$(total length), location, season, and gender (tab. 1). A scatterplot of standardized residuals indicated that the data were normally distributed and that there were two outlying data points. Mahalanobis distances (Pallant 2002) were used to determine that these data points should be kept in the analysis. Very young specimens were included as described above.

Length-length Relationship

Studies on the life history of fishes vary in the methods used to measure length (e.g., Kimura et al. 1979; Pearson et al. 1991). To facilitate comparisons with other studies, the length-length conversion parameters for treefish were computed. The relationship between total length (cm) and standard length (cm) was found by fitting a linear regression for all fish from Santa Catalina, Santa Cruz, and Anacapa islands (n = 310). Small fish were assigned a gender as outlined above. A two-way analysis of covariance (ANCOVA) was used to examine whether sex or location (Santa Cruz + Anacapa Island vs. Santa Catalina Island) affected the length-length relationship.

Length-age Relationship

The relationship between length and age was estimated using the von Bertalanffy growth function (VBGF; Ricker 1975) fitted using FISHPARM (Prager et al. 1989):

$$L_t = L_\infty[1 - e^{-k(t - t_o)}] \tag{3}$$

where L_t = length at age t (years);
L_∞ = theoretical maximum length;
k = rate of increase in length increments; and
t_0 = theoretical age at which $L_t = 0$.

Small fish were included using the previously described methods. As sex and latitudinal variation have been shown to affect growth, the VBGF was fitted to nine combinations of data: (1) all specimens from southern California (n = 311); (2) females from southern California (n = 166); (3) males from southern California (n = 145); (4) all samples from Santa Catalina Island (n = 158); (5) all samples from Santa Cruz Island (n = 146); (6) females from Santa Catalina Island (n = 89); (7) males from Santa Catalina Island (n = 60); (8) females from Santa Cruz Island (n = 74); and (9) males from Santa Cruz Island (n = 71).

An analysis of the residual sums of squares was used to compare VBGFs between sexes and locations (Chen et al. 1992). An F-statistic was computed as:

$$F = \frac{(RSS_p - RSS_s) \div (DF_p - DF_s)}{(RSS_s) \div (DF_s)} \tag{4}$$

where RSS_p = RSS of VBGF fitted to pooled growth data;
RSS_s = sum of RSS of each VBGF fitted to separate samples;
DF_p = degrees of freedom for VBGF fitted to pooled growth data; and
DF_s = sum of degrees of freedom of each VBGF fitted to sample data.

The degrees of freedom for the critical F-statistic were $3(K\text{-}1)$ and $N\text{-}3K$ for the numerator and denominator respectively, where K is the number of samples being compared, and N is the sample size used to obtain the pooled VBGF.

Reproduction and Maturity

Gonads were staged while fresh using a dissecting microscope, stored in 90% ethanol, and reexamined between six and 18 months after the initial staging. The stage of gonad development was identified using categories from Wyllie Echeverria (1987). Males were classified as mature if their testes were staged as spermatogenic, spawning or recently spawned, or if their

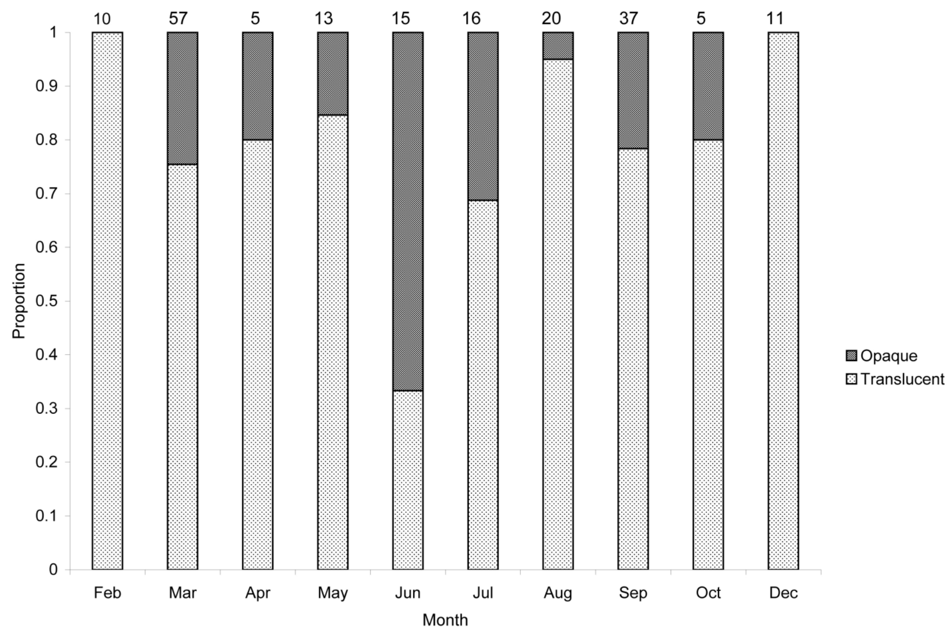

Figure 2. Frequency of edge state (opaque vs. translucent) for otoliths from *Sebastes serriceps* aged zero to five years, demonstrating the seasonal deposition of opaque band. Numbers above columns indicate sample sizes.

testes were relatively large and staged as resting. Females were classified as mature if the ovaries were staged as fertilized or in parturition. Ovaries staged as vitellogenic, spawned, or resting that contained evidence of residual eyed larvae or that had thick ovary walls were also considered mature. Some females appeared to have vitellogenic ovaries with no evidence of reproduction during the previous year, such as residual pigments or thick ovary walls. Following the recommendations of Bobko and Berkeley (2004), these fish were staged as first year/vitellogenesis, and classified as immature because it is impossible to predict whether they would reproduce during the year.

Differentiating between the immature and resting stages of rockfish gonads can be difficult (Love and Johnson 1998). In this study we followed the recommendations of Gunderson et al. (1980) and used only mature specimens to determine length and age at maturity: testes from mature fish collected between August and December (n = 55), and ovaries from mature specimens collected between February and May (n = 68).

A gonosomatic index (GSI) was calculated using the equation from Love et al. (1990):

$$\text{GSI} = 100[(W_g) \div (W_T)] \tag{5}$$

where W_g = gonad weight; and
W_T = total body weight.

GSI values were calculated for all mature fish from southern California (n = 213) and changes in GSI by month were plotted for males (n = 105) and females (n = 108).

GSI values from mature females (n = 30) during months of peak reproductive output (February to May) were examined for trends. Because a $\log_{10}$-transformation of the GSI values only served to normalize three of the five stages (fertilization, parturition, and recently spawned; Kolmogorov-Smirnov p = 0.137, p = 0.200, and p = 0.200 respectively), a Kruskal-Wallis H test was used to examine the effect of each gonad stage upon GSI values.

