Abstract.–We collected data on age-length and length-weight relationships, age and length at first maturity, and spawning seasons of grass rockfish, *Sebastes rastrelliger*, and brown rockfish, *S. auriculatus*, off southern California. In addition, we also collected data on fecundity of grass rockfish. For both species, males and females grew at the same rates and von Bertalanffy age-length parameters for grass rockfish were l_∞ = 51.3 cm, k = 0.11, t_0 = –2.41 and for brown rockfish l_∞ = 51.4 cm, k = 0.16, t_0 = –0.55. Male and female grass rockfish matured at about the same length and age, between 22 and 28 cm and between 2 and 5 yr. There was also little difference between the sexes for brown rockfish; they matured between 19 and 32 cm and between 3 and 6 yr. Grass rockfish spawned from January to March, peaking during January; brown rockfish spawned from January to June (and perhaps August), also peaking in January. Fecundity of grass rockfish ranged from about 80,000–760,000 eggs.

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Aspects of the life histories of grass rockfish, *Sebastes rastrelliger*, and brown rockfish, *S. auriculatus*, from southern California

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Rockfishes (Scorpaenidae: *Sebastes*) are of major commercial importance in California waters. Until recently, almost all of these fishes were landed dead, destined either to be sold whole or as fillets, as fresh or frozen products (Lea, 1992). The sale of live rockfish formed only a very small part of the commercial fishery, and most of this catch was sold in Asian markets and restaurants, particularly in San Francisco and Los Angeles. Recently, however, landings in the live fish fishery have increased sharply. Documented landings (almost certainly an underestimate of the true catch) escalated from about 52,000 pounds in 1989 to 987,000 pounds in 1995 (McKee-Lewis[1]). Live finfish caught in California waters are now widely sold in many local and overseas venues. Within the state, most of the fish destined for the live fish market are caught off southern and central California.

The live-fish fishery targets primarily those inshore species easily held alive, i.e. various rockfishes, California sheephead (*Semicossyphus pulcher*), California halibut (*Paralichthys californicus*) and cabezon (*Scorpaenichthys marmoratus*). Among the important rockfishes are grass rockfish (*S. rastrelliger*) and brown rockfish (*S. auriculatus*). Over 100,000 pounds of grass rockfish were landed in the live fish fishery in 1995 (McKee-Lewis[1]). Despite their importance to this fishery, relatively little was known of their biology.

Before our study, virtually nothing had been published on the life history of grass rockfish. They are solitary crevice-dwellers, inhabiting high relief substratum from Yaquina Bay, Oregon, to Bahia Playa Maria, central Baja California (Miller and Lea, 1972). Grass rockfish are among the shallowest-dwelling rockfishes, found from the intertidal waters to 46 m, usually to depths of about 10 m (Feder et al., 1974; Eschmeyer et al., 1983; Yoshiyama et al., 1986). Grass rockfish feed on fishes, crabs, shrimps, and other crustaceans (Quast, 1968; Grossman, 1986).

Somewhat more was known regarding brown rockfish, which range from Prince William Sound, northern Gulf of Alaska, to Bahia San Hipolito, central Baja California, and which inhabit subtidal waters to depths of 135 m (Love et al.[2]). Unlike grass rockfish, brown

[1] McKee-Lewis, K. 1994. California Department of Fish and Game, Marine Resources Division, 4949 Viewridge Ave., San Diego, CA. Personal commun.

[2] Love, M. S., L. Thorsteinson, C. W. Mecklenburg and T. A. Mecklenburg. 1998. A checklist of marine and estuarine fishes of the Northeast Pacific, from Alaska to Baja California. Biological Resources Division, U. S. Geological Survey.

rockfish may be found in small aggregations. The young are often found in nearshore bays, often around piers or over rubble. Older fish tend to move out of shallow waters and live over both high and low relief, often near the sand-rock interface (Matthews, 1990; Adams, 1992). Brown rockfish feed on crustaceans and fishes (Quast, 1968; Washington et al.[3]). In Puget Sound, spawning occurs during June, whereas off central California larvae are released in December–January and May–June (Wyllie Echeverria, 1987; Washington et al.[3]). There has been no published information on growth rates. In addition, despite their importance, little work on this species has been conducted in southern California.

Knowledge of the life history of a species is an essential prerequisite for effective fisheries management. Our goal was to fill gaps in knowledge of the basic life history of these two species in southern California waters.

