FRI-UW-8907
July 1989

LIFE HISTORY CHARACTERISTICS OF COMMERCIALLY IMPORTANT GROUNDFISH SPECIES OFF CALIFORNIA, OREGON AND WASHINGTON

Ellen K. Pikitch
Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195

and

Jean Beyer Rogers
Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield
Marine Science Center
Newport, OR 97365

FINAL REPORT

FRI-UW-8907
July 1989

FISHERIES RESEARCH INSTITUTE
School of Fisheries WH-10
University of Washington
Seattle, WA 98195

LIFE HISTORY CHARACTERISTICS OF COMMERCIALLY IMPORTANT GROUNDFISH SPECIES OFF CALIFORNIA, OREGON AND WASHINGTON

Ellen K. Pikitch
Fisheries Research Institute
School of Fisheries WH-10
University of Washington
Seattle, WA 98195

and

Jean Beyer Rogers
Department of Fisheries and Wildlife
Oregon State University
Mark O. Hatfield
Marine Science Center
Newport, OR 97365

FINAL REPORT

Approved

Submitted 6-30-89

R. C. Fronn
Director

ABSTRACT

This report contains a detailed compilation of life history information for 15 commercially important groundfish species that are caught off the coasts of California, Oregon and Washington.

The compilation was initially developed to obtain parameter estimates needed to conduct a modeling study on the long-term effects of mesh size regulations on the west coast trawl fishery. However, the information contained herein may be useful for a number of other types of investigations. Information on stock-recruitment relationships of several of the species was not available from any source, so we developed our own parameter estimates.

Included in the compilation are parameter estimates for equations relating fish length to age, maturity, fecundity and weight. Estimates of instantaneous natural mortality rates and stock-recruitment curve parameters are also provided. The species we considered in this review are: widow rockfish (*Sebastes entomelas*), yellowtail rockfish (*Sebastes flavidus*), canary rockfish (*Sebastes pinniger*), chilipepper (*Sebastes goodei*), bocaccio (*Sebastes paucispinis*), Pacific ocean perch (*Sebastes alutus*), lingcod (*Ophiodon elongatus*), sablefish (*Anoplopoma fimbria*), Dover sole (*Microstomus pacificus*), petrale sole (*Eopsetta jordani*), English sole (*Parophrys vetulus*), rex sole (*Glyptocephalus zachirus*), arrowtooth flounder (*Atheresthes stomias*), shortspine thorney-head (*Sebastolobus alascanus*), and longspined thorneyhead (*Sebastolobus altivelis*).

CONTENTS

INTRODUCTION 1

LIFE HISTORY PARAMETERS 2

- Age and Growth 2
- Natural Mortality 2
- Maturity-Length Relationship 6
- Fecundity-Length Relationship 6
- Length-Weight Relationship 13
- Length-Girth Relationship 13
- Stock Recruitment 19
  - Stock-Recruitment Equations 19
  - Parameter Estimation Methodology 23
  - Parameter Estimates 26
  - Application 28

SELECTION OF PARAMETERS 29

- Age and Growth 29
- Natural Mortality 29
- Maturity-Length Relationship 30
- Fecundity-Length Relationship 30
- Length-Weight Relationship 31

ACKNOWLEDGMENTS 31

REFERENCES 32

LIST OF TABLES

Table Page

1. Age and growth parameter estimates of commercially important groundfish species found off the coasts of California, Oregon and Washington 3

2. Natural mortality estimates (M) and instantaneous total mortality estimates (Z) for commercially important groundfish species found off the coasts of California, Oregon and Washington 7

3. Parameter estimates for equations describing relationships between maturity and length for commercially important groundfish species found off the coasts of California, Oregon and Washington 10

4. Parameter estimates describing the relationship between length and fecundity for commercially important groundfish species found off the coasts of California, Oregon and Washington 14

5. Paremter estimates for the exponential equation describing the relationship between length and weight [length = a(weight)b] for commercially important groundfish species found off the coasts of California, Oregon and Washington 16

6. The relationship between length and the girth of roundfish or the width of flatfish (girth or width (cm) = a(length (cm) + b) based on data from the 1986 NMFS West Coast Groundfish survey (Vaga and Pikitch 1987)........ 20

7. Parameter estimates for stock-recruitment relationships for commercially important groundfish found off the coasts of California, Oregon and Washington, with estimates adjusted to the International North Pacific Fisheries Commission's Columbia Area when necessary for species commercially important to that area 21

8. Computation of the density dependent parameters (r) in the Cushing's recruitment curve (recruitment = a stock^{r}) for commercially important groundfish species based on the cube root of their fecundity at 50% maturity 27

INTRODUCTION

Understanding of the nature of the Washington, Oregon and California groundfish trawl fishery and the life history characteristics of the species it exploits is crucial for the formulation of management strategies. Differences in growth rates, age of maturity, mortality rates and other characteristics result in differences in species-specific responses to changes in fishing intensity and gear.

This review of life history characteristics was initially undertaken to obtain parameter estimates needed to conduct a modeling study on the long-term effects of mesh size regulations on the west coast trawl fishery. However, this information may also be useful for other types of investigations. The only other compilation of life history information for these species was presented in a brief summary several years ago (Pacific Fisheries Management Council[1] 1982). Our paper both updates and expands that literature review and provides life history information in sufficient detail to allow selection of parameter estimates for each species and area. Included, when available, is information on geographical locations of sample collections, year(s) and month(s) collected, sample size, range of size or age groups included in the data set and methodology used.

Using available data, we developed parameter estimates for the stock-recruitment relationships for lingcod (*Ophiodon elongatus*), rex sole (*Glyptocephalus zachirus*), and arrowtooth flounder (*Atheresthes stomias*) in the International North Pacific Fisheries Commission's (INPFC) Columbia Area, the area chosen for the initial investigation of the effects of mesh size on fishery yield. We also made adjustments to stock-recruitment relationships found in the literature for other species to make this data applicable to the Columbia Area.

Parameter estimates are given for equations relating stock abundance to recruitment, and fish length to age, age at maturity, fecundity and weight. Estimates of instantaneous mortality rates (M or Z) are also presented. Except where noted otherwise, parameter estimates were taken directly from the sources cited.

Life history characteristics were compiled for: widow rockfish (*Sebastes entomelas*), yellowtail rockfish (*Sebastes flavidus*), canary rockfish (*Sebastes pinniger*), chilipepper (*Sebastes goodei*), bocaccio (*Sebastes paucispinis*), Pacific ocean perch (*Sebastes alutus*), lingcod, sablefish (*Anoplopoma fimbria*), Dover sole (*Microstomus pacificus*), petrale sole (*Eopsetta jordani*), English sole (*Parophrys vetulus*), rex sole, arrowtooth flounder, shortspine thorneyhead (*Sebastolobus alascanus*), and longspined thorneyhead (*Sebastolobus altivelis*).

---

[1] Available from PFMC, 12000 SW First Avenue, Portland, OR 97201.

When available, parameter estimates based on data collected off the coasts of California, Oregon and Washington were used; otherwise, Canadian data were sought.

LIFE HISTORY PARAMETERS

Age and Growth

The most commonly used equation to describe the relationship between age, t, and length at age, l_t, is the von Bertalanffy (Gulland 1964) equation:

$$l_t = L_\infty (1 - e^{-K(t-t_0)})$$

where L_∞ , K, and t_0 are model input parameters.

Another equation used to describe growth (McClure 1982; Six and Horton 1977) is the exponential formula:

$$l_t = a(t)^b$$

where a and b are model input parameters.

Fish age was primarily determined by counting annual rings on scales or otoliths. Otolith readings are preferred for determining age of long-lived groundfish species since scales on older fish are difficult to interpret and subject to regeneration (Kimura et al. 1979; Six and Horton 1977). Growth parameter estimates are generally not greatly affected by the ageing method used, however, since growth of many fishes diminishes significantly at an age substantially less than that of maximum longevity (Archibald et al. 1981).

Undoubtedly, significant annual variation in growth rates occurs for these species due to changing environmental conditions or density dependent effects. However, insufficient information was available to assess the extent of such variation. Parameter estimates for length-age equations are summarized in Table 1.

Natural Mortality

Estimation of the instantaneous natural mortality rate (M) of exploited populations is difficult. Assuming independence of natural and fishing mortality, an estimate of M can be obtained if the

Table 1. Age and growth parameter estimates of commercially important groundfish species found off the coasts of California, Oregon and Washington.

Area	Years (months) collected	Sex	von Bertalanffy's equation[1]			Range (ages)	n	Ageing[4] method	Source
			L_∞	k	t_o				
Widow rockfish									
CA, OR, WA	80-82	M	46.7394	0.1650	-1.9355	3.8-21	2184	SS	Lenarz 1987
	80-82	F	51.5690	0.1501	-1.4109	3.8-23	2003	SS	
CA		Both	49.748	0.21456	-0.1148	0-14	151(921)	SC	Phillips 1964[3]
Canary rockfish									
CA OR, WA	80	M	52.12	0.1878	0.1693	2-60	516	SE	Wilson 1984
		F	57.70	0.1624	0.1435	2-34	363	SE	
Columbia area	80-82	M	51.29	0.162	-2.634	6-35	1311	BB	Golden and Demory 1984
		F	57.32	0.152	-1.221	6-35	907	BB	
N.CA-WA	77-78	M	55.72	0.178	0.596		817	SU	Boehlert 1980
		F	66.11	0.118	-0.240		557	SU	
OR	72, 74 (2 readings)	M	53.60-	0.185517-	0.6810-	2-22		SU	Six and Horton 1977
		M	53.50	0.183965	0.5421			SU	
		F	60.95-	0.146062-	0.5367-	3-23		SU	
		F	57.43	0.177790	0.8960			SU	
CA		Both	63.34	0.12235	-0.4021	0-16	143(1285)	SC	Phillips 1964[3]
Chilipepper									
CA OR, WA	77	M	38.66	0.30	-0.15	2-11	958	SU	Wilkins 1980
		F	53.19	0.18	-0.43	2-15	1194	SU	
CA		Both	52.018	0.18204	-0.2283	0-15	138(960)	SC	Phillips 1964[3]
Bocaccio									
CA OR, WA	77	M	76.58	0.13	-1.81	4-10	199	SU	Wilkins 1980
		F	87.76	0.11	-1.73	3-11	187	SU	
CA		Both	76.342	0.14784	-0.6439	0-16	155(1008)	SC	Phillips 1964[3]

Table 1 - continued.

Area	Years (months) collected	Sex	von Bertalanffy's equation[1]			Range (ages)	n	Ageing[4] method	Source
			L_∞	k	t_o				
Pacific ocean perch									
Columbia area	77	M	45.74	0.110	-4.36	6-18	621	SU	Golden et al. 1980
		F	49.53	0.100	-4.24	6-18	548	SU	
Vancouver area (100-149m)		M	42.30	0.170	-1.64	6-18	304	SU	"
(150-199m)		M	46.17	0.080	-8.65	7-18	176	SU	"
		F	49.39	0.097	-4.97	6-18	191	SU	"
WA	72	M	43.15	0.1320	-2.1186	2-22	836	SU	Gunderson 1977
		F	48.47	0.0908	-3.5041	2-24	843	SU	
Yellowtail rockfish									
CA OR, WA	77	M	49.04	0.209	-0.185	5-22	2684	SU	Fraidenburg 1980[a]
		F	55.54	0.163	-0.250	5-21	1527	SU	
WA	75-77	M	42.0	0.35	0.40	3-7	29	SU	Barker 1979
		F	51.0	0.18	0.89	3-7	34	SU	
		Both	41.0	0.36	0.55	1-7	152	SU	
CA		Both	49.25	0.17249	-0.3219	0-17	140(1120)	SC	Phillips 1964
Lingcod									
N.CA	67-71	M	85(TL)	0.214	-1.33		126	SU	Miller and Geibel 1973
		F	154.6(TL)	0.087	-1.70		112	SU	
Sablefish									
WA OR	85	M	67.588	0.13278	6.082	2-14	661		Parks and Shaw 1987
		F	79.509	0.13171	-4.463	2-23	553		
Rex sole									
OR	69, 71	M	33.42(TL)	0.1778	0.8551	2-10	257	SU	Hosie 1975
		F	37.21(TL)	0.1749	0.5667	2-13	234	SU	
OR	71-74 (6-9)	M	31.10(TL)	0.2274	-0.36			SU	Demory et al. 1976
		F	38.50(TL)	0.1454	-1.19			SU	

Table 1 - continued.

Area	Years (months) collected	Sex	von Bertalanffy's equation[1] L_∞	k	t_o	Range (ages)	n	Ageing[4] method	Source
Dover sole									
OR	71-74	M	44.08	0.2186	-0.02			SC	Demory et al. 1976
		F	60.70	0.1110	-0.18				
Petrale sole									
OR	71-74	M	45.4	0.2018	-1.82			SC	Demory et al. 1976
		F	54.4	0.219	0.08				
English sole									
OR	71-74	M	36.3	0.256	-1.08			IO	Demory et al. 1976
		F	42.6	0.265	-0.40				
Arrowtooth flounder									
OR	71-74	M	43.10	0.3481	-1.37			SU	Demory et al. 1976
		F	68.80	0.1562	-0.46				

Area	Years collected	Sex	Exponential equation[2] a	b	Range (ages)	n	Ageing[4] method	Source
Yellowtail rockfish								
OR	78-80	Both	13.7965	0.52966	3-8	77	SU	McClure 1982
OR (2 readings)	73-74	M	27.9962-	0.18068-	6-21		SU	Six and Horton 1977
		M	28.4118	0.17206	6-21		SU	
		F	25.0841-	0.26386-	6-20		SU	
		F	23.6646	0.28150	6-20		SU	

[1] $FL(cm) = L_\infty[1-e^{-k\,(age - t_o)}]$.

[2] $FL(cm) = a\ Age^{\,b}$

[3] Sample size in parentheses (n) is number of back-calculations; TL converted to FL using equations from Echeverria and Lenarz (1982).

[4] Ageing method:
- SU = surface otoliths
- SE = section otoliths
- BB = break and burn otoliths
- SC = scales
- SS = surface with difficult to read otoliths sectioned
- IO = interopercular bones

total instantaneous mortality rate (Z) and the instantaneous fishing mortality rate (F) are known. Estimates of Z are often obtained via examination of catch curves (e.g., see Ricker 1975).

Subtraction of estimates of F from Z was used to estimate M in many of the sources reviewed (Table 2). Lingcod was the only species for which F was estimated by tagging. Poor survival resulting from stress induced by capturing fish from extreme depths limits the usefulness of tagging studies for many groundfish species. Hightower and Lenarz (1986) and Fraidenburg (1981) estimated M directly from catch curves for widow and yellowtail rockfish, respectively. In both cases only data from older fish that were alive before the species were targeted on were used. Some investigators used means other than catch curves to estimate M (Table 2).

In contrast to growth parameters, estimates of natural mortality are sensitive to the ageing methodology used in determining them. There is an inverse relationship between natural mortality and longevity (Hoenig 1983) thus surface otolith readings, which tend to underestimate longevity, often result in overestimates of M (Archibald et al. 1981). Estimates of M have therefore been revised recently for many species using cross-sectioned otolith readings.

Maturity-Length Relationship

Most sources (see Table 3) expressed maturity-length relationships via the equation:

$$\text{Proportion mature at length } l = \frac{1}{1 + e^{al + b}}$$

where a and b are constants.

Some references only provided information on length of first maturity for individual fish or length at 50% or 100% maturity for a given year class.

Table 3 provides information on length-specific maturity in the form(s) given in the original sources. The species included in this review are thought to spawn once per year, except for bocaccio, which may spawn twice a year (Moser 1967).

Fecundity-Length Relationship

Fecundity at length is usually expressed as an exponential relationship:

$$E = a(l)^b$$

Table 2. Natural mortality estimates (M) and instantaneous total mortality estimates (Z) for commercially important groundfish species found off the coasts of California, Oregon and Washington.

Area	Years collected	Sex	Range (ages)	M	Z	n	Ageing[2] method	Data analysis method	Source
Widow rockfish									
				0.15-0.20		10,000	SU	catch curve of unfished population	Hightower and Lenarz 1986
Yellowtail rockfish									
OR, BC WA	67-83			0.075-0.10				most reasonable based on trials	Taggart 1985
				0.125				basis not stated	Swartzman et al. 1985
OR	78-80		>5		0.548		SU	catch curve (hook and line, recreation and research)	McClure 1982
WA	75-77		13-18	0.25		58	SU	catch curve of unfished population (trawl, commercial and research trawl, commercial)	Fraidenburg 1981
OR	73-74 (2 readings)		14-18		.29-.40		SU	catch curve (com(mercial trawl)	Six and Horton 1977
Canary rockfish									
OR, WA	80-84		15-35		0.115		BB	catch curve (trawl, commercial)	Golden and Demory 1984
CA, OR WA	80	M	12-60	0.005	0.089	967	SE	catch curve (trawl,research)	Wilson 1984
		F	12-34	0.091	0.178	1464	SE		
OR	73-74 (2 readings)		15-23		0.26-0.27		SU	catch curve (commercial trawl)	Six and Horton 1977
OR	78-80		8-18		0.262		SU	catch curve (hook and line, research and recreation)	McClure 1982

Table 2 - Continued.

Area	Years collected	Sex	Range (ages)	M	Z	n	Ageing[2] method	Data analysis method	Source
Canary rockfish - continued									
CA, OR WA	77	M F	14-19 14-20		0.564 0.615		SU	catch curve (trawl, research)	Boehlert[1] 1980
Chilipepper									
				0.20				based on V-B growth (k = 0.18) and max age 29 years	Henry 1985
Bocaccio									
CA				0.25					Thomas 1985
Pacific ocean perch									
				0.05			BB	based on max age 70-90 years	Ito et al. 1986
WA	66-72			0.20			SU	catch curve (trawl, commercial and research)	Gunderson 1977
Lingcod									
WA	76			0.23-0.31	0.40	35 41 tags	SU	tagging and catch curve (recreation)	Barker 1979
Sablefish									
BC				0.10				basis not stated, estimate used	McFarlane et al. 1985
Rex sole									
OR	71-74	M F	6-16 6-16		0.64 0.51		SU	catch curve	Hosie 1975
OR	71-74	M F	7-16 7-18		0.56 0.50		SU	catch curve	Demory et al. 1976
WA	75-76	M F	5-18 5-14		0.41-0.58 0.43-0.55		SU	catch curve	Barss et al. 1977
OR				0.20				life history	PFMC 1982

Table 2 - Continued.

Area	Years collected	Sex	Range (ages)	M	Z	n	Ageing[2] method	Data analysis method	Source
Dover sole									
				0.15					Demory et al. 1984
Petrale sole									
		M		0.25					Demory 1984a
		F		0.20					
English sole									
		M		0.26					Demory 1984a
		F		0.26					
Arrowtooth flounder									
OR	71-74	M	4-20		0.37		SU	catch curve	Demory et al. 1976
		F	4-22		0.34				
WA	75-76	M	6-17		0.35-0.42		SU	catch curve	Barss et al. 1977
		F	7-23		0.16-0.42				
OR				0.20				life history	PFMC 1982

[1] Data analyzed by Wilson (1984).

[2] Ageing method:
SU = Surface otoliths
SE = Sectioned otoliths
BB = Break and burn otoliths

Table 3. Parameter estimates for equations describing relationships between maturity and length for commercially important groundfish species found off the coasts of California, Oregon and Washington.

Area	Years (months) collected	Sex	Constants[1]		n	Average length (cm) at maturity[2]			Source
			a	b		1st	50%	100%	
Widow rockfish									
CA	80-82	M	-0.3390	15.4551	2467	58.5(TL)	58.5(TL)		Echeverria 1987[3]
		F	-0.8372	33.8270					
CA	77-82	M			1237	25	32	46	Barss and
		F			1165	25	33	46	Echeverria 1987
OR	79-80	M			688	31	33	38	
		F			646	35	38	43	
CA		Both			466	30	31		Phillips 1964[3]
Yellowtail rockfish									
CA	80-82	M	-0.4063	12.8487	2310				Echeverria 1987[3]
		F	-0.4439	14.7270					
WA	77(9)	M	-0.3684	14.9884	199				Gunderson et al.
	75-78	F	-0.5315	23.9411	186				1980
	(12-4)								
CA		Both				450	27	32	Phillips 1964[3]
Canary rockfish									
CA	80-82	M	-0.3036	12.3699	1205				Echeverria 1987[3]
		F	-0.6310	13.984					
OR	78-80	M				39	39		McClure 1982
	(6-9)	F				43	43		
WA	77(9)	M	-0.4694	18.5360	199				Gunderson et al.
	75-78	F	-0.6171	30.3776	186				1980
	(1-4)								
CA	M						34		Phillips 1964[3]
	F				613	24	34		
Chilipepper									
CA	80-82	M	-0.3218	7.0105	2568				Echeverria 1987[3]
		F	-0.3953	11.3170					

Table 3 - continued.

Area	Years (months) collected	Sex	Constants[1]		n	Average length (cm) at maturity[2]			Source
			a	b		1st	50%	100%	
Chilipepper - continued									
CA	77 (7-8)	M	-0.3028	7.8943	485				Gunderson et al. 1980
		F	-0.6982	25.8478	243				
CA		M			783		25		Phillips 1964[3]
		F				21	27		
Bocaccio									
CA	80-82	M	-0.2564	10.7040	3806				Echeverria 1987[3]
		F	-0.2876	13.7028					
CA		Both			711	34	39		Phillips 1964[3]
CA	77-82	M			85		28	32	Echeverria 1987
		F				26	26	32	
Pacific ocean perch									
WA	68-72	M	-0.7057	20.7327	551				Gunderson 1977
		F	-0.7546	25.8327	211				
Lingcod									
CA	67-71 (12-2)	M			111	39(TL)	59(TL)		Miller and Geibel 1973
		F			180	51(TL)		76.5(TL)	
CA	(10-11)	M			64	58.5(TL)			Phillips 1959
		F			55	58.5(TL)			
Sablefish									
CA	80-82	M	-0.37	18.29			50.0		Fujiwara 1985 (est. from widest depth range)
		F	-0.32	17.47			55.0		
WA, OR	85 (8-9)	M						50.8	Parks and Shaw 1987
		F						55.3	
CA	80-82	M			1038			54.8	Parks and Shaw 1983
		F			1520			56.3	
		Both						55.8	
CA	43-52	M					23.5	26.7	Phillips and Imamura 1954
		F					26.3	30.0	
Rex sole									
OR	69-73 (9-10)	M				13(TL)	16(TL)	21(TL)	Hosie 1975
		F				16(TL)	24(TL)	30(TL)	

Table 3 - continued.

Area	Years (months) collected	Sex	Constants[1]		n	Average length (cm) at maturity[2]			Source
			a	b		1st	50%	100%	
Dover sole									
Col.A	85-86 (12-1)	F			370	24(TL)		32(TL)	Yoklavich and Pikitch 1988
Col.A	80-81							37(TL)	Demory et al. 1984
OR	48-50 (5-10)				2086	33(TL)	38(TL)	42(TL)	Harry 1959
CA	49	M			295	30(TL)	32(TL)	39(TL)	Hagerman 1952
		F			846	33(TL)	35(TL)	45(TL)	
Petrale sole									
OR	48-51	M			267	29(TL)	36(TL)	38(TL)	Harry 1959
		F			1492	31(TL)	40(TL)	45(TL)	
CA	59-62	F				35(TL)		42(TL)	Porter 1964
English sole									
OR	50-51	M			27	18(TL)	26(TL)	29(TL)	Harry 1959
		F			2090	26(TL)	31(TL)	35(TL)	
Arrowtooth flounder									
BC	80	M			672	30	31	42	Fargo et al. 1981
	(6)	F				29	37	43	
OR							42		PFMC 1982
Longspine thornyhead									
C.CA	60	M			32	25(TL)		28(TL)	Best 1964
		F			18	27(TL)		28(TL)	
OR	79-82	M			23			25	Barss†
		F			20			25	
Shortspine thornyhead									
OR	79-82	M			500		<17	26	Barss†
		F			600		22	44	

[1] Proportion mature at length = $\frac{1}{1 + e^{ax + b}}$
where x=FL(cm)

[2] Length measurements are fork lengths, FL, except where indicated as (TL) (total length).

[3] TL converted to FL using equation from Echeverria and Lenarz (1982)

†Barss, W., personal communication, March 1987, Oregon Dep. Fish Wildl., Newport, OR (unpubl. data).

where E is number of eggs, l is length, and a and b are constants. Some sources used the linear equation:

$$E = a + b(l)$$

to describe the relationship between egg production and length. Fish below the size at 50% maturity were often not used to derive the relationship, either because of lack of availability or exclusion because differentiation of mature and immature fish at small sizes is difficult and can lead to underestimation of fecundity (Gunderson et al. 1980). We fit data presented in Phillips (1964), Harry (1959), and Porter (1964) to the exponential model, to obtain parameter estimates for some of the species (Table 4). Other estimates in Table 4 were taken directly from the sources cited.

Length-Weight Relationship

In all sources reviewed, the length-weight relationship for all species was expressed by:

$$W = a(L)^b$$

where W is weight, L is length and a and b are estimated parameters (Table 5). The relationship can vary due to changes in maturity, season, stomach fullness, or environmental conditions (Bagenal and Tesch 1978), so it is important to use parameters estimated from representative data when possible.

Length-Girth Relationship

Although the relationship between length and girth (or width) has not traditionally been included in life history characteristics of fish, it can be used to relate other characteristics based on length to gear selectivity. A given trawl net mesh size, for instance, would be more likely to select groundfish based on their girth and flatfish based on their width than on length. Girths or widths selected can be converted to lengths for each species and sex j, using equations of the form:

$$g_j = a(l_j) + b$$

where g is girth or width, l is length, and a and b are constants.

Table 4. Parameter estimates describing the relationship between length and fecundity for commercially important groundfish species found off the coasts of California, Oregon and Washington.

	Month(s)	Year(s)	Exponential equation[1]			Range in fork	
Area	collected	collected	a	b	n	lengths (mm)[3]	Source
Widow rockfish							
CA	10-12	58-59	0.002693	4.98789	20	309-503	Phillips 1964[†]
OR	12-1	80-81	0.001	5.431	64	333-520	Boehlert et al. 1982
Yellowtail rockfish							
CA	10-1	58-61	0.007834	4.691782	15	287-519	Phillips 1964[†]
Canary rockfish							
CA	10-12	58-60	0.123946	4.013613	10	469-653	Phillips 1964[†]
Chilipepper							
CA	10-12	58-60	0.013358	4.360991	23	292-539	Phillips 1964[†]
Bocaccio							
CA	10-2	58-60	0.001878	4.878193	24	359-724	Phillips 1964[†]
Pacific ocean perch							
OR-WA	11-3	67-68	0.131×10^{-5}	4.98838	171		Snytko 1971
WA	9-11	51-52	4.8556×10^{-15}	6.33454	13		Westrheim 1958
OR WA	8-9	73	0.193×10^{-9}	7.32506	41		Gunderson 1977
Lingcod							
BC		38-42	0.2831	3.0011	55	741-1175	Hart 1967
Sablefish							
BC	2	81	1.11987	2.8244	220	579-1150	Mason et al. 1983
Rex sole							
OR	2	70	0.0091	4.22667	13		Hosie 1975
Dover sole							
N.OR	12	85	0.3892	3.19	57	345-500	Yoklavich and Pikitch 1988
Petrale sole							
OR	8,12	63	-1.9346	3.980	50	305-510	Porter 1964[†]
English sole							
OR		49-50	0.620811	3.60802	15	300-430	Harry 1959[†]

Table 4 - continued.

Area	Month(s) collected	Year(s) collected	Linear equation[2] a	b	n	Range in fork lengths (mm)[3]	Source
Widow rockfish							
OR	12-1	80-81	-1,999,220	59,182.4	64	333-520	Boehlert et al. 1982
Yellowtail rockfish							
WA	9	77	-3,235,161	82,721.8	49	440-570	Gunderson et al.1980
Canary rockfish							
CA WA	8-9	77	-2,330,029	64,221.3	56	490-640	Gunderson et al.1980
Chilipepper							
N. CA	8	77	-870,717	24,297.4	22	380-520	Gunderson et al.1980
C. CA			-658,047	20,809.4	61	380-510	
Bocaccio							
CA	1-4	61	-901,943	24,299	13		MacGregor 1970†
Dover sole							
OR	10-12	42-57	-338463	9420	22	420-570	Harry 1959
Petrale sole							
OR	8	63	-356,503	2310	12	410-510	Porter 1964
OR	12	63	-1,665,654	5030	38	305-500	
CA	10	63	-2,526,700	7500	30	320-520	

Area	Month(s) collected	Year(s) collected	Number of eggs	n	Range in fork lengths (mm)[3]	Source
Dover sole						
CA		49	37,188-229-615	8	362-504	Hagerman 1952
Petrale sole						
OR			98,000 at 36-40 cm TL			PFMC 1982
Arrowtooth flounder						
OR			1,000,000 at 42 cm			PFMC 1982

[1] $F(eggs) = a (FL (cm))^b$

[2] $F(eggs) = a + b (FL(cm))$

[3] TL converted to FL as needed using equations from Echeverria and Lenarz (1982).

†Equation calculated from data in publication.

Table 5. Parameter estimates for the exponential equation describing the relationship between length and weight ($\text{weight} = a(\text{length})^b$) for commercially important groundfish species found off the coasts of California, Oregon and Washington.

Area (year) collected	Sex	Constants a	Constants b	Constants n	Range in fork lengths (cm)[1]	Source
Widow rockfish						
CA	Both	0.0045	3.34091	45	10-51	Phillips 1964[†]
Yellowtail rockfish						
OR (78-80)	Both	0.0510	2.646	17 M	20-54	McClure 1982
				40 F	25-54	
N.CA-B.C. (75-77)	M	0.0173	2.97	949	30-55	Fraidenburg 1980[b]
	F	0.0092	3.14			
WA (75-77)	Both	0.0044	3.20728	145	8-43	Barker 1979
Canary rockfish						
Combined Area	M	0.0848	2.596	1294		Golden and Demory 1984
	F	0.0652	2.665	776		
	Both	0.0623	2.677	2214		
OR (78-80)	M	0.0564	2.707	138	15-59	McClure 1982
	F	0.0222	2.958	196	20-59	
	Both	0.0127	3.120	334		
CA	Both	0.0117	3.10728	67	10-71	Phillips 1964[†]
Chilipepper						
CA	Both	0.0072	3.19899	47	9-52	Phillips 1964[†]
Bocaccio						
CA	Both	0.0079	3.1067	711	17-78	Phillips 1964[†]
Pacific ocean perch						
OR (50-52)		0.0103	3.08686	371		Alverson and Westrheim 1961
Lingcod						
WA	Both	0.007177	3.0687	238	(TL)	Bargmann 1982
WA	M	0.0852	3.24	59	(TL)55-87	Wendler 1953
	F	0.0303	3.12	150	(TL)53-109	

Table 5 - continued.

Area (year) collected	Sex	Constants			Range in fork lengths (cm)[1]	Source
		a	b	n		
Sablefish						
WA OR(85)	Both	0.00366	3.24316	1270	10-95	Parks and Shaw 1987
CA (80-82)	Both	0.00203	3.39	414		Fujiwara 1985
Rex sole						
OR	M	0.0097	3.4782	950	11-50	Hosie 1975[††]
(69-72)	F	0.00100	3.4743	1121		
OR	M	0.00088	3.5428		(TL)	Demory et al. 1976
(71-74)	F	0.00090	3.5269		(TL)	
WA	M	0.00098	3.51367		(TL)	Barss et al. 1977
(75-76)	F	0.00081	3.57285		(TL)	
Dover sole						
OR	M	0.0134	2.8911		(TL)	Demory et al. 1976
(71-74)	F	0.0102	2.9655		(TL)	
N. OR (85)	F	0.00595	3.083	115	28.7-55(TL)	Yoklavitch and Pikitch 1988
WA	M	0.0108	2.95833			Barss et al. 1977
(75-76)	F	0.0075	3.06697			
N. CA (48-49)	M	0.0111	2.945861	488 (19 averages)	33-52(TL)	Hagerman 1952[†]
	F	0.0108	2.972811	1,738 (32 averages)		
Petrale sole						
OR	M	0.0040	3.2812		(TL)	Demory et al. 1976
(71-74)	F	0.0030	3.3760		(TL)	
WA	M	0.0077	3.135			Barss et al. 1977
(75-76)	F	0.0036	3.348			
English sole						
OR	M	0.0078	3.0132		(TL)	Demory et al. 1976
(71-74)	F	0.0022	3.4003		(TL)	
WA	M	0.0155	2.83217			Barss et al. 1977
(75-76)	F	0.0080	3.04795			

Table 5 - continued.

Area (year) collected	Sex	Constants a	 b	 n	Range in fork lengths (cm)[1]	Source
Arrowtooth flounder						
OR (71-74)	M F	0.00878 0.00268	2.9822 3.3160			Demory et al. 1976
WA (75-76)	M F	0.00321 0.00342	3.26895 3.26485			Barss et al. 1977
Longspine thornyhead						
CA (60)	Both	0.00211	2.90152	50	(TL)	Best 1964

[1] Length measurements are fork lengths, FL, except where indicated by TL (total length).

† Data reanalyzed to convert to g and FL(cm).
†† values are averages of quarterly seasonal values.

FL(cm) conversion from TL(cm) using equations from Escheverria and Lenarz (1982).

Data on girth of groundfish and width of flatfish at length from a west coast National Marine Fisheries Service (NMFS) survey[2] conducted in 1986 were used to estimate the constants in the equation for all species reviewed except longspine thorneyhead (Vaga and Pikitch 1987) (Table 6). Girth measurements in the data were taken at point of maximum circumference, while width measurements were taken at point of maximum width.

Stock Recruitment

Understanding of stock-recruitment relationships is presently in the developmental stage for most of the species reviewed. Equations describing the stock-recruitment relationships were found from outside sources for all the species except lingcod, rex sole, arrowtooth flounder, bocaccio and the *Sebastolobus* species (Table 7).

Stock Recruitment Equations

Both the Cushing (1971) recruitment equation and the Beverton and Holt (1957) equation have been used to describe the relationship between stock and recruitment for the species reviewed. Those equations have been selected because they are consistent with the assumption that in the ocean environment increases in fish stock abundance will never lead to decreases in recruitment. Attempts to determine the actual shapes of the stock-recruitment curves from the limited data available for these species have thus far apparently been unsuccessful.

The Cushing and Beverton-Holt curves are very similar except that the Beverton-Holt curve is more sensitive to reductions in stock size at low stock levels (Kimura 1988). Kimura demonstrated that the equations can be expressed in such a manner that the only difference between the parameters of the two equations is a so-called shape parameter. He gave the equations in a form where recruitment in year i (R_i) is expressed as a function of the recruitment from an unfished, equilibrium (virgin) stock (R_1), the proportion of the virgin biomass remaining at time i-k (B_{i-k}/B_1), where k = age at recruitment, and the shape parameter (r or A):

Cushing $$R_i = R_1 (B_{i-k}/B_1)^r \qquad (1)$$

Beverton-Holt $$R_i = R_1 (B_{i-k}/B_1)/(1-A(1-B_{i-k}/B_1)) \qquad (2)$$

---

[2] Data obtained from Mark Wilkins, NMFS, RACE Division, 7600 Sand PointWay NE, Seattle, WA 98115.

Table 6. The relationship between length and the girth of roundfish or the width of flatfish (girth or width (cm) = a(length (cm)) + b) based on data from the 1986 NMFS West Coast Groundfish survey (Vaga and Pikitch 1987).

Species	Sex	Constants	
		a	b
Widow rockfish	F	0.6777	-2.5353
	M	0.6616	-2.0517
Yellowtail rockfish	F	0.7297	-3.0721
	M	0.7678	-4.3694
Canary rockfish	F	0.7087	-0.2662
	M	0.6968	-0.2147
Chilipepper	F	0.7012	-33.2951
	M	0.6176	-17.6703
Bocaccio	F	0.6602	-50.9341
	M	0.6262	-38.1779
Pacific ocean perch	F	0.7491	-3.4916
	M	0.7202	-2.4867
Lingcod	F	0.5273	-5.8654
	M	0.5326	-5.6662
Sablefish	F	0.5621	-6.6691
	M	0.5255	-4.8213
Rex sole	F	0.3283	-18.2834
	M	0.3119	-14.3119
Dover sole	F	0.3283	-1.4664
	M	0.3238	-1.1350
Petrale sole	F	0.4831	-3.6229
	M	0.4547	-2.5211
English sole	F	0.3679	-1.2906
	M	0.3460	-0.7984
Arrowtooth flounder	F	0.3313	-0.9756
	M	0.2795	2.3167
Shortspine thornyhead	F	0.5587	-8.8290
	M	0.6308	-29.0228

Table 7. Parameter estimates for stock-recruitment relationships for commercially important groundfish found off the coasts of California, Oregon, and Washington, with estimates adjusted to the International North Pacific Fisheries Commission's Columbia Area when necessary, for species commercially important to that area..

Species	Area for which original biomass estimates were derived	Adjustment factor[1]	$\frac{r(0.5)}{(1.0)}$[2]	Recruitment parameters[3] Beverton-Holt A	Recruitment parameters[3] Cushing r	Columbia area virgin biomass B_1	Virgin recruitment R1 Millions Females	Virgin recruitment R1 Millions Males	Virgin recruitment R1 Metric tons	Age at recruitment k	Natural mortality M	Source
Widow rockfish	CA-WA	.56	0.9	0.889	0.15	90,720	00.00	00.00	14,280	5	0.15	Hightower[†]
Yellowtail rockfish	Columbia area	1.0	0.84	0.81	0.25	55,500- 61,400			3,089- 3,845	10	0.075- 0.10	Taggart 1985
Canary rockfish	Columbia area	1.0	1.0	1.00	0.00	24,484- 47,309			2,330- 4,502	10	0.10	Golden 1984
Chilipepper	CA	-	0.9	0.889	0.15					3	0.20	Henry[††]
Pacific ocean perch	Columbia area	1.0	0.71- 0.84	0.59- 0.81	0.25- 0.50	70,000- 77,500			5,284- 5,532	10	0.05	Ito et al. 1986
Sablefish	CA-WA	.29	0.9	0.889	0.15	67,135			5,522	3	0.10	McDivitt[†††]
Dover sole	Area 2B	3.33	1.0	1.00	0.00		45.16	36.43	4,556	5		Pikitch 1987
English sole	Area 2B	3.33	1.0	1.00	0.00		18.12	2.60	328	1		Pikitch 1987

Table 7 - Continued.

Species	Area for which original biomass estimates were derived	Adjustment factor[1]	$\frac{r(0.5)}{(1.0)}$[2]	Recruitment parameters[3] Beverton-Holt A	Cushing r	Columbia area virgin biomass B1	Virgin recruitment R1 Millions Females	Males	Metric tons	Age at recruitment k	Natural mortality M	Source
Petrale sole	Area 2B	3.33	1.0	1.00	0.00		7.76	12.52	891	1		Pikitch 1987
Lingcod	Columbia area	1.0	0.95	0.95	0.073	10,000-11,000			1,460-1,606	7	0.27	Present study
Rex sole	Cape Blanco-Col R,OR	1.35	0.70	0.75	0.083	15,744-16,376*			2,157-2,244	10	0.20	Present study
Arrowtooth flounder	Cape Blanco-Col R,OR	1.35	0.999	0.999	0.002	10,207-10,475*			582-597	4	0.20	Present study

[1] Multiplier applied to original biomass and recruitment estimates to obtain estimates for the Columbia area.

[2] $\frac{r(0.5)}{(1.0)}$ = proportional reduction in recruitment relative to virgin recruitment when biomass is reduced to 50% of virgin biomass (Kimura 1980). Note, most values were assumed by sources rather than estimated from data.

[3] A and r estimates were obtained by substituting $\frac{r(0.5)}{(1.0)}$ for $\frac{R_i}{R_1}$ in equations (1) and (2), respectively.

† Hightower, J.E., personal communication, February 1987, National Marine Fisheries Service, Tiburon, CA.

†† Henry, F.D., personal communication, February 1987, California Department of Fish and Game, Menlo Park, CA.

††† McDivitt, S., personal communication, February 1987, National Marine Fisheries Service, 7600 Sand Point Way, Seattle, WA 98115-6349.

* Demory et al. 1976.

Parameter Estimation Methodology

Virgin biomass and resulting recruitment biomass were generally estimated by outside sources using either an age-structured model (Hightower and Lenarz 1986), or Stock Reduction Analysis (SRA) which does not require knowledge of the age-structure of the catch (Kimura et al. 1984, Kimura 1985, Kimura 1988). Pikitch (1987), however, assumed equilibrium conditions for Dover sole, petrale sole and English sole during a specific time period, and estimated recruitment from virgin biomass by dividing actual landings by the landings-per-recruit that would be expected for the age at entry and fishing mortality rate estimated for that time period. For purposes of comparison, the estimates of Pikitch (1987), given in numbers of fish, were converted to metric tons. This was done by multiplying the number of fish by the average weight at age of recruitment, which were calculated from the equations for age-length and length-weight (Tables 1 and 5).

Biomass estimates used in this report were from different areas, making comparisons between species difficult. Since the Columbia Area was chosen for the initial investigation of the effects of mesh size on yield, an attempt was made to adjust the given biomass estimates to reflect actual biomass in that area. When the estimates pertained only to a part of the Columbia Area, as for Dover sole, petrale soleand English sole, they were extrapolated based on relative geographic area. That is:

$$B_{col} = B_A \, (G_{col}/G_A) \qquad (3)$$

where B_{col} is the biomass estimated for the Columbia Area, B_A is the biomass estimated for the area given in the literature, G_{col} is the geographic area of the Columbia Area, and G_A is the geographic area of the area given. In cases where the estimates were given for an area greater than the Columbia Area, as for widow rockfish and sablefish, the proportion of the total biomass attributed to the Columbia Area was estimated using relative biomass estimates from the 1980 NMFS survey data (Coleman 1986).

For chilipepper, the estimates in the literature were based on an area outside of the Columbia Area. Since that species was not considered commercially important to the Columbia Area, it was not included in the initial investigation and no attempt was made to adjust the estimates.

The shape parameters given by outside sources were usually based on assumptions about the proportion of the recruitment from virgin stock (R_i/R_1) that is present when the virgin biomass is reduced by 50% (B_{i-k}/B_1=0.5). This assumption is referred to as r(0.5/1.0). Shape parameters based on a range of assumptions were usually tested; the values recorded were those judged reasonable by the sources.

To allow comparison of the stock-recruitment relationships of the species when Cushing shape parameters were given, the relationships were converted to "equivalent" Beverton-Holt shape parameters and vice versa. The converted equations are equivalent in the sense that they yield the same recruit biomass ratio (R_i/R_1) for a spawning stock biomass equal to one-half the virgin stock biomass. The conversion was accomplished by solving Equations (1) and (2), with R_i/R_1 equal for both equations and B_{i-k}/B_1 set equal to 0.5, yielding the following relationship between the shape parameters:

$$A = 2 - (1/0.5^r) \tag{4}$$

where A is the Beverton-Holt parameter and r is the Cushing parameter.

We also developed an independent method of estimating the shape parameters for the equations based on Cushing's (1971) empirical finding that the strength of the relationship between stock abundance and recruitment varies among species in relation to their fecundity. Cushing (1971) found an inverse relationship between the cube root of the fecundity of the average sized mature female and the Cushing recruitment shape parameter r. His data included negative values of r at extremely high fecundities, indicating that beyond a certain point increases in stock abundance could cause a reduction in recruitment. As stated earlier, this is unlikely to occur in the ocean environment. Cushing's data were therefore reanalyzed with negative values of r changed to 0.01, a value which indicates minimal effects of stock size on recruitment. The modified data were fit to a negative exponential equation (See Equation (7) below). Since the actual average size of a reproductive female was not available for the species reviewed, fecundities at sizes of first and 50% maturity were tested in the resulting equation. The size criteria picked was the one which led to values most comparable to those found in the literature.

Stock-recruitment relationships for lingcod, rex sole, arrowtooth flounder, the *Sebastolobus* species, and bocaccio were not available from any source. Bocaccio was not deemed to be commercially important to the Columbia Area, so no attempt was made to develop a relationship for that species. Sufficient information was not available on the *Sebastolobus* species to allow any estimates of the stock-recruitment relationship to be made, although they do comprise a significant share of Columbia Area landings.

Estimates were derived for lingcod, rex sole and arrowtooth flounder in the Columbia Area based on the limited information available. Our methods for estimating the shape parameters and virgin recruitment biomasses were the same for all three species, but our method of estimating virgin stock biomass differed for lingcod and the other two species. Estimates of the shape parameters (r) were derived from Equation (7) using fecundity at the size of 50% maturity. The values for r for the Cushing recruitment equation were then converted to equivalent values for A for the Beverton-Holt equation using Equation (4).

Recruitment from virgin biomass was estimated for all three species using Kimura's (1985) Equation 5:

$$R_1 = B_1 [[1\text{-}\exp(\text{-}M)] + \rho[\exp(\text{-}2M)\text{-}\exp(\text{-}M)]]/[1\text{-}\rho(\omega)\exp(\text{-}M)] \qquad (5)$$

where B_1 is virgin biomass, M is natural mortality, and ρ and ω are parameters estimated using Schnute's growth equation (Schnute 1985, Equation 1.14):

$$W_{k+j} = W_{k-1} + (W_k - W_{k-1})(1-\rho^{1+j})/(1-\rho) \text{ for } j \geq 0 \qquad (6)$$

where W_i represents average weight per individual of age i.

Schnute's equation was fit to data on average (males and females combined) weight-at-age data (W_{k+j}), including ages greater than or equal to the age at recruitment (k), using nonlinear least squares regression (Statgraphics 1985). Three parameters were estimated: ρ, W_{k-1} and W_k. The parameter ω was derived by dividing the estimate for W_{k-1} by the estimate for W_k. Estimates of weight at age and M were taken from Tables 1, 2 and 5. The age at recruitment for the three species was determined using data on the lengths and weights of the fish collected on commercial vessels in the Columbia Area from June 1985 to December 1986 (Pikitch, unpublished data). For arrowtooth flounder and rex sole, the average of male and female ages corresponding to the modal length in the catch were chosen as ages of recruitment. Kimura et al. (1984) suggest using the modal length of the catch as the age of recruitment; they point out that stating overestimation on the age at recruitment is preferable to underestimation. For lingcod, data were available only on the total weight and number in the catch, so the average male and female age at the mean weight in the catch was selected as the age of recruitment.

The virgin biomass of lingcod was estimated using SRA since age-structured catch data were not available. A computer program for SRA with Schnute's growth equation and a Beverton-Holt relationship (Kimura 1985, Kimura 1988) was obtained from Daniel Kimura, National Marine Fisheries Service, 7600 Sand Point Way N.E., Bin C15700, Seattle, Washington 98115-0070.

The data base used was lingcod yearly catch data for the Columbia area from 1956 to 1986 (Lynde 1986; Pacific Fishery Information Network (PacFIN), Summary Report for May 25, 1982-March 16, 1987).

Inputs to the SRA computer program included the shape parameter (A), natural mortality (M), age at recruitment (k), and estimates of ω and ρ from Schnute's growth equation (Schnute 1985, Equation 1.14). The shape parameter A was derived using Equation (4). The other parameters used were the same those used to calculate virgin recruitment. Given the catch data and the input parameters, different values for virgin biomass were tried in the model until the program produced a 1983 biomass of lingcod of about 4000 metric tons (t) and a reduction in biomass from 1980 to 1983 of approximately 0.5, as indicated by National Marine Fisheries Service groundfish surveys (Coleman 1986; Weinberg et al. 1984).

Stock Reduction Analysis or an age-structured model could not be used to determine virgin biomass for arrowtooth flounder and rex sole since they are subject to discard and landings data may not reflect actual catches. Biomass estimates from the Oregon Department of Fish and Wildlife surveys conducted in 1971-74 (Demory et al. 1976) were considered to be the best estimates available for virgin biomass. Since these estimates represented only part of the Columbia Area, they were expanded based on relative geographic area.

Parameter Estimates

Virgin biomass and resulting recruitment biomass estimates for the Columbia Area were greatest for widow rockfish, followed by sablefish, Pacific ocean perch and yellowtail rockfish (Table 6). The flatfish species as a group tended to have lower recruitment biomasses than did the rockfish species (Table 6).

In general, reductions in stock were assumed to have little effect on recruitment. The strongest effect assumed was for Pacific ocean perch (Table 6) (where an A of 1.0 and a r of 0.0 indicates no effect). Yellowtail rockfish was the only other species for which an estimate of r was assumed to be greater than 0.15 (or an estimate for A less than 0.889).

The values for the shape parameters (r) derived using our equation based on Cushing's 1971 data were found to be comparable to those from outside sources when the fecundities at the size of 50% maturity were used (Table 8). The equation we fit was

$$r = e^{-0.0623}\,\sqrt[3]{eggs} \qquad n = 30 \qquad r^2 = 0.79. \tag{7}$$

Table 8. Estimates of the density dependent parameter (r) in Cushing's recruitment curve (recruitment = a stock^r) and related parameters for commercially important groundfish species.

	Length at 50% maturity		Fecundity at 50% maturity			r	
Species	Length (cm)	Source	No. eggs	$3\sqrt{\text{eggs}}$	Source	Derived from equation 7	Estimate from literature[1]
Widow rockfish	38	Barss & Echeverria 1987	249,711	63	Boehlert et al. 1982	0.020	0.15
Yellowtail rockfish	45	Gunderson 1980	487,320	79	Gunderson 1980	0.007	0.25
Canary	49	Gunderson 1980	816,814	94	Gunderson 1980	0.003	0.00
Chilipepper	29	Echeverria 1987	31,860	32	Phillips 1964	0.139	0.15
Bocaccio	48	Echeverria 1987	298,617	67	Phillips 1964	0.016	Not available
Pacific ocean perch	34	Gunderson 1977	31,887	32	Gunderson 1977	0.139	0.25 - 0.50
Sablefish	55*	Fujiwara 1985	92,182	45	Mason et al. 1983	0.060	0.15
Dover sole	27*	Yoklavich and Pikitch 1988	14,329	24	Yoklavich and Pikitch 1988	0.220	0.00
Petrale sole	40	Harry 1959	98,000	46	PFMC 1982	0.057	0.00
English sole	31	Harry 1959	149,219	53	Harry 1959	0.037	0.00
Lingcod	64*	Miller & Geibel 1973	74,553	42	Hart 1967	0.073	
Rex sole	24	Hosie 1975	6,205	18	Hosie 1975	0.318	
Arrowtooth flounder	37	Fargo et al. 1981	1,000,000	100	PFMC 1982	0.002	

[1] See Table 7 for literature sources for each species.

*Approximate lengths

Some of the variation between the values were estimated using the preceding equation. Variation found in the literature could be attributed to the fact that our shape parameters were based on fecundities selected as being most representative of the Columbia Area, while the shape parameters in the literature were for areas with different fecundities. The most notable difference between the estimates was that we predicted that a reduction in stock would have a far greater effect on Dover sole recruitment than was previously thought. Although flatfish were generally considered by Cushing (1971) to have such high fecundities that there was virtually no effect on recruitment if the stock was reduced, our equation predicts that the greatest effects would be experienced by two flatfish species, Dover sole and rex sole.

Estimates derived from Schnute's (1985) growth equation, which were used to estimate recruitment from virgin biomass for lingcod, arrowtooth flounder and rex sole were not listed in Table 7, but may be of interest. The lingcod estimate for ω was 0.79 and for ρ was 0.979; for arrowtooth flounder, ω was equal to 0.684 and ρ was 0.899; for rex sole, ω was 0.88 and ρ was 0.881.

Application

All of the estimates, either derived for this project or reported from other sources, should be considered only approximations of the true stock-recruitment curves, and sensitivity analysis should be employed, if possible, when using any of the values given. Equation (7), derived to predict the strength of a stock-recruitment relationship based on the fecundity of the species, can be used to estimate the actual values of the shape parameters when necessary, as we did for lingcod, arrowtooth flounder and rex sole. Equation (7) is primarily useful in providing a method of determining the relative strengths of the stock-recruitment relationships for the various species. Regardless of the way in which the equation is used, the reproductive strategies of the species should be considered. The shape parameter we derived for lingcod, for instance, may indicate a relatively stronger relationship than is actually the case, since lingcod nesting behavior may increase the survival of their eggs. Our estimate was not adjusted because the estimated value already indicated a very weak stock-recruitment relationship.

The other values we derived, while considered the best we could obtain, were based on limited and often unreliable data. For example, the length-age relationship of lingcod is considered to be questionable (Adams 1986). Our methods of allocating biomass to the Columbia Area may also not be accurate. However, the proportion of the total commercial landings 1980-85 attributed to the Columbia Area for widow rockfish and sablefish (PFMC 1986) were close to the proportions we used for those species.

It is expected that the stock-recruitment relationships of all the species reviewed will be better understood with additional data and further refinement of the methods used.

SELECTION OF PARAMETERS

Age and Growth

Parameter estimates applicable to the Columbia Area were chosen for the initial investigation of the effects of mesh size on yield. Bocaccio and chilipepper were not included since they were not considered commercially important to the area.

Selection of parameters for input in the model was limited to those obtained using the von Bertalanffy equation for the sake of simplicity, and to those derived from otoliths rather than scales. More than one choice of parameters was available in the literature for canary rockfish, Pacific ocean perch, yellowtail rockfish and rex sole (Table 1). Since growth parameter estimates are generally not affected by the methodology used to read the otoliths (Archibald et al. 1981), this factor was not given emphasis in selecting the estimates.

The estimates for canary rockfish determined by Golden and Demory (1984) were selected over other available estimates because they were specific to the Columbia Area and were developed from the most recent data and the largest sample size. Wilson (1984) did use a greater range of ages, but the younger ages were not relevant to the modeling exercise because they were below the age of first capture. At the older ages the estimates of the two authors were very close. The estimates of Golden et al. (1980) were chosen for Pacific ocean perch because they were specific to the Columbia Area and were based on the most recent data. Gunderson's (1977) estimates for Pacific ocean perch, which resulted in up to 3 years slower growth, were based on slightly larger sample sizes and range of ages. Fraidenburg's (1980a) parameters were selected for yellowtail rockfish because they were derived from the largest number of fish from the widest size range. For rex sole, Demory et al.'s (1976) estimates were used because he collected all fish at the same time of year, reducing variation which can occur due to different growth periods after formation of an annulus.

Natural Mortality

In contrast to growth parameters, estimates of natural mortality are sensitive to the otolith ageing methodology used in determining them. Estimates based on the preferred cross-section methodology were, therefore, selected when possible. Pacific ocean perch and yellowtail rockfish were the only species for which more than one estimate of M was available (Table 2). Ito et al.'s (1986) estimate was chosen for Pacific ocean perch since it was based on cross section readings. Taggart's (1985) estimate was selected for yellowtail rockfish since it was most compatible with a cross section-based estimate of M for this species obtained for Canadian fish (Archibald et al. 1981).

When ranges were given in the literature, the midpoint was used, with the exception of widow rockfish. The lower endpoint of the range given for widow rockfish by Hightower and Lenarz (1986) was selected for the model since it was most compatible with estimates of M for other rockfish. It is also likely that widow rockfish were caught and discarded in the years before they became commercially important. Thus Hightower and Lenarz's analyses may have overestimated M, by attributing all mortality to natural causes, when some of the mortality measured may have been caused by fishing.

Maturity-Length Relationship

Parameter estimates for the maturity-length equation were taken from the literature when available. Two or more sets of parameter estimates were available for yellowtail and canary rockfish (Table 3). The estimates of Gunderson et al. (1980) were selected for both species since they were based on data collected in Washington and, therefore, were more representative of the Columbia Area than Echeverria's (1987) California-based estimates. Barss and Echeverria (1987) found that length at maturity of widow rockfish differed among geographic areas.

When parameter estimates were not available for a species, data on length at first, 50%, and 100% maturity were used and equations were fitted to the available values (Vaga and Pikitch 1987). More than one set of estimates for length at maturity were available for several of the species (Table 3). Estimates from Miller and Geibel (1973), Harry (1959), and Fargo et al. (1981) were selected for lingcod, petrale sole and arrowtooth flounder, respectively, since they were the most complete. Yoklavich and Pikitch's (1988) values were used for Dover sole since they were based on the most recent data.

Fecundity-Length Relationship

Exponential rather than linear equations were selected to express the relationship between fecundity and length because that form more accurately portrays length at first maturity. Choices of parameter estimates for the exponential equation were available in the literature for widow rockfish and Pacific ocean perch (Table 4). Phillip's (1964) information for widow rockfish was used because the range of his data included the size at first maturity. Boehlert et al. (1982) used larger fish and found that the exponential equation did not fit their data as well as the linear equation. Snytko's (1971) estimates were selected for Pacific ocean perch since they were based on the largest sample of fish, which were collected over several years. Values of fecundity at length derived using Snytko's equation were between those derived from estimates given in the two other sources.

Length-Weight Relationship

Choices of parameter estimates for the length-weight equation were available for all species except widow rockfish, Pacific ocean perch and longspine thornyhead (Table 5). Estimates from McClure (1982), Golden and Demory (1984), Parks and Shaw (1987), and Demory et al. (1976) were selected for yellowtail rockfish, canary rockfish, sablefish and arrowtooth flounder, and petrale sole and English sole, respectively, because they were most representative of the Columbia area. Estimates from Bargmann (1982) and Demory et al. (1976) were chosen for lingcod and rex sole, respectively, because they were based on the most recent data. Demory et al.'s (1986) estimate for Dover sole was selected because it was most representative of the area for both males and females.

ACKNOWLEDGMENTS

We are grateful to everyone who provided us with unpublished documents, information, and computer programs. Robert Demory, Oregon Department of Fish and Wildlife, Newport, Oregon is deserving of special thanks for sharing his knowledge of the available groundfish publications and resource people. Marcus Duke and Teresa Ketchem provided help in editing and typing the paper. This work was supported by the National Marine Fisheries Service, Northwest and Alaska Fisheries Center, Seattle, Washington through the Cooperative Institute for Marine Resources Studies at the Hatfield Marine Science Center, Newport, Oregon (Contract No. NA-85-ABH-0025), and by Saltonstall-Kennedy funds (Grant No. NA-86-ABH-00035) administered through the West Coast Fisheries Development Foundation awarded to E. Pikitch.

REFERENCES

Alverson, D. L., and S. J. Westrheim. 1961. A review of the taxonomy and biology of the Pacific ocean perch and its fishery. Cons. Perm. Int. Explor. Mer Rapp. P.-V. Reun. 150:12-27.

Adams, P. 1986. Status of lingcod (*Ophiodon elongatus*) stocks off the coast of Washington, Oregon, and California. In Status of the Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 7, 59 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Archibald, C. P., W. Shaw, and B. M. Leaman. 1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-1979. Can. Tech. Rep. Fish. Aquat. Sci. 1048, 57 p.

Bagenal, T. B., and F. W. Tesch. 1978. Age and growth. In T. B. Bagenal (editor), Methods for assessment of fish production in freshwater, 3rd edition, p. 101-136. Blackwell Scientific Publications, Oxford, England.

Bargmann, G. G. 1982. The biology and fisheries for lingcod (*Ophiodon elongatus*) in Puget Sound. Wash. Dep. Fish., Tech. Rep. 66, 69 p.

Barker, M. W. 1979. Population dynamics of recreationally exploited marine bottomfish of northern Puget Sound. Ph.D. Thesis, Univ. Washington, School of Fisheries, Seattle, WA, 134 p.

Barss, W., and T. W. Echeverria. 1987. Maturity of widow rockfish *Sebastes entomelas* from the northeastern Pacific, 1977-82. In W. L. Lenarz (editor), widow rockfish, p. 13-18. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 48.

Barss, W. H., R. L. Demory, and N. Ten Eyck. 1977. Marine resource surveys on the continental shelf and upper slope off Washington, 1975-1976. Unpubl. Rep., 34 p. Available from Oregon Department of Fish and Wildlife, Marine Region, Marine Science Drive, Building 3, Newport, OR 97365.

Best, E. A. 1964. Spawning of the longspine channel rockfish, *Sebastolobus altivelis* Gilbert. Calif. Fish Game 50(4):265-267.

Beverton, R. J. H., and S. J. Holt. 1957. On the dynamics of exploited fish populations. U.K. Minst. Agric. Fish. Fish. Invest. Lond. (Ser. 2)19, 533 p.

Boehlert, G. W. 1980. Size composition, age composition, and growth of canary rockfish, *Sebastes pinniger*, and splitnose rockfish, *S. diploproa*, from the 1977 rockfish survey. Mar. Fish. Rev. 42(3-4):57-63.

Boehlert, G. W., W. H. Barss and P. B. Lamberson. 1982. Fecundity of the widow rockfish, *Sebastes entomelas*, off the coast of Oregon. Fish. Bull., U.S. 80(4):881-884.

Coleman, B. A. 1986. The 1980 Pacific west coast bottom trawl survey of groundfish resources estimates of distribution, abundance, length and age composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-100, 181p.

Cushing, D. H. 1971. The dependence of recruitment on parent stock in different groups of fishes. J. Cons. Int. Explor. Mer 33(3):340-362.

Demory, R. L. 1984a. Progress report on the status of English sole in INPFC Columbia-Vancouver Areas in 1984. In Status of Pacific Coast groundfish fishery and recommendations for management in 1985, Appendix 10, 26 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Demory, R. L. 1984b. Progress report on the status of petrale sole in the INPFC Columbia-Vancouver Areas in 1984. In Status of Pacific Coast groundfish fishery and recommendations for management in 1985, Appendix 12, 16 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Demory, R. L., J. T. Golden, and E. K. Pikitch. 1984. Status of Dover sole (*Microstomus pacificus*) in the INPFC. In Status of Pacific Coast groundfish fishery and recommendations for management in 1985, Appendix 11, 71 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Demory, R. L., M. J. Hosie, N. Ten Eyck, and B. O. Forsberg. 1976. Marine resource surveys on the continental shelf off Oregon, 1971-74. Unpubl. rep., 49 p. Available from Oregon Department of Fish and Wildlife, Marine Region, Marine Science Drive, Building 3, Newport, OR 97365.

Echeverria, T., and W. H. Lenarz. 1982. Conversions between total, fork, and standard lengths in 35 species of Sebastes from California. Fish. Bull., U.S. 82 (1): 249-251.

Echeverria, T. W. 1987. Thirty-four species of California rockfishes: maturity and seasonality of reproduction. Fish. Bull., U.S. 85(2):229-250.

Fargo, J., L. A. Lapi, J. E. Richards, and M. Stocker. 1981. Turbot biomass survey of Hecate Strait, June 9-21, 1980. Can. MS Rep. Fish. Aquat. Sci. 1630, 84 p.

Forrester, C. R. 1969. Life history information on some groundfish species. Fish. Res. Board Can. Tech. Rep. 105, 17 p.

Fraidenburg, M. E. 1980a. Yellowtail rockfish (*Sebastes flavidus*) length and age composition off California, Oregon and Washington in 1977. Mar. Fish. Rev. 42(3-4):54-63.

Fraidenburg, M. E. 1980b. Biological statistics of yellowtail rockfish (*Sebastes flavidus*, Ayres) in the Northeast Pacific. Wash. Dep. Fish., Tech. Rep 55, 64 p.

Fraidenburg, M. E. 1981. First estimates of natural mortality for yellowtail rockfish. Trans. Am. Fish. Soc. 110(4):551-553.

Fujiwara, S. 1985. Comparison of two otolith aging methods for sablefish, *Anoplopoma fimbria*. M.S. Thesis, Humboldt State Univ., Arcata, CA. 117 p.

Golden, J. T. 1984. A progress report on the status of canary rockfish in the INPFC Columbia, Vancouver and Eureka areas in 1982-83. Unpubl. manuscr. Available from Oregon Dept. Fish and Wildlife, Marine Region, 2030 Marine Science Drive, Bldg. 3, Newport, OR 97365, 31 p.

Golden, J. T., and R. L. Demory. 1984. A progress report on the status of canary rockfish in the INPFC Columbia, Vancouver and Eureka areas in 1984. In Status of the Pacific coast groundfish fishery through 1984 and recommended ABC for 1985, Appendix 7, 22 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Golden, J. T., R. L. Demory, and W. H. Barss. 1980. Abundance, size and age composition, and growth of Pacific ocean perch, *Sebastes alutus*, sampled during 1977. Mar. Fish. Rev. 42(3-4):41-47.

Gunderson, D. R., P. Callahan, and B. Goiney. 1980. Maturation and fecundity of four species of *Sebastes*. Mar. Fish. Rev. 42(3-4):74-79.

Gunderson, D. R. 1977. Population biology of Pacific ocean perch, *Sebastes alutus*, stocks in the Washington-Queen Charlotte Sound region, and their response to fishing. Fish. Bull., U.S. 75:369-403.

Hagerman, F. B. 1952. The biology of the dover sole, *Microstomus pacificus* (Lockington). Calif. Div. Fish Game Fish. Bull. 78, 64 p.

Harry, G. Y. 1959. Time of spawning, length at maturity, and fecundity of the English, petrale, and Dover soles (*Parophrys vetulus, Eopsetta jordani*, and *Microstomus pacificus*, respectively). Fish. Comm. Oreg. Res. Briefs 7(1):5-13.

Hart, J. L. 1967. Fecundity and length-weight relationships in lingcod. J. Fish. Res. Board Can. 24(11):2485-2489.

Henry, F. D. 1985. A progress report on the status of Chilipepper (*Sebastes goodei*) off California. In Status of the Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 5, 16 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Hightower, J. E., and W. H. Lenarz. 1986. Status of the widow rockfish survey. In Status of the Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 4, 34 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Hoenig, J. H. 1983. Empirical use of longevity data to estimate mortality rates. Fish. Bull. U.S. 82(1):898-903.

Hosie, M. J. 1975. Biology of the rex sole, *Glyptocephalus zachirus* Lockington, in waters off Oregon. M.S. Thesis, Oregon State Univ., Corvallis, OR, 43 p.

Ito, D. H., D. K. Kimura, and M. E. Wilkins. 1986. Current status and future prospects for the Pacific ocean perch resource in waters off Washington and Oregon. In Status of the Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 3, 44 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Kimura, D. K. 1985. Changes to stock reduction analysis indicated by Schnute's general theory. Can. J. Fish. Aquat. Sci. 42(12):2059-2060.

Kimura, D. K. 1988. Using classical recruitment curves in stock reduction analysis. J. du Cons. 44.

Kimura, D. K., J. W. Balsiger, and D. H. Ito. 1984. Generalized stock reduction analysis. Can. J. Fish. Aquat. Sci. 41(9):1325-1333.

Kimura, D. K., R. R. Mandapat, and S. L. Oxford. 1979. Method, validity, and variability in the age determination of yellowtail rockfish (*Sebastes flavidus*), using otoliths. J. Fish. Res. Board Can. 36(4):377-383.

Lenarz, W. H. 1987. Aging and growth of widow rockfish. In W. L. Lenarz (editor), Widow rockfish. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 48:31-35.

Lynde, M. V. H. 1986. The historical annotated landings (HAL) database: documentation of annual harvest of groundfish from the northeast Pacific and eastern Bering Sea from 1956 to 1980.

MacGregor, J. S. 1970. Fecundity, multiple spawning, and description of the gonads in *Sebastodes*. U.S. Fish Wildlife Serv., Spec. Sci. Rep. Fish. 596, 12 p.

Mason, J. C., R. J. Beamish, and G. A. McFarlane. 1983. Sexual maturity, fecundity, spawning, and early life history of sablefish (*Anoplopoma fimbria*) off the Pacific coast of Canada. Can. J. Fish. Aquat. Sci. 40(12):2126-2134.

McClure, R. E. 1982. Neritic reef fishes off central Oregon: aspects of life histories and the recreational fishery. M.S. Thesis, Oregon State Univ., Corvallis, OR, 94 p.

McFarlane, G. A., W. Shaw and A. V. Tyler. 1985. Sablefish. In A. V. Tyler and G. A. McFarlane (editors), Groundfish stock assessments for the west coast of Canada in 1984 and recommended yield options for 1985, p. 163-186. Can. Manuscr. Rep. Fish. Aquat. Sci. 1813, 353 p.

Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera*, experiments in Monterey Bay, California. Calif. Dep. Fish Game, Fish Bull. 158, 137 p.

Moser, H. G. 1967. Reproduction and development of *Sebastes paucispinis* and comparison with other rockfishes off southern California. Copeia 1967(4):773-797.

Nielsen, L. A., D. L. Johnson, and S. S. Lampton. 1983. Fisheries techniques. American Fisheries Society, Bethesda, Maryland. 468 p.

Pacific Fishery Management Council. 1982. Fishery management plan and environmental impact statement for the California, Oregon and Washington groundfish fishery. NOAA/NMFS Cooperative agreement 80-ABH-00003, 308 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Pacific Fishery Management Council. 1986. Status of the Pacific coast groundfish fishery through 1986 and recommended acceptable biological catches for 1987. NOAA/NMFS Cooperative agreement NA-86-ABH-00003, 284 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Pacific Fishery Information Network (PacFIN). 1987. PFMC gear group report: commercial groundfish landed catch (metric tons) for the year for each INPFC area. Report #9. Unpubl.

manuscr., 8 p. Available from Northwest and Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115.

Parks, N. B., and F. R. Shaw. 1983. Changes in relative abundance and size composition of sablefish (*Anoplopoma fimbria*) in coastal waters of California, 1980-82. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-51, 16 p.

Parks, N. B., and F. R. Shaw. 1987. Change in relative abundance and size composition of sablefish (*Anoplopoma fimbria*) in coastal waters of Washington and Oregon, 1979-85. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-124, 41 p.

Phillips, J. B. 1959. A review of the lingcod, *Ophiodon elongatus*. California Fish Game 45(1):19-27.

Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus *Sebastodes*). Calif. Dep. Fish Game, Fish Bull. 126, 70 p.

Phillips, J. B., and S. Imamura. 1954. The sablefish fishery in California. Bull. Pac. Mar. Fish. Comm. 3:5-37.

Pikitch, E. K. 1987. Use of a mixed species yield-per-recruit model to explore the consequences of various management policies for the Oregon flatfish fishery. Can. J. Fish. Aquat. Sci. 44(Suppl. 2):349-359.

Porter, P. 1964. Notes on fecundity, spawning, and early life history of the petrale sole (*Eopsetta jordani*), with descriptions of flatfish larvae collected in the Pacific Ocean off Humboldt Bay, California. M.S. Thesis, Humboldt State Coll., Arcata, CA, 98 p.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can. 191, 382 p.

Schnute, J. 1985. A general theory for analysis of catch and effort data. Can. J. Fish. Aquat. Sci. 42(3):414-429.

Six, L. D., and H. F. Horton. 1977. Analysis of age determination methods for yellowtail rockfish, canary rockfish, and black rockfish off Oregon. Fish. Bull., U.S. 75(2):405-414.

Snytko, V. A. 1971. Biology and peculiarities of distribution of Pacific ocean perch (*Sebastes alutus* G.) in Vancouver-Oregon areas. Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr. 79:3-41. (Transl. 1973, Fish. