Maturation and Fecundity of Four Species of *Sebastes*

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Introduction

The 1977 survey of rockfish resources offered a unique opportunity to carry out studies of the reproductive biology of yellowtail rockfish, *Sebastes flavidus*; canary rockfish, *S. pinniger*; bocaccio, *S. paucispinis*; and chilipepper, *S. goodei*. Because of their commercial importance these species were singled out for intensive study, and detailed information on their size composition, age composition, and abundance were obtained. Studies of the reproductive biology of these four species were also undertaken to examine their fisheries potential in further detail. The primary objective of these studies was the determination of length-maturity and length-fecundity relationships.

Length-maturity relationships have previously been examined for all four species off California (Phillips, 1964), while Westrheim (1975) provided similar information for yellowtail and canary rockfish off Vancouver Island, B.C. Both workers reported their results as estimates of the length at which 50 percent of the specimens examined were mature ($l_{.50}$), rather than discussing the length-maturity relation in general.

Fecundity studies on these species have also been quite limited, with little work being carried out subsequent to the pioneering work by Phillips (1964). Phillips estimated the fecundity of 24 bocaccio, 23 chilipepper, 15 yellowtail, and 10 canary rockfish, which were collected off California. Subsequent to Phillips' report, additional work on fecundity was carried out by MacGregor (1970) who presented data on the number of oocytes and embryos in 13 specimens of bocaccio, and by Snytko and Borets (1972), who determined the fecundity of 16 specimens of yellowtail rockfish and 4 of bocaccio.

The data collected during the 1977 Rockfish Survey substantially increased the information available on the reproductive biology of the four species examined, and the purpose of this paper is to summarize it.

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ABSTRACT—Length-maturity relationships were determined for yellowtail rockfish, Sebastes flavidus; *canary rockfish,* S. pinniger, *chilipepper,* S. goodei, *and bocaccio,* S. paucispinis. *Length-fecundity relationships were determined for all but the latter. Geographic differences in fecundity were examined for canary rockfish and chilipepper; significant differences were found in samples from chilipepper populations that were 93-185 km (50-100 nautical miles) apart. The results obtained in this study were compared with the limited information published previously. The management implications of differences in fecundity are discussed.*

Methods

For each specimen examined for maturity, fork length was recorded to the nearest centimeter, and maturity state was categorized according to the criteria shown in Table 1. The number of individuals examined, by species, sex, date, and geographic region is shown in Table 2.

All species of *Sebastes* are ovoviviparous, with embryo release occurring 1-5 months after mating for those species that have been studied to date. A primary requisite in determining the length-maturity relation is that maturity observations be obtained when the gonad development of mature individuals is readily apparent. For males, this means that maturity observations should be obtained near the mating period, while female observations should be obtained between the time when vitellogenesis begins ("maturing" state) and embryo release is completed. If this is not accomplished, differentiation of sexually mature and immature individuals is imprecise, leading to erroneous conclusions regarding the length-maturity relation.

An examination of the maturity state of adult fish collected during the survey (Table 3) indicates that males of most species were suitable for the determination of the length-maturity relationships, although the bocaccio examined were just beginning active spermatogenesis. All female yellowtail and

Table 1.— Description of the stages used to describe rockfish maturity.

Sex and maturity stage	Description of gonads
Male	
Immature	Testes string-like, translucent or translucent white.
Maturing	Testes large and swollen, somewhat rounded in cross section, white. Sections of fresh testes produce free-flowing sperm.
Copulation	Milt can be expressed by applying pressure on the body. Testes divided into an inner layer of lighter color with sperm in ampullae, and a more transparent outer layer with voided ampullae.
Sexually inactive	Testes ribbon-like, triangular in cross section, brown. Sections of fresh testes do not have free-flowing sperm.
Female	
Immature	Ovary small and translucent or small and yellow.
Maturing	Ovary firm, eggs yellowish and opaque.
Yolk cleared (eggs fertilized)	Ovary not firm, eggs yellowish and translucent.
Ripe (with embryos or larvae)	Ovary not firm, eggs translucent with black dots or visible larvae.
Spent	Ovary large and flaccid with a reddish purple or dark gray color
Sexually inactive	Ovary firm, gray or pink, some with black blotches.

canary rockfish examined during the survey (August-September) were maturing but only a limited number of suitable maturity observations could be collected during this period. Fortunately, the Washington State Department of Fisheries has been obtaining maturity observations from commercial landings of yellowtail and canary rockfish since 1975 providing a larger volume of data, obtained nearer the spawning period, for length-maturity analysis of these species.

Maturity observations for female chilipepper collected during the survey indicated that the embryo release period encompasses a relatively short period of time and that most of the individuals examined were just beginning to approach it. Female bocaccio, on the other hand, exhibited a wide range of maturity states, indicating either a single, broad spawning period or multiple spawning. Moser (1967) reported multiple spawning for bocaccio off San Diego and Newport Beach, Calif.

Since a large proportion of both male and female bocaccio examined during the survey were inactive, the length-maturity relationships developed for them should be regarded as tentative, and more detailed studies should be undertaken. It is clear from the results in Table 3, however, that such studies should be carried out somewhat later in the year than July-August.

Ovaries were collected from all four species for the determination of fecundity, but it was later concluded that the bocaccio ovaries were unsuitable for this purpose. Information on the date and location of chilipepper, yellowtail, and canary rockfish collections is shown in Table 4.

All ovaries collected were placed in modified Gilson's solution (Bagenal and Braum, 1968) with the 20 g of mercuric chloride being replaced by 20 ml of Formalin[1] after Ito[2]. After about 2 months, ovarian tissue was removed from the eggs and the fluid was changed. By frequently teasing the ovaries apart and shaking the storage jars, the eggs of several specimens were completely separated from the surrounding ovarian tissue and ready for counting within 3 months of collection.

Mature oocytes, that would presumably develop into viable larvae prior to the next spawning season, were differentiated from immature oocytes on the basis of size frequency curves (Fig. 1). These were obtained by selecting ovaries from several adult specimens at random, and subsampling the oocytes with the same technique used to estimate fecundity (described below). Size frequency for the oocytes was then determined by placing the subsample in a Petri dish and systematically measuring those oocytes lying on transect lines drawn on the dish until 300 observations had been recorded. These observations provided the basis for concluding that most bocaccio ovaries collected were not mature enough to allow differentiation of mature and immature oocytes. Only one of the 10 specimens examined for Figure 1 exhibited the distinct mode of large, maturing oocytes that was typical of the other species examined. On the basis of the data in Figure 1, all chilipepper, yellowtail, and canary rockfish oocytes larger than 0.22 mm were counted as mature oocytes.

Fecundity was estimated through

Table 2.—The number of individual fish examined by species, sex, date, and geographic region.

Species and sex	Area (north latitude)	Date	No. of fish
Canary rockfish			
Males	45°32′-47°30′	8/31-9/16/77	199
Females	47°05′-48°10′	1/25/-4/26[1]	186
Yellowtail rockfish			
Males	46°52′-48°16′	9/14-9/21/77	277
Females	46°20′-48°27′	12/7-4/26[1]	509
Chilipepper			
Males	34°27′-40°05′	7/13-8/16/77	485
Females	34°27′-39°29′	7/13-8/9/77	243
Bocaccio			
Males	34°08′-40°05′	7/8-8/17/77	91
Females	34°08′-40°26′	7/8-8/17/77	84

[1]Collected during 1975-78 by the Washington State Department of Fisheries.

Table 3.—Percentage of adult rockfish in each maturity stage, by species, sex, and season.

	Males				Females					
Species and sampling period	Maturing	Copulation	Inactive	Number examined	Maturing	Yolk cleared	Ripe	Spent	Inactive	Number examined
Canary rockfish										
Aug.-Sept.	100	0	0	173	100					21
Jan.-Apr.					14	35	31	10	11	94
Yellowtail rockfish										
Sept.	100	0	0	238	100					85
Dec.-Apr					54	13	9	5	18	293
Chilipepper										
July-Aug.	85	0	15	346	59	34	0	2	5	147
Bocaccio										
July-Aug.	29	0	71	56	14	10	8	16	53	51

Table 4.—Date and location of collections for fecundity studies.

Species	Area (north latitude)	Date	No. of fish
Canary rockfish	40°27′-40°29′	8/13	15
	44°23′-46°23′	8/29-9/8	6
	47°29′-47°30′	9/16	10
	48°00′-48°01′	9/25	25
			56
Yellowtail rockfish	48°04′-48°16′	9/21/-9/24	49
Chilipepper	38°03′-38°06′	8/1	22
	39°00′-39°46′	8/7-8/12	61
			83

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]D.H. Ito. 1977. Fecundity of the copper rockfish, *Sebastes caurinus* (Richardson), from Puget Sound, Washington. Unpubl. manuscr., 8 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

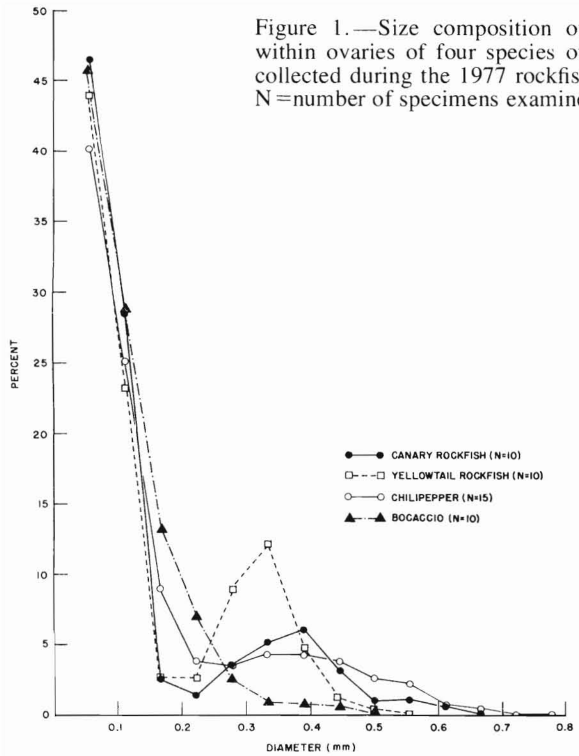

Figure 1.—Size composition of oocytes within ovaries of four species of rockfish collected during the 1977 rockfish survey. N=number of specimens examined.

subsampling by volume. The ovarian contents from each fish were removed from the storage solution, screened to remove large particles of ovarian tissue that remained, and placed in a large beaker. Water was then added until 2,000 ml of oocytes and water had been obtained. The mixture was stirred magnetically until all oocytes were distributed throughout the water column and a 1-5 ml subsample withdrawn with a pipette. Three to six subsamples were taken in this manner, the exact number depending on the standard deviation of the first three subsamples.

The oocytes in each subsample were counted twice (usually by different observers) using a binocular microscope. The mean number of eggs per milliliter was calculated for each of the 3-6 subsample means, and the coefficient of variation (CV = standard deviation /mean of subsample counts) for these subsample means had the following distribution:

CV (%)	Canary rockfish	Yellowtail rockfish	Chili-pepper
0-5.4	62%	78%	69%
5.5-11.4	38	22	31
Total	100%	100%	100%

For most specimens the standard deviation of the subsample means was within 5 percent of the grand mean, regardless of which species was involved. The fecundity of each specimen was estimated from the formula: $F = 2{,}000\,n$, where F = fecundity and n =mean number of eggs per milliliter in the subsamples.

Results

Because of the limited number of maturity observations available, no attempt was made to examine geographic trends in the length-maturity relationship. Instead, the data available for each species were pooled and a single length-maturity relationship determined for each sex.

The length-maturity data (Fig. 2) seemed to conform to a logistic model of the form:

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

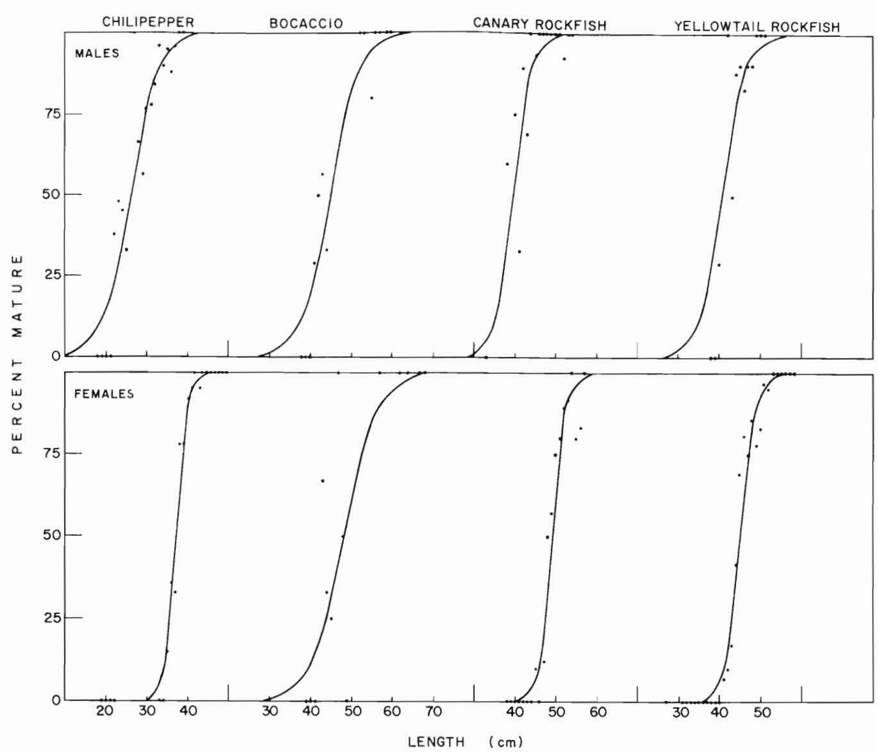

Figure 2.—Proportion of sexually mature fish within each size group, together with the predicted proportion mature (line), by sex and species. Points based on less than three observations were not plotted.

where P_x = proportion mature at length x, and a and b are constants. Maxium likelihood estimates of a and b were obtained and are shown in Table 5. The predicted length[3] at 50 percent maturity ($l_{.50}$) and 95 percent confidence limits around these estimates are also presented in this table.

Only those specimens of chilipepper larger than 37 cm, yellowtail rockfish larger than 43 cm, and canary rockfish larger than 48 cm were used in determining the length-fecundity relation so as to minimize the possibility of including immature individuals in the collections. Differentiation of mature individuals that will spawn next season becomes difficult below these sizes, and the mean fecundity of adult fish could easily be underestimated.

The length-fecundity relationships for chilipepper, canary rockfish, and yellowtail rockfish (Fig. 3-5) all seemed to conform to a linear model: $F = a + bL$, where F = fecundity, a and b are constants, and L = fork length in centimeters.

Length-fecundity relationships for fish are usually curvilinear ($F = aL^b$), and the linear relationship obtained in this study probably resulted from the practice of truncating the analysis near the size at 50 percent maturity. Even those individuals that appeared to be immature contained oocytes that were large enough to be included in the fecundity counts, however, even though there was little likelihood that these fish would mate and develop a brood of embryos. It was concluded that truncating the data at the size where

[3]APL computer program available from Russell Kappenman, Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Table 5.—Maximum likelihood estimates for the parameters of the logistic equation relating proportion mature to length. Predicted length at 50 percent maturity ($l_{.50}$) and 95 percent confidence limits for $l_{.50}$ are also presented.

Species and sex	$\hat{a}$	$\hat{b}$	$l_{.50}$ (cm)	95% confidence interval for $l_{.50}$
Canary rockfish				
Males	−0.4694	18.5360	39.5	(37.9, 41.1)
Females	−0.6171	30.3776	49.2	(48.4, 50.0)
Yellowtail rockfish				
Males	−0.3684	14.9884	40.7	(38.8, 42.6)
Females	−0.5315	23.9411	45.0	(44.5, 45.6)
Chilipepper				
Males	−0.3028	7.8943	26.1	(25.1, 27.0)
Females	−0.6982	25.8478	37.0	(36.3, 37.8)
Bocaccio				
Males	−0.2962	13.2798	44.8	(42.8, 46.9)
Females	−0.2527	12.1677	48.2	(45.4, 50.9)

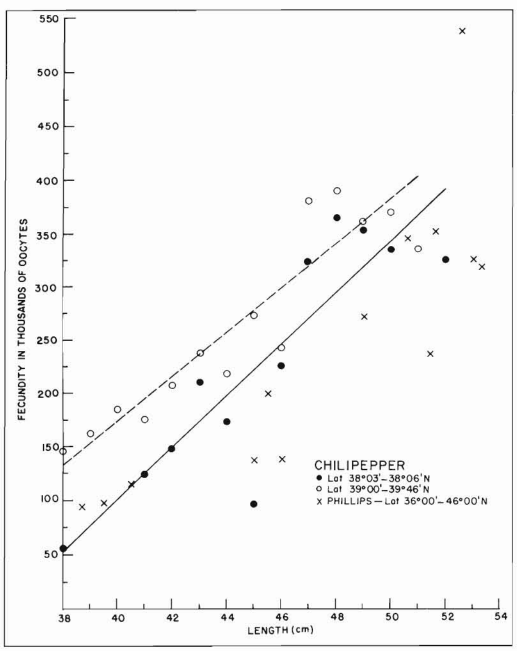

Figure 3.—Predicted relationship between fecundity and length for chilipepper, by geographic region (solid line = southern region, dashed line = northern region). Mean fecundity at each length from the original data and from Phillips' (1964) data is also shown.

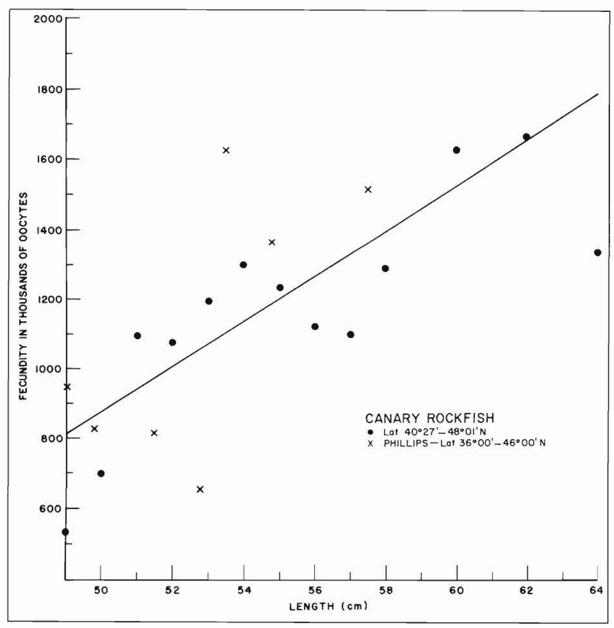

Figure 4.—Predicted relationship between fecundity and length for canary rockfish (line). Mean fecundity at each length from the original data and from Phillips' (1964) data is also shown.

differentiation of mature and immature individuals becomes difficult was preferable to including questionable data in the analysis.

Separate length-fecundity relationships were determined for canary rockfish from lat. 40°27′-40°29′N (Cape Mendocino, Calif.); lat. 47°29′-47°30′N (Sealion Rock, Wash.); and lat. 48°00′-48°01′N (Carrol Island, Wash.), and for chilipepper from lat. 38°03′-38°06′N (Pt. Reyes, Calif.) and lat. 39°00′-39°46′N (Pt. Arena-Cape Vizcaino, Calif.). For each species, the hypothesis that the data from all geographic regions could be fitted to a common line was then tested.

This was done by determining the residual sums of squares (SS) about the separate lines for each geographic region (full model) and around a single regression line (reduced model) where geographic differences were ignored. The hypothesis could then be tested by computing the test statistic:

$$F = \frac{\text{Reduced } SS - \text{Full } SS}{\text{Reduced df} - \text{Full df}} \div \frac{\text{Full } SS}{\text{Full df}}.$$

The degrees of freedom (df) for the full model $= \Sigma(n_i - 2)$ (where n_i = number of specimens in the ith geographic region) and df for the reduced model $= (\Sigma n_i) - 2$.

The results for canary rockfish indicate no significant reduction in residual variance by employing the full model ($F = 1.57$ with 4,44 df; $P(F \geqslant 1.57) = 0.2$), while a significant reduction was found in the case of chilipepper ($F = 7.03$ with 2,79 df; $P(F \geqslant 7.03) = 0.0015$). In light of these results, a single regression line was used to describe the length-fecundity relation for yellowtail and canary rockfish, while separate regression lines were used for each geographic region in the case of chilipepper.

The final models used to describe the length-fecundity relationships for the three species in question were:

Yellowtail rockfish
$F = 82721.8L - 3235161$,
Canary rockfish
$F = 64221.3L - 2330029$, and

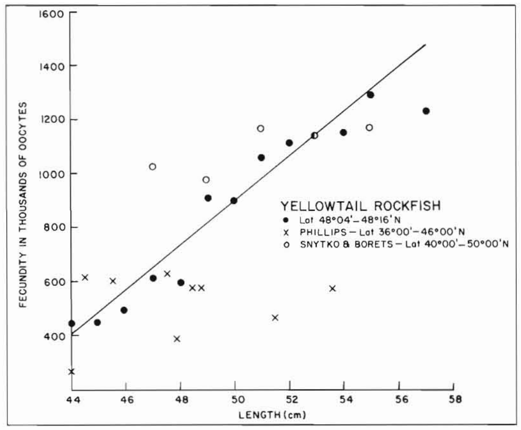

Figure 5.—Predicted relationship between fecundity and length for yellowtail rockfish (line). Mean fecundity at each length from the original data and from the data in Phillips (1964) and Snytko and Borets (1972) is also shown.

Chilipepper
lat. 38°03′-38°06′N
$F = 24297.4L - 870717$
lat. 39°00′-39°46′N
$F = 20809.4L - 658047$.

The regression lines predicted from the above equations are shown in Figures 3 through 5.

Discussion

The values of $l_{.50}$ obtained for yellowtail rockfish and canary rockfish off Washington-Oregon agree well with those reported by Westrheim (1975) for the west coast of Vancouver Island, particularly when the method used to measure length is considered. All of Westrheim's measurements were made to the nearest lower centimeter, so that his $l_{.50}$ values must be adjusted upward about 0.5 cm to compare his results with those in Table 5. When this is done, his $l_{.50}$ estimates for yellowtail rockfish become 40.5 cm for males and 42.5 cm for females, while corresponding estimates for canary rockfish become 41.5 and 48.5, respectively.

Phillips' (1964) results for chilipepper and bocaccio differ widely from those in Table 5, however. Phillips reported that 50 percent of the bocaccio he examined (presumably both sexes) were mature at 41.3 cm total length (TL), far below the values obtained during the rockfish survey (44.8 cm fork length (FL) for males and 48.2 cm FL for females). As pointed out earlier, the bocaccio encountered during the survey were less advanced in their reproductive cycle than would be optimal for length-maturity studies, so that the results for this species are the least reliable presented. Further examination of the length-maturity relationships of bocaccio should be undertaken to resolve the differences between the results obtained in 1977 and those of Phillips.

The results shown in Table 5 for chilipepper also differ substantially from Phillips, and in this case the data obtained during the survey are quite reliable. The discrepancy between $l_{.50}$ values obtained for males (26.1 cm FL vs. 29.2 cm TL) can be explained to a large degree by differences in the methods used to obtain length measurements, but this is not the case with females (37.0 cm FL vs. 30.5 cm TL).

Fecundity estimates obtained by Phillips (1964) and Snytko and Borets (1972) have been plotted in Figures 3-5, to allow direct comparison with the estimates obtained in this study. Phillips measured total length for the specimens in his collection and, if his observations could readily be converted to fork length, they would all be shifted to the left somewhat. This would enhance the agreement between his results for chilipepper and those found in the current study to some degree, although geographic differences in fecundity could still be responsible for some of the differences indicated in Figure 3. This is particularly true if a substantial fraction of his specimens came from the region south of lat. 38°00′N.

In the case of yellowtail and canary rockfish, the data collected by previous workers are too limited to allow more than a general observation that their estimates are within the range of values found in the current study.

A clear difference in fecundity exists between the species examined in this paper, with yellowtail rockfish and canary rockfish being far more fecund than chilipepper of the same size. A comparison of the fecundity of the five major commercial species of rockfish off the Pacific coast is presented in Table 6.

The length-fecundity relation, size at maturity, and L_∞ information for Pacific ocean perch off Washington and Vancouver Island were obtained from Gunderson (1977), and Phillips' (1964) length-fecundity data were used to obtain a relationship for bocaccio ($F = 0.02997L^{4.1416}$, where L = length in centimeters). Westrheim and Harling's (1975) estimates of L_∞ were used for yellowtail and canary rockfish, and L_∞ for chilipepper and bocaccio were obtained from Wilkins (1980) and Phillips (1964), respectively.

Table 6.—Fecundity (F) at the size at 50 percent maturity and theoretical maximum length (L_∞) for the five species of northeast Pacific rockfish most important to commercial fishermen.

Species	L_{50} (cm)	F_{50}	L_∞ (cm)	F_∞
Pacific ocean perch	34	30,000	48.5	430,000
Yellowtail rockfish	45	490,000	53.0	1,150,000
Canary rockfish	49	820,000	56.9	1,320,000
Chilipepper	37	70,000	53.2	440,000
Bocaccio	48	280,000	81.3	2,440,000

Table 6 indicates that Pacific ocean perch and chilipepper are characterized by a much lower fecundity than the other species, a difference which must be taken into account when developing management programs for these species. Cushing and Harris (1973) have suggested that fecund species have the greatest capacity for stabilizing their numbers, so that species such as bocaccio, yellowtail rockfish, and canary rockfish should be far more resilient to intensive fishing than Pacific ocean perch or chilipepper.

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