Reproductive biology, growth, and natural mortality of Puget Sound rockfish, *Sebastes emphaeus* (Starks, 1911)

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In spite of being one of the most common rockfish in the rocky nearshore region of the Strait of Georgia, relatively little is known about the early life history, ecology, recruitment, and reproductive biology of Puget Sound rockfish, *Sebastes emphaeus*.

In rockfish, fecundity at 50% maturity ranges from 2,000 (*S. dalli*) to 417,000 (*S. paucispinis*) eggs per female (Haldorson and Love, 1991). Parental care in this genus is essentially lecithotrophic, characterized by primitive, unspecialized viviparity at an evolutionary stage when eggs, embryos, and early larval stages are protected inside the female body rather than born live as fairly advanced young (Wourms, 1991). Although most other northeastern Pacific *Sebastes* release their young between January and July (Westrheim, 1975), parturition occurs in August and September for Puget Sound rockfish (Moulton, 1975; Beckmann, 1995).

The goals of this study were to delineate the spawning season more closely and to determine the age and length at first maturity, the growth and mortality rates, and the length-fecundity relationship for Puget Sound rockfish.

Materials and methods

A total of 362 Puget Sound rockfish older than age 0 were collected during 23 sampling trips in coastal waters of the San Juan Islands, from 26 June 1994 to 12 March 1995 (Table 1). The fish were collected either by anglers using hook-and-line gear or by SCUBA divers using spears and hand nets. The average collection depth for these rockfish was 15 m to 21 m, with a maximum depth of 76 m.

In addition, 19 collection trips were made with hand nets for young-of-the-year (YOY) specimens. These trips extended from 26 February through 18 August 1994, and 424 YOY were obtained.

The spawning period was defined as occurring from the time when the first females with spent ovaries were caught to the time when no females with embryos were observed. A total of 253 females older than age 0, collected between June 1994 and March 1995, were classified by maturity stage according to the criteria described in Finckh McDermott (1994). Nonlinear least square regression was used to fit the data to the logistic model:

$$P_L = \frac{1}{1+e^{-(\alpha+\beta L)}},$$

where P_L = proportion mature at length L (mm FL);
α, β = constants; and
$-\frac{\alpha}{\beta}$ = length at which 50% of fish are mature ($=L_{0.5}$).

Sagittal otoliths were removed from the fish and stored in 50% ethanol. Readings prepared by the break-and-burn method were taken either from left or right otoliths, following the international convention of considering 1 January as the birth date. All final age determinations were made by the coauthor with extensive age-determination experience (B. Goetz), after examining the results obtained by the senior author and then examining edge type and annulus formation for the entire collection. A sample of 59 otoliths was read twice (with six months between readings) and showed 66% agreement (to the ex-

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Table 1

Date and sampling method for collections of Puget Sound rockfish older than age 0.

Date	Number collected	Method	Date	Number collected	Method
26 Jun 1994	6	spear	3 Aug 1994	41	hook and line
28 Jun 1994	4	spear	8 Aug 1994	19	hook and line
29 Jun 1994	12	spear or hand net	21 Aug 1994	11	spear or hook and line
5 Jul 1994	5	hook and line	26 Aug 1994	8	hook and line
6 Jul 1994	22	spear	29 Aug 1994	8	hook and line
7 Jul 1994	11	spear	30 Aug 1994	10	hook and line
7 Jul 1994	20	hook and line	2 Sep 1994	21	hook and line
13 Jul 1994	35	hook and line	6 Sep 1994	7	hook and line
22 Jul 1994	15	hook and line	10 Sep 1994	13	hook and line
24 Jul 1994	3	hand net	30 Dec 1994	21	hook and line
26 Jul 1994	6	hand net	12 Mar 1995	37	hook and line
28 Jul 1994	27	hook and line			

act year) between independent readings, with no obvious bias.