RESULTS

Age

Like all other species of *Sebastes* studied thus far, *S. serriceps* deposits annual growth rings on its sagittae, allowing the sagittae to be used to measure its age. Edge analysis revealed that one opaque band was deposited annually during the summer months, usually in June (fig. 2). Length-age frequency plots revealed distinct size modes that, particularly for younger ages, consisted largely of one year class (fig. 3). Measurements taken from photographs of transverse sections of otoliths revealed a similar pattern relating otolith size to specimen age (fig. 4). Our aging methods thus validated, we identified the youngest individual in this study as less than 1 year old and the oldest as 25 years old. Previously, *S. serriceps* was posited to attain a maximum age of 23 years (Love et al. 2002).

Mortality Rate

The instantaneous rate of mortality was estimated by fitting a nonlinear catch curve using FISHPARM (Prager

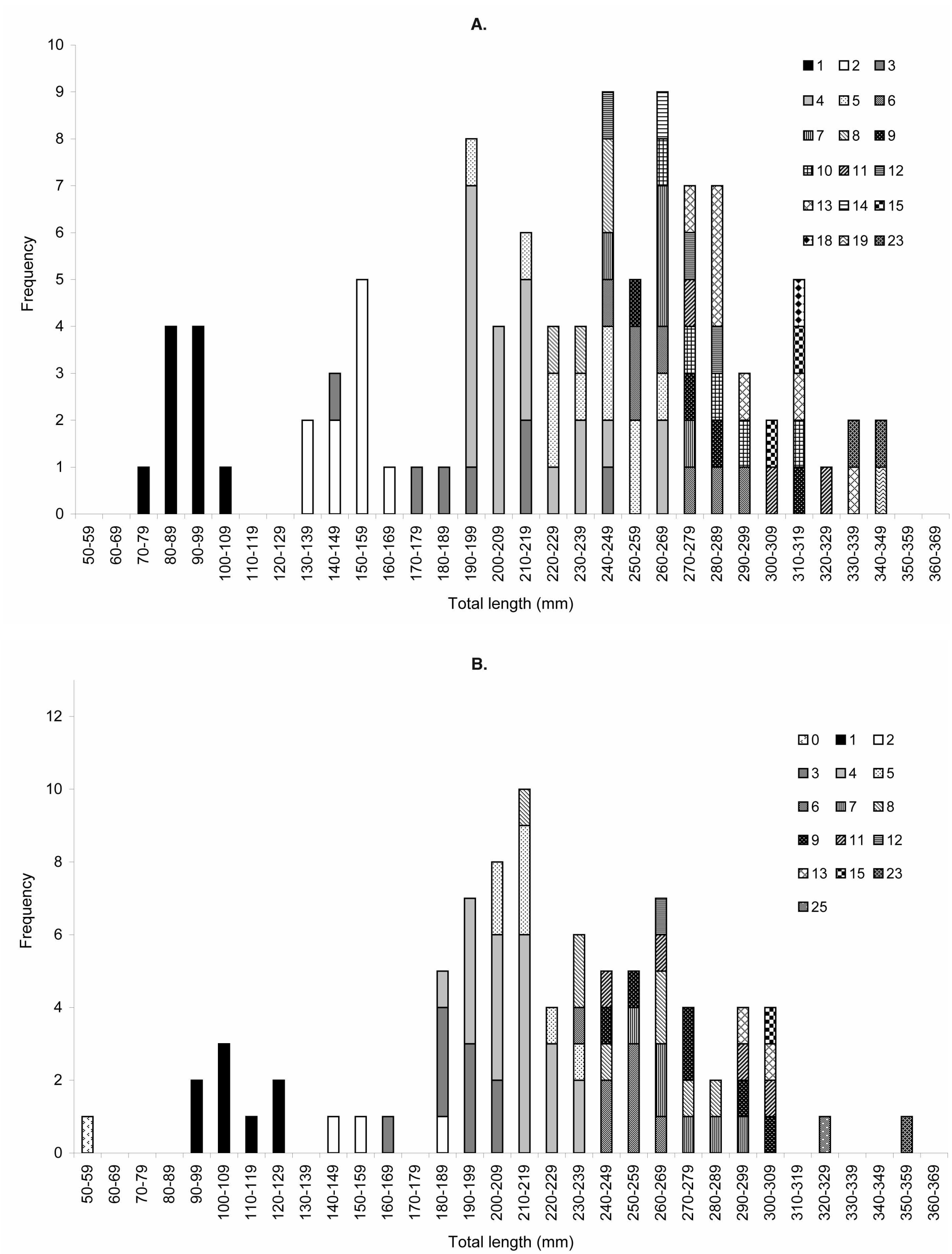

Figure 3. Length-frequency plots by age (years) for *Sebastes serriceps* from Santa Catalina, Santa Cruz, and Anacapa Islands for three seasons: A. February, March, and April; B. May, June, and July; and C. September, October, and December.

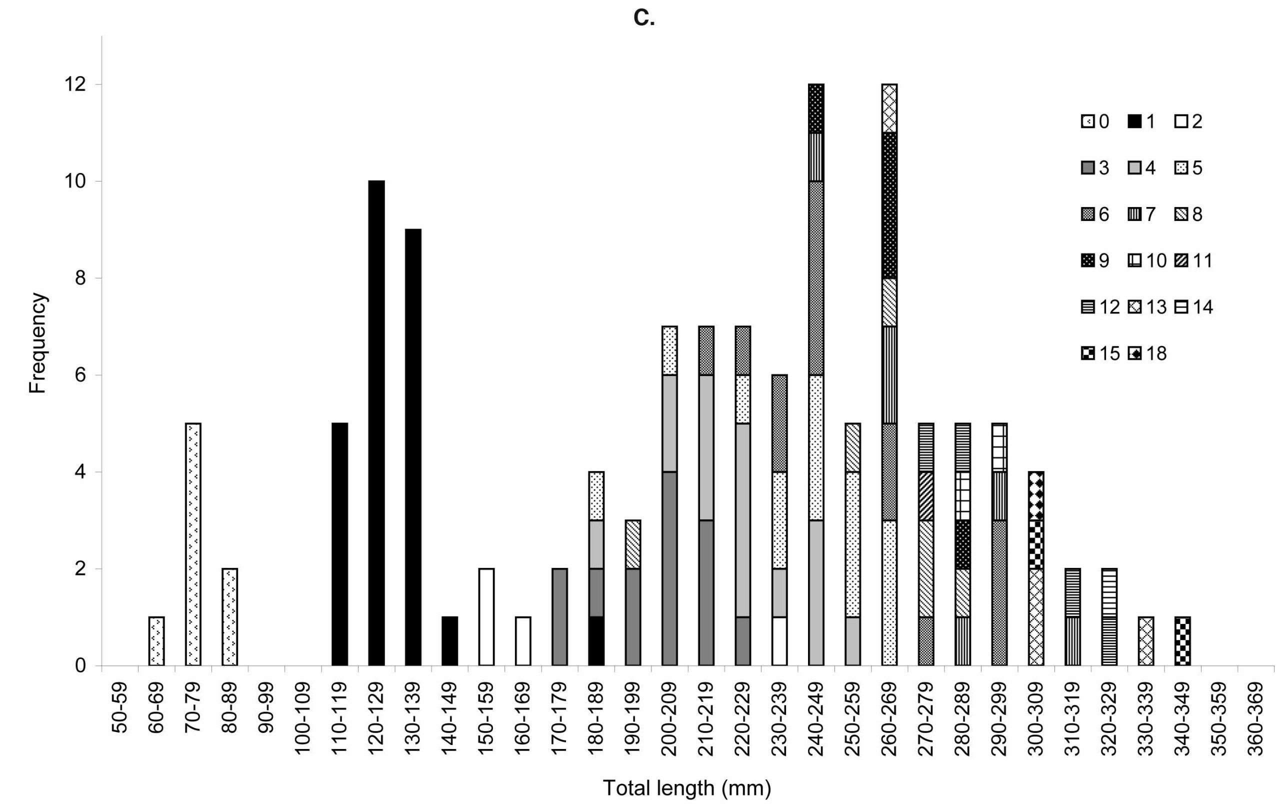

Figure 3 (continued). Length-frequency plots by age (years) for *Sebastes serriceps* from Santa Catalina, Santa Cruz, and Anacapa Islands for three seasons: A. February, March, and April; B. May, June, and July; and C. September, October, and December.

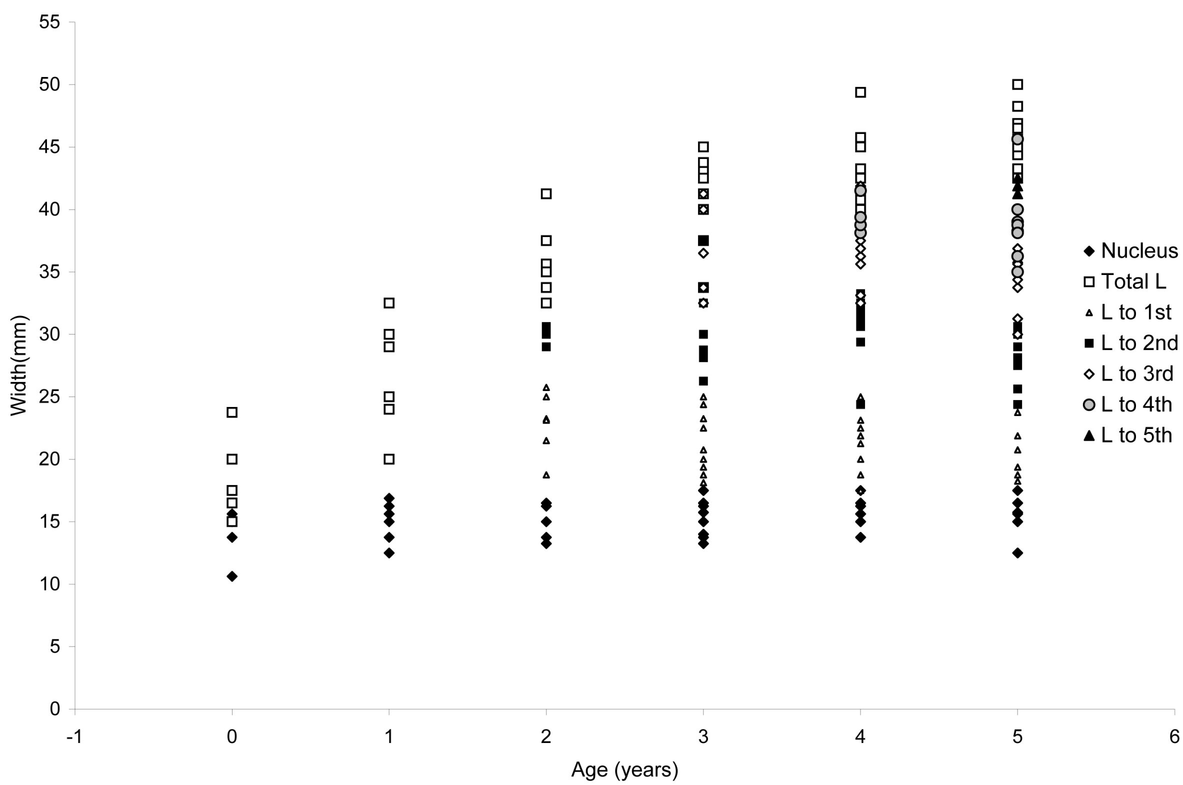

Figure 4. Measurements of total section width, and the distance across the nucleus and annuli for transverse otolith sections from *Sebastes serriceps*, based on photographic images measured by overlain grids using PowerPoint.

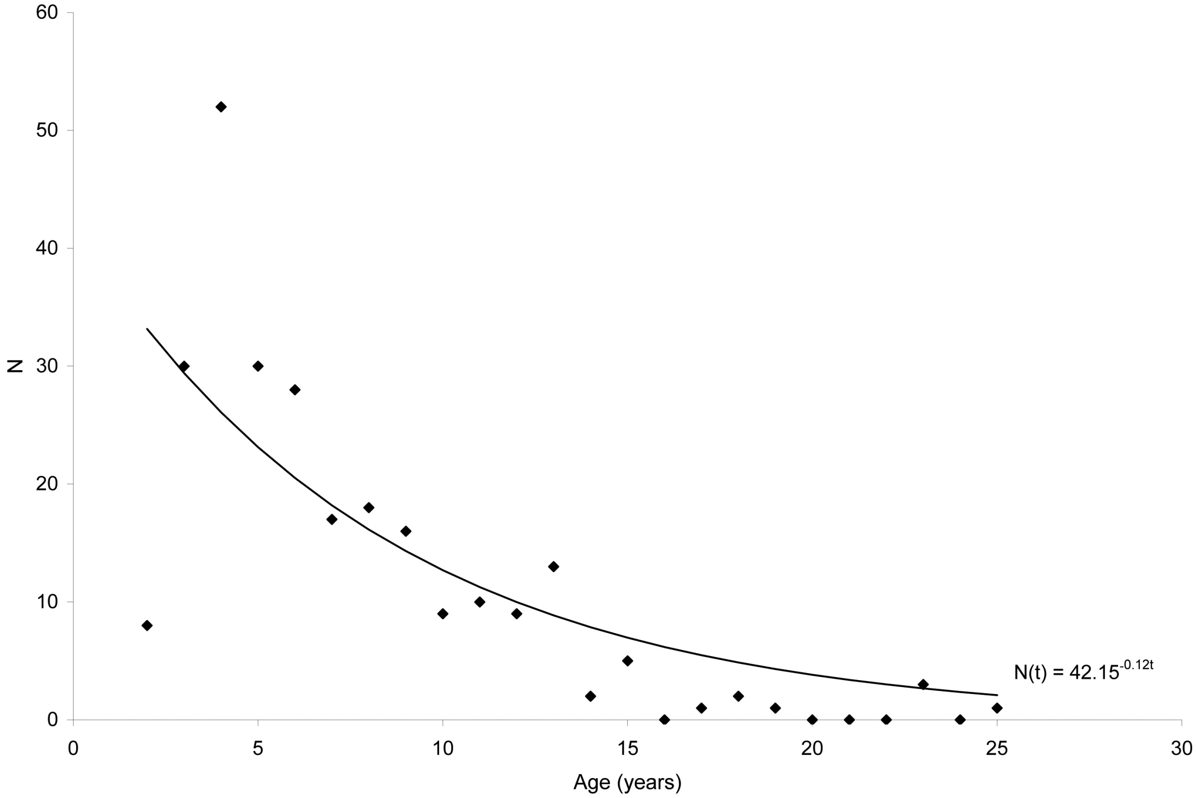

Figure 5. Catch curve for *Sebastes serriceps* in the Southern California Bight.

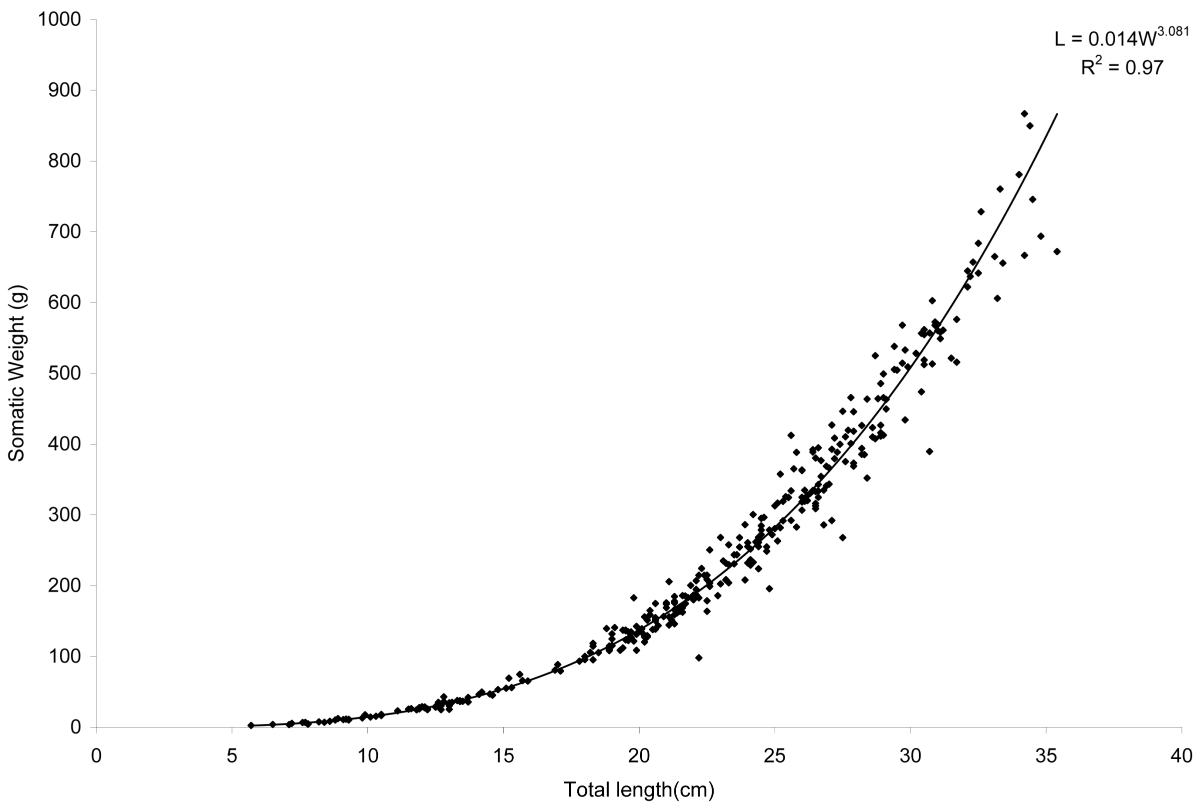

Figure 6. Length-weight relationship for *Sebastes serriceps* collected in southern California.

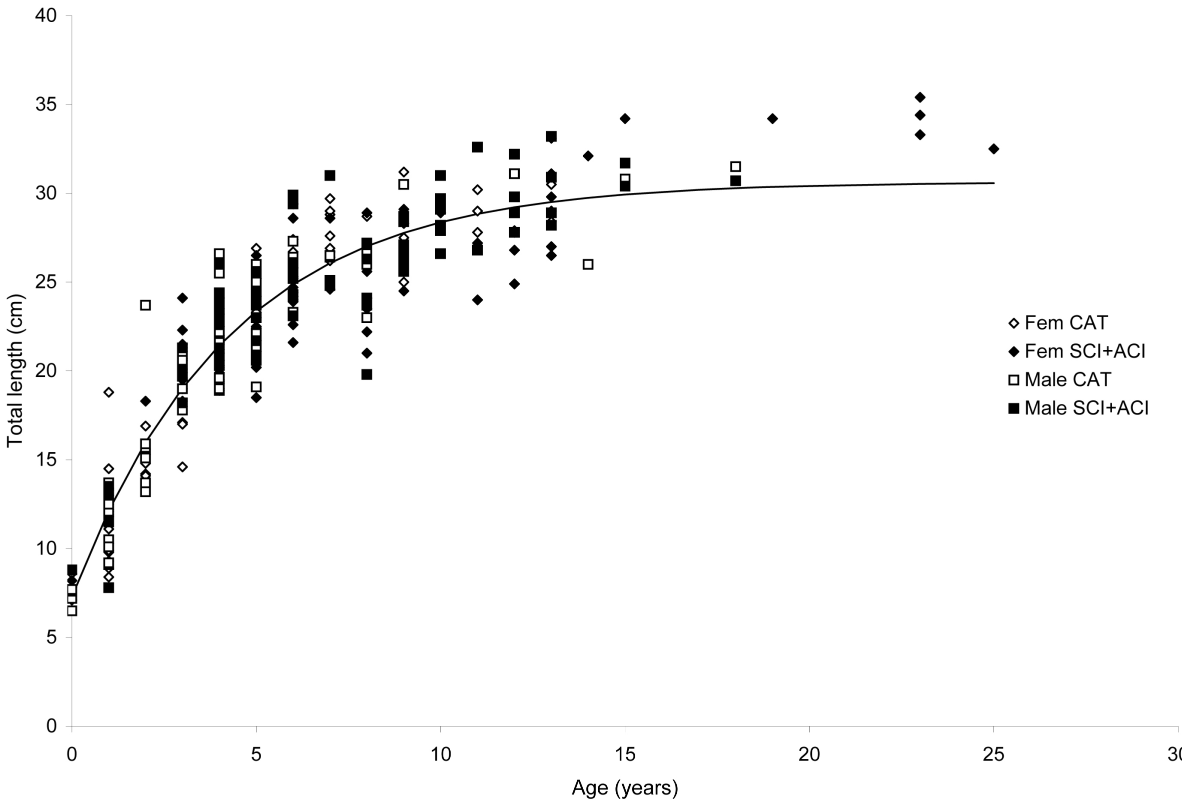

Figure 7. Von Bertalanffy growth curve for *Sebastes serriceps* from southern California.

et al. 1989). The data were described by equation 1, with the instantaneous rate of mortality $Z = 0.12$ and the constant $N_o = 42.15$ for *Sebastes serriceps* within the Southern California Bight (fig. 5).

Length-weight Relationship

The weight and length data were fitted using equation 2. For *Sebastes serriceps*, $a = 0.014$ and $b = 3.081$ (fig. 6). A two-tailed Student's *t*-test did not quite reject the null hypothesis that $b = 3.0$ ($t = 0.0595$, $df = 335$), indicating that growth of *S. serriceps* cannot be distinguished from isometric growth. A stepwise, multiple linear regression was performed to ascertain whether gender, location, and/or season affected the length-weight relationship. Total length accounted for 99.7% of the variance in somatic weight ($\beta = 0.997$, $p < 0.0005$). None of the other variables had a significant effect on somatic weight (location: $\beta = -0.010$, $p = 0.109$; gender: $\beta = 0.001$, $p = 0.870$; season: $\beta = 0.001$, $p = 0.906$).

Sexual Dimorphism

We found no difference between the mean length of female ($\overline{x} = 21.9$ cm TL; SD $\pm$ 6.5) and male ($\overline{x} = 22.2$ cm TL; SD $\pm$ 6.6) treefish using an independent samples *t*-test ($t = -0.42$, $p = 0.67$).

Length-length Relationship

A two-way ANCOVA revealed that neither sex nor location significantly affected the relationship between standard and total lengths (sex: $F = 0.067$, $p = 0.796$; location: $F = 0.147$, $p = 0.702$). Therefore, parameters for length-length conversions are reported for all fish collected from the Southern California Bight ($n = 310$). The relationship between total length and standard length was described by the equation $y = ax + b$, where y and x are lengths, and a and b are conversion parameters. The equation to determine total length (TL) given standard length (SL) is: TL = 1.22(SL) + 0.17; and to compute standard length given total length is: SL = 0.82(TL)–0.07. $R^2 = 1.00$ for both conversion relationships.

Length-age Relationship

An analysis of residual sums of squares indicated that there was no statistically significant difference between the VBGFs of males and females ($F = 0.6529$, $\upsilon_1 = 3$, $\upsilon_2 = 305$). Similarly, no significant difference between the VBGFs of specimens from Santa Catalina Island and Santa Cruz Island was found ($F = 2.9070$, $\upsilon_1 = 3$, $\upsilon_2 = 298$), nor was a significant difference found between sexes at either location (Catalina: $F = 0.7846$, $\upsilon_1 = 3$, $\upsilon_2 = 152$; Santa Cruz Island: $F = 1.1458$, $\upsilon_1 = 3$, $\upsilon_2 = 140$). Given the lack of difference between

TABLE 2
Weight-length Relationship Variables for Several *Sebastes* Species.

	Weight-length variables			von Bertalanffy growth function parameters			
Species	a	b	Max total length (cm)	Sex	L_∞	k	t_o
Sebastes carnatus†	0.0186	2.957	42.5	n/a	n/a	n/a	n/a
S. caurinus†	0.0172	3.018	26.4	Both	50.00	0.120	n/a
S. chrysomelas†	0.0081	3.257	39.6	F	21.50	0.21	–0.72
				M	19.90	0.28	–0.28
S. nigrocinctus†	0.0090	3.205	63.5	n/a	n/a	n/a	n/a
S. rastrelliger§	0.045	2.77	55.9	Both	51.3	0.11	–2.41
S. rosenblatti¥	0.01103	3.10572	48.3	F	57.99	0.053	–2.468
				M	56.11	0.058	–2.103
S. rubrivinctus	0.0146★	3.000★	44.0†	n/a	n/a	n/a	n/a
S. serriceps‡	0.01404	3.081	40.6	Both	30.6	0.23	–1.2

¥Love et al. 1990; §Love and Johnson 1998; †Love et al. 2002; ★www.fishbase.org; ‡This study.

these groupings, VBGF parameters are reported for *Sebastes serriceps* from the Southern California Bight (tab. 2). The von Bertalanffy growth parameters (standard errors) are L_∞ = 30.64 cm TL (0.44), k = 0.233 (0.01), and t_o = –1.167 (0.01) (fig. 7). L_{max} for the species is reported to be 41 cm TL (Miller and Lea 1972). The largest fish in this study was a 23-year-old female that measured 35.4 cm total length. The four oldest specimens (age 19 to 25 years) were all females; the oldest male was 18 years old.

Reproduction and Maturity

The smallest mature female was 19.0 cm total length and 4 years old. The smallest mature male was 19.7 cm total length and 3 years old. The age at 50% maturity was 4 years for females and 3 years for males. The total length at 50% maturity was 19.0 to 20.9 cm for both males and females. All females were mature by 23 cm total length and 5 years old, and all males were mature by 25 cm total length and 7 years old.

Testes were found to be undergoing spermatogenesis from September to at least December, and more males spawned during December than any other month. One male was found to be spermatogenic in March and one in July; one male was found to be spawning in March and one in May. There is evidence that spawning occurred as early as October because recently spawned males were observed during this month. During June, July, and August, all testes were classified as either recently spawned or resting (fig. 8A).

Ovaries were observed to contain eyed larvae only during the month of March, although fertilized ovaries were observed from February to March, with peak occurrence in February. Females were found in vitellogenesis year-round, with the exception of April, during which all female fish were classified as resting (fig. 8B). Young-of-the-year *Sebastes serriceps* were observed at Santa Catalina Island as early as June (Jana Cobb, pers. comm.[1]), suggesting that larvae and juveniles spend at least three months in the plankton before recruiting to the benthos.

TABLE 3
Results From a Kruskal-Wallis H Test Examining the Effect of Gonad Stage on the Gonosomatic Index for Mature Female *Sebastes serriceps*.

Gonad stage	n	Mean rank
Vitellogenesis	11	15.09
Fertilization	6	35.33
Parturition	7	38.43
Spawned	17	17.35
Resting	3	16.00

Gonosomatic indices varied with month (fig. 9). The peak GSI for females occurred in February and March, which corresponded to maximum fertilization and parturition (fig. 8B). The peak for males occurred in October and is most likely associated with spermatogenesis and the onset of copulation (fig. 8A). The maximum (13.39) and minimum (0.04) GSI for females were both higher than the maximum (9.61) and minimum (0.01) GSI for males. A Kruskal-Wallis test to ascertain the affect of gonad stage on GSI was significant at the Bonferonni-adjusted α = 0.017 level (chi-square = 23.910, df = 4, p < 0.0005). Mean ranks indicated that females in parturition had the highest GSI values and females in vitellogenesis the lowest (tab. 3).

DISCUSSION

Using edge analysis and length-frequency plots, the annual deposition of rings on the sagittae of *Sebastes serriceps* was validated for fish less than 6 years of age, suggesting that analyzing sagittal otoliths is an appropriate method for estimating the age of *S. serriceps*. Although there is some variation in opaque band deposition, it is similar to that observed for other rockfish

[1]Jana Cobb, Department of Biology, California State University, Northridge, CA

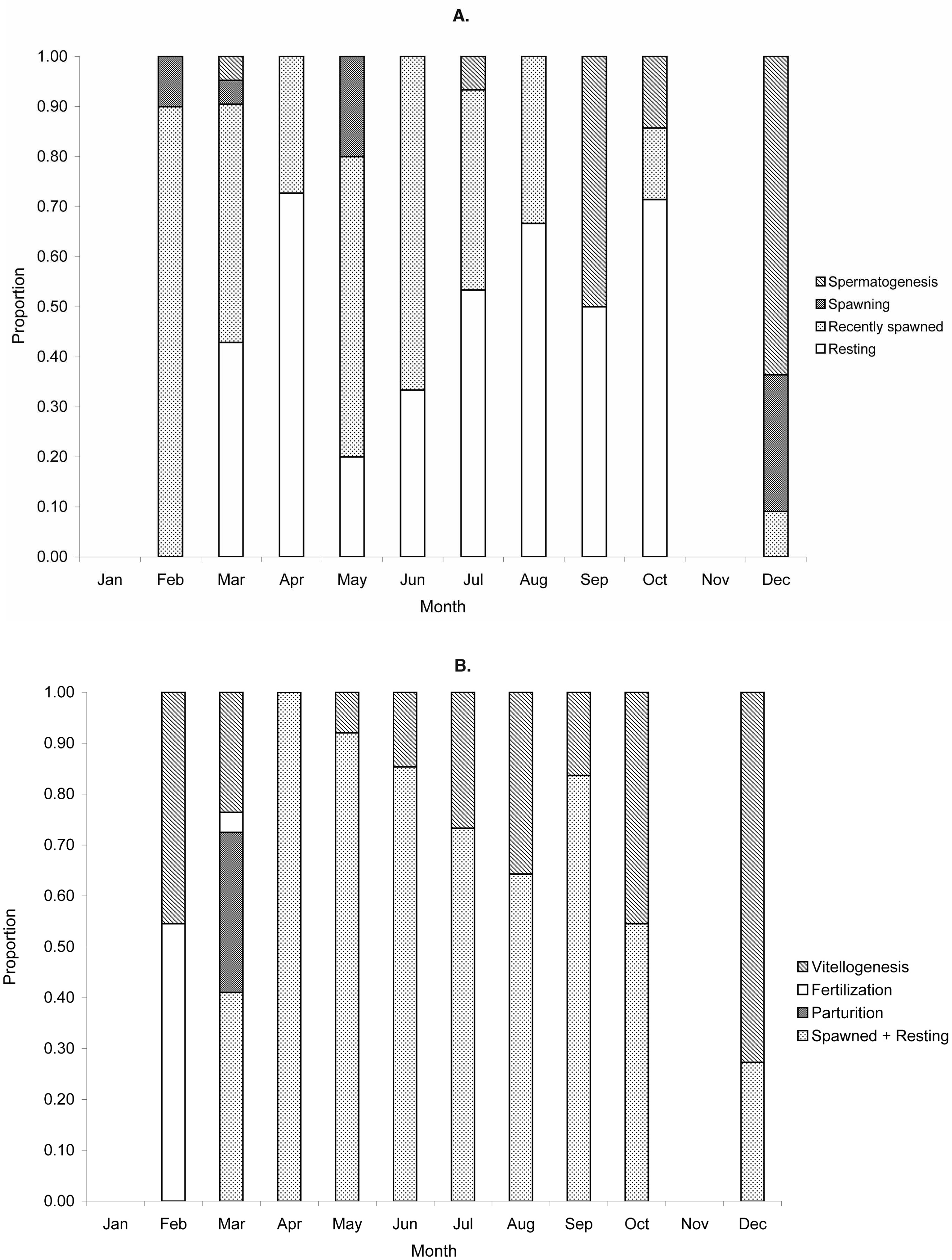

Figure 8. Seasonal variation in gonad stage of *Sebastes serriceps*: A. males; and B. females.

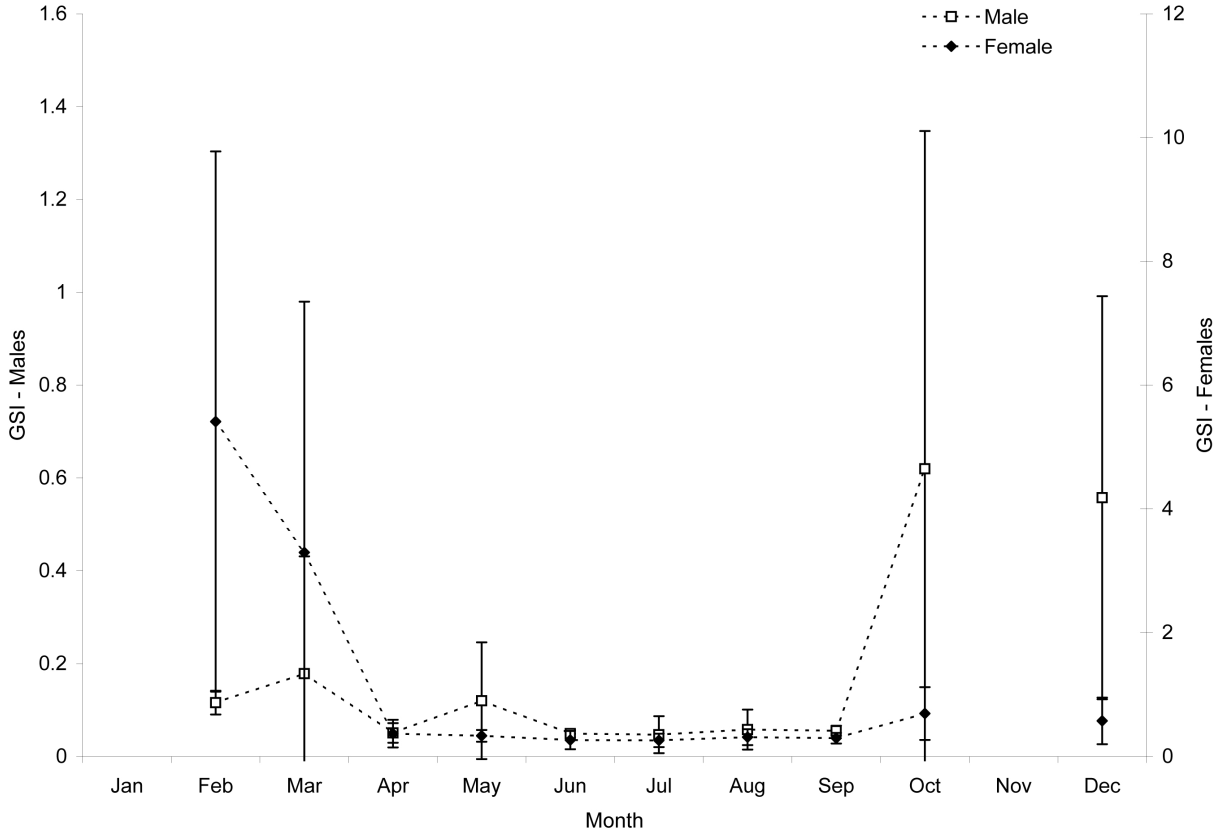

Figure 9. Changes in the average gonosomatic indices of male and female *Sebastes serriceps* from California. Error bars are ±1 standard deviation.

species (Kimura et al. 1979; Pearson et al. 1991; Laidig et al. 2003). Since *S. serriceps* appears to be residential, tagging studies could be used to further validate age determination for older fish.

Several trends in growth and life history have been reported for *Sebastes*. While most rockfish are slow-growing and have VBGF *k*-values between 0.1 and 0.3, Love et al. (1990) found variation in growth rates within the genus, reporting that smaller-bodied species grow more quickly than larger-bodied species. As a mid-sized rockfish, the treefish has a mid-range *k*-value of 0.23, which is similar to that of the ecologically similar *S. chrysomelas* (tab. 2). The length-weight relationship of *S. serriceps* is also similar to other species of solitary, benthic rockfishes as well as to two species closely related to treefish, *S. rubrivinctus* and *S. nigrocinctus* (R. Vetter, pers. comm.[2]) (tab. 2). Love et al. (2002) reported that longevity in rockfishes is positively correlated with body size, northern or cooler water, and deeper depth distribution. *S. serriceps* is a mid-sized rockfish that inhabits the warmer waters of southern California and has a relatively shallow depth distribution. Compared to *S. serriceps*, *S. nigrocinctus* has a more northerly distribution and *S. rubrivinctus* inhabits deeper waters (Love et al. 2002). *S. nigrocinctus* has been aged to 116 years and *S. rubrivinctus* to 38 years (Love et al. 2002). One of the smallest rockfish species, *S. emphaeus*, grows no larger than about 18 cm and lives up to 22 years; one of the largest species, *S. borealis*, reaches up to 120 cm in length and has been aged to 157 years (Love et al. 2002). The maximum reported size for *S. serriceps* is 41 cm and it has been aged to 25 years. When compared with congeners and assessed in light of the trends described above, the aspects of the life history of *S. serriceps* quantified in this study are as expected.

We found no evidence of sexual dimorphism in *Sebastes serriceps*. Males and females did not differ significantly in their mean total lengths. No difference between sexes was found in the length-weight relationship, which is not surprising considering that Love et al. (1990) found no sex-related difference in the length-weight relationship of 14 of the 19 species they examined. Comparison of von Bertalanffy growth functions (VBGF) also revealed no sexual dimorphism in the length-age relationship. This lack of sexual dimorphism in growth is unusual but not unheard of in the genus. Love et al. (2002) reported that six of the 39 species for which data were available showed no difference in length at age be-

[2]Dr. Russell D. Vetter, NOAA, Southwest Fisheries Science Center, La Jolla, CA

tween males and females. In addition, Love and Johnson (1998) report no significant difference between the growth rates of male and female *S. auriculatus* and *S. rastrelliger*, although they did report that the oldest fish for both species were females. *S. serriceps* seems to be similar; the four oldest individuals collected were female, yet no difference was found between male and female growth rates (fig. 7). Sexual dimorphism may be related to some combination of fecundity and territoriality (Lenarz and Wyllie Echeverria 1991). *S. serriceps* is known to exhibit aggressive behavior (Haaker 1978; J. Hyde, pers. comm.[3]) and is likely to defend territories. All else being equal, if both sexes defend territories, it is expected that they would be of equal size, as observed in *S. chrysomelas* and *S. carnatus* (Larson 1980). However, there are species, such as *Hypsypops rubicundus*, that exhibit little sexual dimorphism although only one sex is territorial (Clarke 1971). Additional research is necessary to ascertain whether both treefish sexes defend territories.

Parturition in rockfish generally occurs in winter or spring (Moser 1967; Wyllie Echeverria 1987) and *Sebastes serriceps* appears to be no exception to this rule, with peak parturition observed in March, and the peak in female gonosomatic index (GSI) in February and March. The autumn peak of male GSI and observed spermatogenesis suggests that, as with other species of *Sebastes* (Moser 1967; Wyllie Echeverria 1987; Bobko and Berkeley 2004), *S. serriceps* is capable of sperm storage for at least three months (fig. 8). Although several congeners have been reported to produce multiple broods per year (Moser 1967; Love et al. 1990), there was no evidence that *S. serriceps* reproduces more than once per year: no eyed larvae were observed undergoing resorption in the presence of vitellogenic eggs (Wyllie Echeverria 1987). However, like *S. rastrelliger* and *S. auriculatus* (Love and Johnson 1998), *S. serriceps* exhibits vitellogenic ovaries throughout the year (fig. 8B). Treefish ovaries staged as vitellogenic between May and December most likely belong to females that did not reproduce during the year (Love and Johnson 1998). In many species of rockfish, males mature at a younger age than females (Wyllie Echeverria 1987; Love et al. 1990). Such a pattern of maturity was not readily apparent for *S. serriceps*: the total length range at 50% maturity was the same for both sexes.

In conclusion, the aspects of the life history of *Sebastes serriceps* examined in this study were similar to comparable species of *Sebastes*. As a shallow-water, medium-sized rockfish with a southerly distribution, it does not exhibit the extreme longevity found in deeper-water, larger, or more northerly distributed species. As with other territorial rockfish in which both sexes defend territories, it does not exhibit sexual dimorphism in its mean length, or weight-length and size-at-age relationships. Areas that warrant further investigation include patterns of geographic variation in life-history characteristics such as growth, mortality, and reproduction. Finally, while *S. serriceps* is part of the recreational and commercial fisheries of California, its fishery has not been formally assessed. With the life-history information now available, an initial assessment of the fishery status of *S. serriceps* is possible.

[3]**John Hyde, Scripps Institution of Oceanography, University of California at San Diego, La Jolla, CA**

ACKNOWLEDGEMENTS

This research represents part of Colton's M.Sc. thesis at San Francisco State University. M. Love, S. Cohen, and two anonymous reviewers contributed valuable comments. L. Krigsman, P. Gundelfinger, M. Johansson, M. Graves, T. Niesen, J. Tustin, J. Cobb, J. Budrick, and E. Kosman helped collect and process specimens. The USC Wrigley Institute for Environmental Studies provided accommodation and equipment. R. Vetter and J. Hyde provided information about rockfish genetics and behavior of *S. serriceps*. Funding was provided by Graduate Assistance in Areas of National Need and the NSF GK-12 program.

LITERATURE CITED

Bobko, S. J., and S. A. Berkeley. 2004. Maturation, ovarian cycle, fecundity and age-specific parturition of black rockfish (*Sebastes melanops*). Fish. Bull. 102:418–429.

Boehlert, G. W. 1977. Timing of the surface-to-benthic migration in juvenile Rockfish, *Sebastes diploproa*, off Southern California. Fish. Bull. 75:887–890.

Boehlert, G. W., and M. Yoklavich. 1984. Variability in age estimates in *Sebastes* as a function of different methodology, different readers, and different laboratories. Calif. Fish Game 74:210–244.

Chen, Y. D. D., D. A. Jackson, and H. H. Harvey. 1992. A comparison of von Bertalanffy and polynomial functions in modelling fish growth data. Can. J. Fish. Aquat. Sci. 49:1228–1235.

Clarke, T. A. 1971. Territory, boundaries, courtship, and social behavior in the garibaldi, *Hypsypops rubicunda* (Pomacentridae). Copeia 2:295–299.

Gunderson, D. R., P. Callahan, and B. Goiney. 1980. Maturation and fecundity of four species of *Sebastes*. Mar. Fish. Rev. 42:74–79.

Haaker, P. L. 1978. Observations of agonistic behavior in the treefish, *Sebastes serriceps* (Scorpaenidae). Calif. Fish Game 64:227–228.

Hobday, A. 2000. Persistence and transport of fauna on drifting kelp (*Macrocystis pyrifera* (L.) C. Agardh) rafts in the Southern California Bight. J. Exp. Mar. Biol. Ecol. 253:75–96.

Hobson, E. S., W. N. McFarland, and J. R. Chess. 1981. Crepuscular and nocturnal activities of Californian nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. U.S. Fish. Bull. 79:1–30.

Jordan, D. S., and B. W. Evermann. 1898. Part II: Fishes of North and Middle America: A Descriptive Catalogue of the Species of Fish-Like Vertebrates found in the Waters of North America, North of the Isthmus of Panama. Smithsonian Institution, NJ, U.S.A: 1241–2183.

Kimura, D. K., R. R. Mandapat, and S. L. Oxford. 1979. Method, validity and variability in the age determination of yellowtail rockfish (*Sebastes flavidus*). J. Fish. Res. Board Canada 36:377–383.

Kosman, E. T., M. A. Colton, and R. J. Larson. 2007. Feeding preferences and size-related dietary shifts of treefish (Scorpaenidae: *Sebastes serriceps*) off southern California. Calif. Fish & Game 93: 40-48.

Laidig, T. E., D. E. Pearson, and L. L. Sinclair. 2003. Age and growth of blue rockfish (*Sebastes mystinus*) from central and northern California. U.S. Fish. Bull. 101: 800–808.

Larson, R. J. 1980. Territorial behavior of the black and yellow rockfish and gopher rockfish (Scorpaenidae *Sebastes*). Mar. Biol. 58:111–122.

Leet, W. S., C. M. Dewees, R. Klingbeil, and E. J. Larson. 2001. California's Living Marine Resources: A Status Report. Calif. Depart. Fish Game, 592 pp.

Lenarz, W. H., and T. Wyllie Echeverria. 1991. Sexual dimorphism in *Sebastes*. Environ. Biol. Fishes 30:71–80.

Love, M. S., and K. Johnson. 1998. Aspects of the life histories of the grass rockfish, *Sebastes rastrelliger*, and brown rockfish, *S. auriculatus*, from southern California. U.S. Fish. Bull. 7:100–109.

Love, M. S., P. Morris, M. McCrae, and R. Collins. 1990. Life history aspects of 19 rockfish species (Scorpaenidae: *Sebastes*) from the southern California bight. NOAA Technical Report NMFS 87, 38 pp.

Love, M., J. E. Caselle, and L. Snook. 2000. Fish assemblages around seven oil platforms in the Santa Barbara Channel area. U.S. Fish. Bull. 98:96–117.

Love, M. S., M. Yoklavich, and L. Thorsteinson. 2002. The Rockfishes of the Northeast Pacific. Berkeley: University of California Press, 416 pp.

MacGregor, J. S. 1970. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. U.S. Fish Wildlife Service, Special Scientific Report—Fisheries 569, 12 pp.

MacLellan, S. E. 1997. How to age rockfish (*Sebastes*) using *S. alutus* as an example—the otolith burnt section technique. Can. Tech. Rep. Fish. Aquat. Sci. 2146: 39 pp.

Miller, D. J., and R. N. Lea. 1972. Guide to coastal marine fishes of California. Calif. Dept. Fish Game, Fish Bull. 157: 235 pp.

Moser, H. G. 1967. Reproduction and development of *Sebastodes paucispinus* and comparison with other rockfishes off southern California. Copeia 1967:773–797.

Pallant, J. 2002. SPSS Survival Manual. Buckingham, U.K.: Open University Press. 286 pp.

Pearson, D. E., J. E. Hightower, and J. T. H. Chan. 1991. Age, growth, and potential yield for shortbelly rockfish, *Sebastes jordani*. U.S. Fish. Bull. 89:403–409.

Phillips, J. B. 1957. A review of the rockfishes of California (family Scorpaenidae). Calif. Dept. Fish Game, Fish Bull. 160: 144 pp.

Prager, M. H., S. B. Saila, and C. W. Recksiek. 1989. FISHPARM: A microcomputer program for parameter estimation of nonlinear models in fishery science, 2nd ed. Old Dominion University Oceanography Technical Report 87–10.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries and Marine Service, Ottawa, 400 pp.

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

Wilson, C. D., and G. W. Boehlert. 1990. The effects of different otolith ageing techniques on estimates of growth and mortality for the splitnose rockfish, *Sebastes diploproa*, and canary rockfish, *S. pinniger*. Calif. Fish Game 76:146–160.

Wyllie Echeverria, T. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. U.S. Fish. Bull. 85:229–250.