Methods

We collected 162 grass rockfish during 1984 and 1996 and 367 brown rockfish between 1977 and 1995. All were collected from southern California waters by spear or hook and line. Data collected included total length (cm), weight (g), sex, capture location, and collection date. In the laboratory, we weighed the gonads, assessed reproductive state, and removed sagittal otoliths.

Age determination

Otoliths were placed on wood blocks and embedded in clear epoxy. Each block with its otoliths was placed on a Buehler Isomet low-speed saw, and an 0.05-cm wafer (transverse section) was cut from it with two diamond-edge blades separated by a stainless steel shim. Before reading, the wafers were burned slightly over an alcohol lamp. The wafers were then placed in a water-filled, black-bottomed watch glass and examined under a dissecting microscope.

Ages were assigned by direct observation of otolith annuli. We aged a total of 149 grass rockfish, including 78 males (16.6–47.5 cm) and 71 females (14.4–50.5 cm), as well as 269 brown rockfish, including 120 males ranging in length from 15.0 to 49.8 cm and 149 females ranging from 17.2 to 53.2 cm. Growth was assumed to be described by the von Bertalanffy growth curve model (von Bertalanffy, 1938):

$$l_t = l_\infty \left(1 - e^{-k(t-t_0)}\right),$$

where l_t = length at time t;
l_∞ = theoretical maximum length;
k = constant expressing the rate of approach to l_∞; and
t_0 = theoretical age at which $l_t = 0$.

Growth equation constants for the von Bertalanffy growth model were calculated from length-at-age data for each species by using the least-squares, nonlinear regression (SYSTAT, 1992).

Maturation and reproduction

We estimated length and age at first maturity by classifying gonads as immature or mature on the basis of criteria given in Westrheim (1975), Gunderson (1977), and Love and Westphal (1981). As with other rockfishes, it was difficult to distinguish between immature and mature resting-stage females during the nonreproductive season. Thus, we did not use females captured during the nonreproductive season for either the length-maturity or age-maturity analyses.

The relationships between length and maturity and age and maturity were established by using a natural log transformation of the equation

$$P_x = \frac{1}{1 + e^{ax+b}}$$

(Gunderson et al., 1980) to yield

$$\ln \frac{(1 - P_x)}{P_x} = ax + b,$$

where p_x = the proportion mature at length or age x; and
a and b = fitted parameters.

We then plotted x against

$$\ln \frac{1 - P_x}{P_x}$$

using simple linear regression to estimate values for a and b. Fifty-percent maturity was calculated by using fitted values of a and b, and by using $p_x = 0.50$ to solve for x.

A gonadosomatic index [(gonad weight)/(total body weight) × 100] was computed to quantify changes in gonad size with season. Gonad condition (immature, resting, vitellogenesis, eyed, spawned [Wyllie Echeverria, 1987]) was determined for each female.

We determined egg production in grass rockfish, counting subsamples of unfertilized eggs. Eggs were

[3] Washington, P. M., R. Gowan, and D. H. Ito. 1978. A biological report on eight species of rockfish *Sebastes* spp. from Puget Sound, Washington. Northeast Alaska Fisheries Center, Processed Rep., 50 p.

excised from the ovarian membrane and placed in Gilson's solution (equal parts concentrated glacial acetic acid, chloroform, and 60% ethanol) for about three months and shaken periodically to loosen them from ovarian tissue. Before counting, the ovaries were repeatedly washed and the egg masses broken up to remove remaining connective tissue. The resulting eggs were weighed; the subsamples were removed and also weighed. Eggs in each subsample were counted and the mean number per weight calculated for each subsample. Egg production, F, was estimated by the calculation

$$(TW \times SN) / (SW),$$

where TW = total weight of gonads;
SN = mean subsample egg number; and
SW = subsample weight.

Results

Age and growth

For each species, the von Bertalanffy parameters were estimated for males and females separately, and for both sexes combined. An ANOVA was used to statistically compare the amount of variance described by both the separate and combined growth curves. ANOVA results concluded that for both grass rockfish (F=1.16, P>0.05) and brown rockfish (F=1.15, P>0.05) there was no significant difference in the amount of variance explained by estimating sex-specific values for the three parameters. Thus, for each species growth of both sexes is adequately depicted by a single growth curve.

The von Bertalanffy parameters for grass rockfish were L_∞ = 51.3 cm, k= 0.11, t_0 = –2.41 (Fig. 1) and for brown rockfish L_∞ = 51.4 cm, k = 0.16, t_0 = –0.55 (Fig. 1). As with other rockfishes, immature fishes grew relatively rapidly slowly as they matured. Within each species, sexes appeared to have similar life spans. The oldest male grass rockfish was 22 yr, the oldest female 23 yr. Male brown rockfish lived to 18 yr, females to 20 yr.

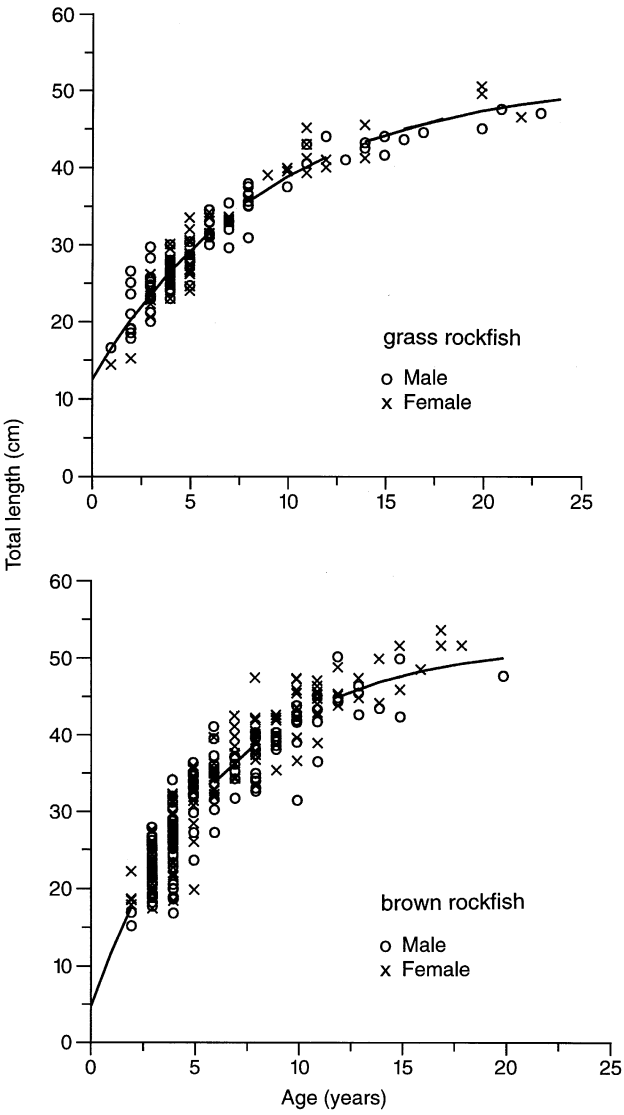

Figure 1
Von Bertalanffy growth curves for grass rockfish (*S. rastrelliger*) and brown rockfish (*Sebastes auriculatus*) from southern California.

Length-weight relationships

For both species, the relationship between total length and weight fitted the relationship

$$W = aL^b,$$

where W = weight in grams;
L = total length in centimeters; and
a and b = constants.

Parameters were estimated with Fishparm v. 3.0 (Saila et al. 1988) by using Marquardt's algorithm for nonlinear least squares parameter estimation.

To test for differences in the relationships between sexes, male and female data within a species were modeled separately. Each relationship was then $\log_{10}$-transformed to create a linear equation, and slopes of the male and female models were compared by using Student's t-test. This process was repeated with gonad weight subtracted from total body weight, to

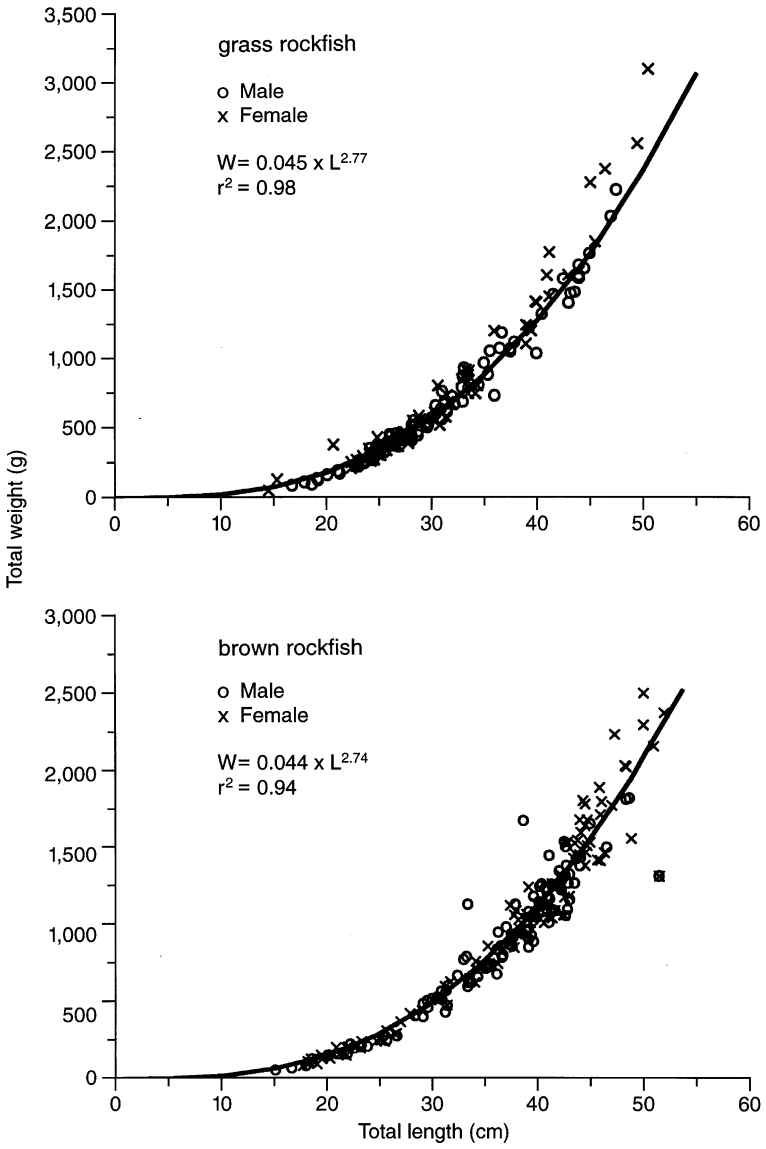

Figure 2

Length-weight relationships for grass rockfish (*S. rastrelliger*) and brown rockfish (*Sebastes auriculatus*) from southern California.

determine if any difference was simply an artifact caused by the larger female gonads.

For grass rockfish, 86 males and 73 females were measured and weighed. Although female grass rockfish tended to be heavier than males at a given length (*T*-test, t=2.21, P<0.05), the difference was not evident when gonad weight was subtracted from total body weight (*T*-test, t=1.66, P>0.05), and we therefore have combined these data into a single figure (Fig. 2).

A total of 116 male and 102 female brown rockfish were sampled. For brown rockfish, there was no significant difference in weight at a given length between males and females (*T*-test, t=0, P>0.05); we have also combined these data into a single figure (Fig. 2).

Length and age at first maturity

For these analyses, we examined 53 female and 64 male grass rockfish and 135 female and 129 male brown rockfish. Both male and female grass rockfish matured over relatively narrow length and age intervals (Table 1; Fig. 3). Both sexes began to mature at 22 cm and all fish were mature by 28 cm.

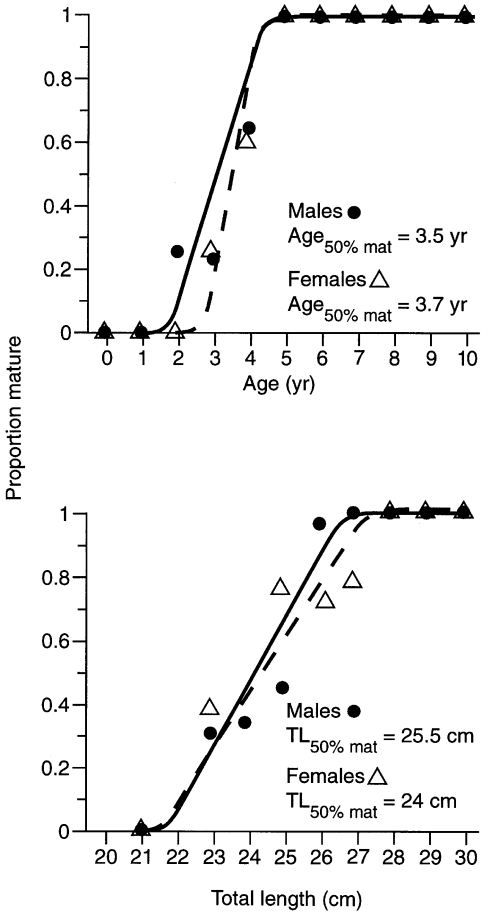

Figure 3

Age-maturity and length-maturity and relationships for male (n=88) and female (n=74) grass rockfish (*Sebastes rastrelliger*) taken in the southern California Bight, including estimated ages and lengths at which 50% of the fish were mature. Solid and dashed lines represent predicted relationship.

Table 1

Maximum-likelihood estimates for the parameters of the logistic equation relating proportion mature to lengths and ages of grass and brown rockfishes. Predictive length ($l_{0.50}$) and age ($Age_{0.50}$) at 50% maturity and mean square error (MSE) of the logistic equation are also presented.

	Length			
Species	a	b	$l_{0.50}$ (cm)	r^2
Grass rockfish				
Male	0.83	20.62	24.5	0.97
Female	0.73	17.49	24.0	0.97
Brown rockfish				
Male	0.38	9.47	25.0	0.85
Female	0.62	16.36	26.4	0.99
	Age			
Species	a	b	$Age_{0.50}$	r^2
Grass rockfish				
Male	1.52	5.36	3.5	0.93
Female	1.95	7.20	3.7	0.99
Brown rockfish				
Male	1.57	6.05	3.9	0.99
Female	1.79	7.51	4.2	0.99

Fifty percent of males were mature at about 24.5 cm, and fifty percent of females at 24 cm. Male grass rockfish matured from 2 to 5 yr, females from 3 to 5 yr.

For brown rockfish, there was also little difference between sexes in either length or age at first maturity (Table 1). Males matured between 19 and 29 cm, females between 21 and 32 cm (Fig. 4). For males, 50% maturity occurred at about 25 cm, for females at 26.4 cm. Age at first maturity for both male and female brown rockfish occurred as early as 3 yr, and all fish were mature by 6 yr (Fig. 4).

Spawning seasons

Grass rockfish released larvae from January to March, reaching a peak in spawning during January (Fig. 5). Females with spawned ovaries were found only during February and March, after which followed a 6-month resting stage. Vitellogenic ovaries were common from December to February. Ovary indices remained at a minimum throughout spring, summer, and early fall, averaging about 0.3% of body weight, then increased to a peak of 6.8% in December (Fig. 6). Testes indices were also low during spring and summer (averaging less than 0.1%), rising to a peak of 0.2% in December (Fig. 6).

Brown rockfish spawned from January to August, reaching a peak in January (Fig. 5). Although females with resting stage ovaries were found from April to November, most occurred during the summer. We found vitellogenesis-stage ovaries during most months, particularly between fall and spring. For females, gonosomatic indices were lowest (averaging 0.6%) from June to November and peaked during January at 7.1% (Fig. 6). Testicular indices were lowest from March to August (averaging 0.15%) and peaked in October at 0.62% (Fig. 6).

Fecundity

The relation between grass rockfish fecundity and total length (Fig. 7) was best described by the function

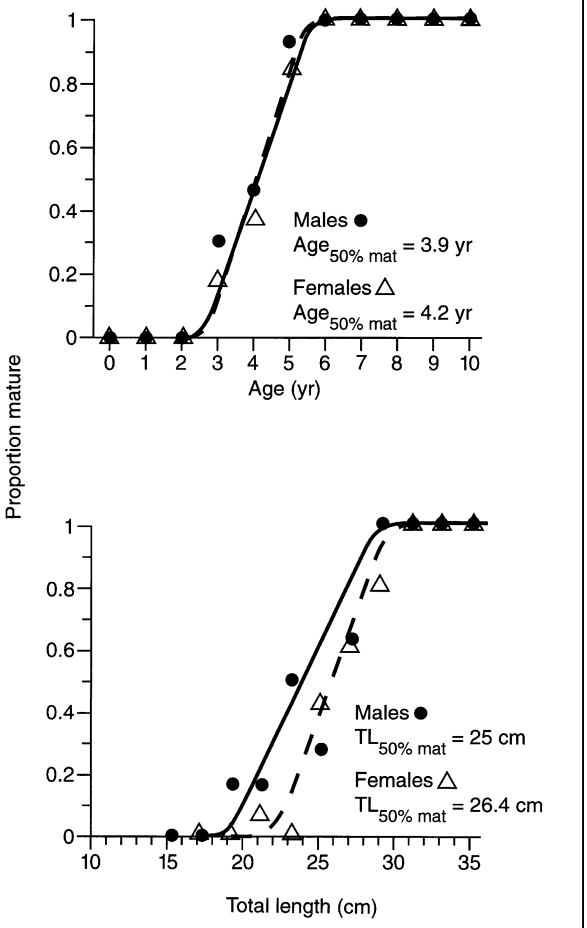

Figure 4

Age-maturity and length-maturity relationships for male (n=120) and female (n=149) brown rockfish (*Sebastes auriculatus*) taken in the southern California Bight, including estimated ages and lengths at which 50% of the fish were mature. Solid and dashed lines represent predicted relationship.

$$F = aL^b,$$

where F = number of eggs in thousands;
L = total length in centimeters; and
a and b = constants.

The value of the parameters a and b were estimated by fitting the linear function log F = log a + b Log L by least squares. Estimated fecundity ranged from 80,000 eggs for a 26 cm TL individual to about 760,000 for one 46.5 cm long.

Discussion

In the northeast Pacific, rockfish growth rates, as measured by the term k, are quite variable (Love et al., 1990), although compared to many other groups, their growth rates are quite low (Beverton and Holt, 1960). The largest species of rockfishes tend to grow slowest (k=0.05, rougheye rockfish, *S. aleutianus*) and dwarf species exhibit relatively rapid growth (k=0.45, halfbanded rockfish, *S. semicinctus*). However, between these extremes there is no relation between maximum size and growth rate. Grass rockfish and brown rockfish growth rates are near the mean for the genus (Love et al., 1990). However, what was usual for the rockfishes was a lack of sexual dimorphism in growth rates. In most species, females grow faster than males, particularly after maturity.

Compared with most other eastern Pacific rockfishes, both species are short-lived. Of the 38 species for which we judge that fairly accurate maximum ages are known, only eight had life spans that were similar to or less than grass and brown rockfishes (Love et al.[4]). Most species lived to more than 30 years, a majority to more than 40 years. Short-lived species tend to be dwarf taxa, such as shortbelly (*S. jordani*), Puget Sound (*S. emphaeus*), squarespot (*S. hopkinsi*), and honeycomb (*S. umbrosus*) rockfishes.

For brown rockfish, there appears to be little difference in age and length at 50% maturity throughout much its range (Table 2). Although fish off central and northern California are older and larger at 50% maturity, those from Washington State and southern California are almost identical. Latitudinal differences in length or age of maturation, or both, occur in a number of rockfish species (e. g. splitnose rockfish, *S. diploproa*; widow rockfish, *S. entomelas*; yellowtail rockfish, *S. flavidus*; black rockfish, *S. melanops*; bocaccio, *S. paucispinis*) with fishes from higher latitudes generally maturing when larger or older or both (Wyllie Echeverria, 1987; Love et al., 1990; Field, 1984). However, this difference does not occur in greenstriped rockfish, *S. elongatus* (Love et al., 1990). Although it is likely that environmental parameters (e.g. water temperature, food availability, growth seasons) play a role in this phenomenon, it is not yet clear how they interact.

With 50% mature at age 4, both grass rockfish and brown rockfish mature at a young age compared with many rockfishes. Off California, most species reach 50% maturity at between 4 and 8 years (Wyllie Echeverria, 1987; Love et al., 1990); thus these two species fall in the younger part of that range. Dwarf species, such as shortbelly rockfish (*S. jordani*), Puget Sound rockfish (*S. emphaeus*) and stripetail rockfish (*S. saxicola*) mature earliest, often when 2 or 3 years old (Moulton, 1975; Wyllie Echeverria, 1987; Love et al., 1990). At the other extreme, the largest and more northerly species, such

[4] Love, M. S., M. Yoklavich, L. Thorsteinson, J. Butler. 1998. A guide to the rockfishes of the northeast Pacific. In prep.

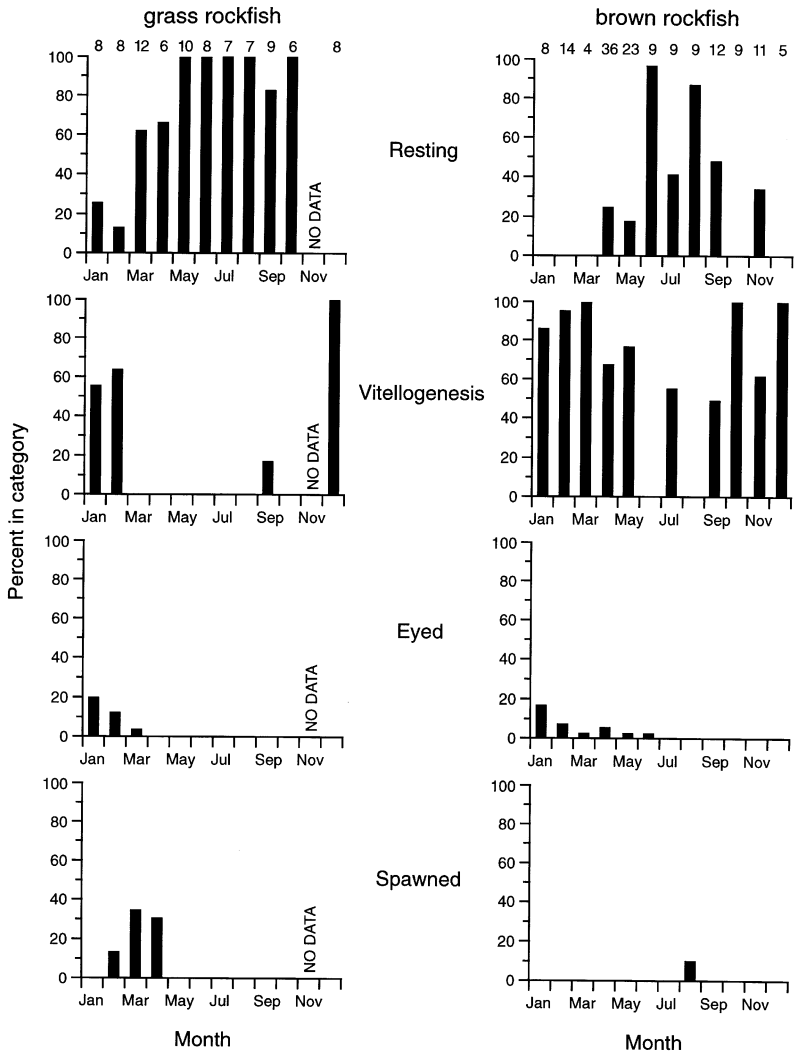

Figure 5

Percent composition by month of four gonad condition stages for female grass rockfish (*Sebastes rastrelliger*) and brown rockfish (*Sebastes auriculatus*) taken in the southern California Bight. The total number of females examined per month is listed at the top of each month in the "resting" section.

Table 2

Age and length at 50% maturity for male and female brown rockfish by area. Data from Washington State from Washington et al. (1978) and from northern-central California from Wyllie Echeverria (1987). Lengths of Washington fish are converted from fork length to total length based on Echeverria and Lenarz (1984).

Sex	Washington	Northern-central CA	Southern CA
Male	4 yr, 24 cm	5 yr, 31 cm	4 yr, 25 cm
Female	4 yr, 26 cm	5 yr, 31 cm	4 yr, 27 cm

as yelloweye rockfish (*S. ruberrimus*) and rougheye rockfish (*S. aleutianus*) may take 20 years or more to mature (McDermott, 1994; O'Connell[5]).

[5] O'Connell, T. 1994. Alaska Department of Fish and Game, 304 Lake St., Room 103, Sitka, AK 99835. Personal commun.

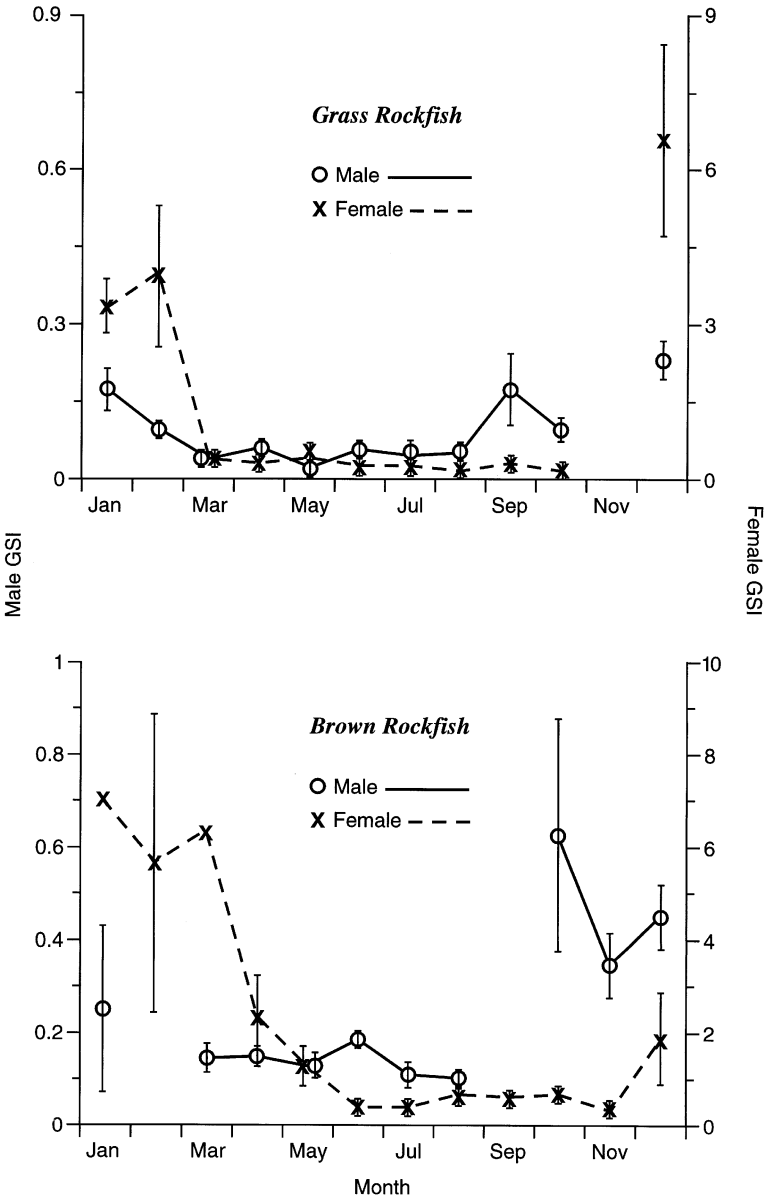

Figure 6

Seasonal changes in the gonosomatic index (GSI-gonad weight as a percent of total body weight) of male and female grass rockfish (*Sebastes rastrelliger*) and brown rockfish (*Sebastes auriculatus*). No samples of grass rockfish were taken during November and no samples of male brown rockfish were taken in February and September. Vertical lines indicate 95% confidence intervals of the mean.

Along the northeast Pacific, the vast majority of rockfish spawn in the late winter and early spring and, as with length and age at maturation, many rockfish species exhibit a latitudinal trend in spawning season. Parturition often starts earlier or is more prolonged (or both) in the southern part of a species' geographic range (O'Connell, 1987; Wyllie Echeverria, 1987; Barss, 1989; Love et al., 1990). The spawning season for brown rockfish from Puget Sound to southern California appears to follow this pattern. Spawning occurs in Puget Sound in June (Washington et al.[3]), in December–January and May–June in northern-central California (Wyllie Echeverria, 1987) and in January–August in southern California.

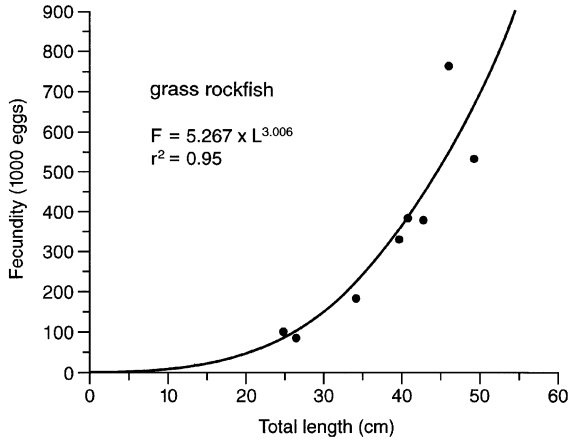

Figure 7

Fecundity-total length relationship for eight grass rockfish (*Sebastes rastrelliger*) taken in the southern California Bight.

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