Age-length relationships were estimated from the mean length at age for age groups 1–13, derived from the otolith readings. The mean length of age-0 fish was estimated from the mean length of the YOY captured with nets during February–August 1994. Lengths for YOY were originally recorded as standard length, and were converted to fork length by using the relationship for shortbelly rockfish (*S. jordani*) reported by Echeverria and Lenarz (1984). The mean age of YOY (0.7 years) was estimated by assuming that parturition occurred on 1 September. Mean length at age for age groups 1–13 was estimated from fish collected during June–December, 1994. Data were fitted to the von Bertalanffy growth model (Ricker, 1975) with nonlinear least squares regression. Male and female fish were treated separately owing to the difference in sex-specific growth rates.

Mortality was estimated from the age composition of catches (281 fish aged successfully, sexes combined) made during June–December. Because Puget Sound rockfish are not the target of any fishery, the catch curve (Ricker, 1975) was used to estimate natural mortality (M) with linear regression of log (frequency) on age. Only fish 3 years and older were used to estimate M, because it was apparent (Fig. 1) that 1- and 2-year-olds were not fully available to our sampling gear.

Fork length (FL) to the nearest millimeter and wet gonad weight (GW) and wet somatic weight (SW) to the nearest milligram were measured for all adult females. Somatic weight was defined as the weight of the fish with the stomach emptied and the gonads removed. The gonadosomatic index ($GSI = GW/SW$) was used to determine relative reproductive effort for a mature female of average size. Allometric relationships between GW-body length and SW-body length were determined by using log-log linear regression (Gunderson and Dygert, 1988). Only fully mature females in the later stages of vitellogenesis were used in estimating GSI. Histological examination of a subsample of 12 individuals, representing a broad range of lengths and relative GSI values, showed that all of them were in the migratory nucleus stage of egg development just prior to ovulation (McDermott[1]).

Fecundity was estimated by counting all nonatretic oocytes in advanced vitellogenesis with subsamples from both ovaries of 16 fish ranging from 112 to 178 mm FL. From preliminary measurements it could be seen that vitellogenetic oocytes were at least twice the size of the resting and immature primary oocytes. All oocytes with the longest axis exceeding 250 µm were counted. A gravimetric subsampling method (Nichol and Pikitch, 1994) was chosen to estimate oocyte numbers.

Because of the nonuniform distribution of oocytes and connective tissue within the ovaries, ovarian sacs and ovarian stroma were removed prior to subsampling. Thin sections of the remaining egg mass were taken from five different transects equally spaced along the longitudinal axis of each ovary. Each subsample was weighed, pipetted into a plastic grid dish, and the eggs of each subsample were counted. Final fecundity estimates were made by multiplying

[1] McDermott, S. 1995. School of Fisheries, Univ. Washington, Seattle, WA 98195. Personal commun.

the mean oocytes/mg, averaged across all subsamples, by total egg mass weight. Fecundity data were fit to an allometric relationship with log length-log fecundity linear regression (Haldorson and Love, 1991).

Results

Females with unfertilized eggs were caught from 26 June to 8 August 1994. Embryos without pigmented eyes were observed from 22 July to 29 August, and embryos with pigmented eyes from 24 July to 29 August. The first spent female was observed on 21 August, and all mature females caught from 31 August to 10 September showed spent ovaries. Only resting females were captured on 30 December. Mature females captured on 12 March 1995, were either resting or in the initial stages of vitellogenesis. Spawning occurred over a relatively short time period, with only 9 days between the time when the first spent female and the last gravid female were observed. Ovaries did not contain developing embryos and cleaving eggs at the same time, indicating that individual Puget Sound rockfish spawn only one brood per season.

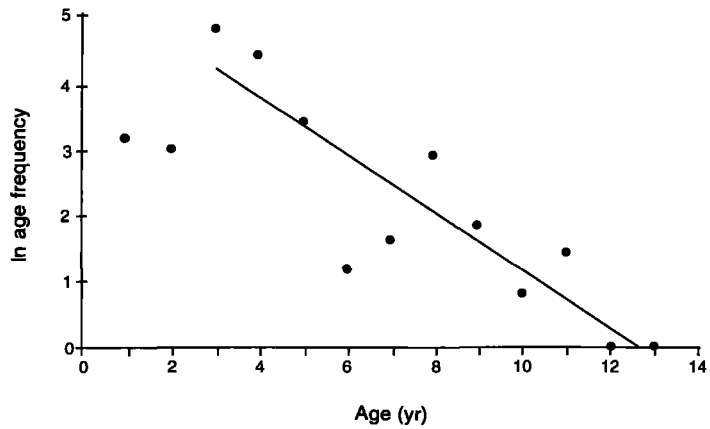

Figure 1

Estimation of natural mortality for Puget Sound rockfish (sexes combined) with a catch curve (predicted line).

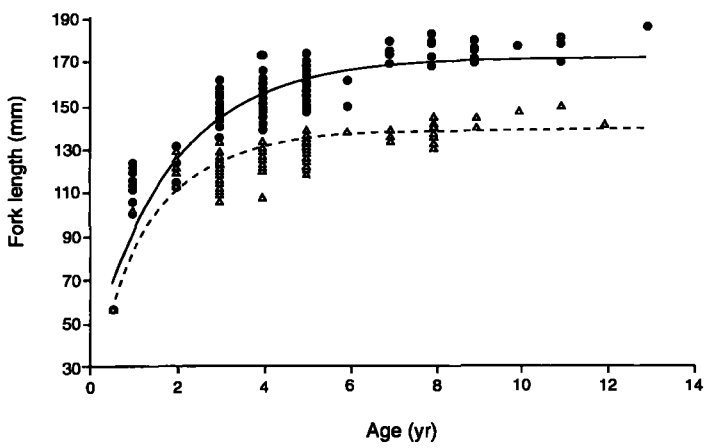

Figure 2

Comparison of female and male age-length (FL) relationships for Puget Sound rockfish. Solid line and filled circles show predicted relationship (von Bertalanffy growth model) and data for females; dashed line and open triangles show predicted relationship and data for males.

The oldest observed fish was a female 13 years old, followed by a 12-year-old male. The largest male caught was 145 mm FL and the largest female 178 mm FL (Fig. 2). The age-length relation (von Bertalanffy growth model) for male Puget Sound rockfish was $L_t = 137.39\ (1 - e^{-0.7042(t+0.3232)})$ and for females $L_t = 170.72\ (1 - e^{-0.5353\ (t+0.4603)})$. Based on the regression result of ln(frequency) = 5.554–0.44 (age), the instantaneous annual rate of natural mortality (M) for fish 3 years and older was estimated to be 0.44 (Fig. 1).

Female Puget Sound rockfish reached sexual maturity at a median length of $L_{0.5}$ = 121.71 mm *FL* (Fig. 3) corresponding to a predicted age of 1.87 years with the von Bertalanffy growth model. The length-maturity parameters derived from the logistic model were $\alpha = -39.678$ and $\beta = 0.326$. The average length of all mature females larger than $L_{0.5}$ was L_{AV} = 150.93 mm.

The somatic weight-length relationship was $SW = 5.882 \times 10^{-5}\ L^{2.687}$ with the predicted somatic weight for L_{AV} = 42.06 g. The gonad weight-length relationship was $GW = 5.869 \times 10^{-7}\ L^{3.151}$ with the predicted gonad weight for L_{AV} = 4.30 g. From these two weights the GSI for Puget Sound rockfish was computed as 0.10.

The lowest fecundity was 3,295 eggs for a female of 112 mm FL and the highest was 57,787 for an individual 156 mm FL (Fig. 4). The length-fecundity (*F*) relationship was $F = 0.052\ L^{2.679}$, and the fecundity for a mature female of average length (150.93 mm) was estimated to be 35,723 eggs. The estimated fecundity per gram for a female $L_{0.5}$ cm long (Haldorson and Love, 1991) was 779 eggs.

Although egg size was variable, the majority of the eggs within an individual female were about the same size and at the same developmental stage. The time span between the capture of the first fertilized female and the first spent female yields a rough estimate of 30 days for the gestation period.

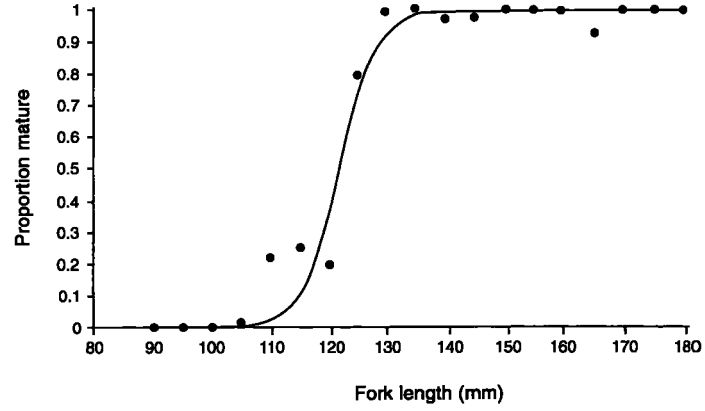

Figure 3

Length-maturity relationship predicted for female Puget Sound rockfish (predicted line). Solid circles indicate data.

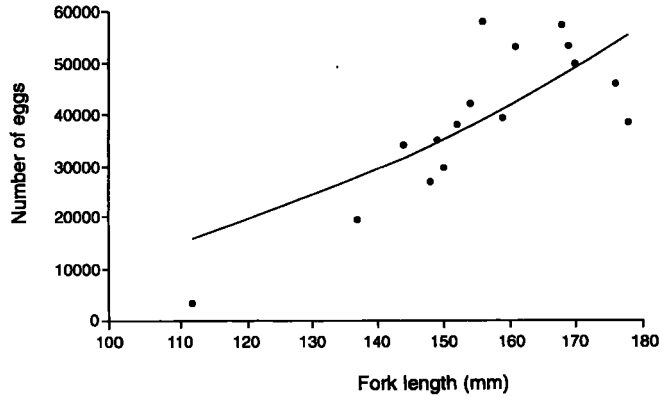

Figure 4

Length-fecundity relationship for female Puget Sound rockfish (predicted line). Solid circles indicate data.

Discussion

Puget Sound rockfish show high fecundity per gram, early age at maturation, small body size, and a relatively short life expectancy compared with other rockfish of the genus. No other rockfish studied to date has a higher fecundity per gram at $L_{0.5}$ (Haldorson and Love, 1991). A high natural mortality would be expected to accompany these life history characteristics, and the estimated M of 0.44 is high compared with that of other rockfish .

Puget Sound rockfish have a GSI (0.10) close to that of other early maturing rockfish (e.g. shortbelly rockfish, GSI=0.07, M=0.26, maturation age=2 years; Gunderson, 1997). However, a comparison of the catch-curve estimate of M with empirically derived estimates suggests some possibility that the catch curve is based on an unrepresentative sample and has been overestimated. The maximum age observed in our study (13 years) corresponds to an M of 0.32 with Hoenig's (1983) empirical estimation technique, whereas the GSI (0.10) gives an estimate of M = 0.18 with Gunderson's (1997) estimator.

A constant recruitment is assumed if the catch curve is used, yet the data in Figure 2 suggest that the 1988 year class (age 6 in 1994) appears to have recruited at significantly lower levels than the others. Our catch-curve estimate of M should probably be regarded as provisional, and additional collections of age-composition data or tagging studies should be undertaken to validate it.

The fecundity of 3,300–57,800 eggs observed for Puget Sound rockfish is in the range of fecundities of similar-size rockfish. Shortbelly rockfish (18–31 cm TL) has a fecundity from 7,000 to 50,000 (Hart 1973). Our fecundity estimates for Puget Sound rockfish are comparable to those obtained by Moulton (1975).

The estimated gestation period for Puget Sound rockfish is similar to the 29-day gestation period reported for yellowtail rockfish (*S. flavidus*), a species which has been shown to be lecithotrophic, providing only a negligible amount of maternal energy during gestation (Hopkins et al. 1995). The high fecundity per gram and relatively brief gestation period suggest that parental care is limited in comparison to other rockfish.

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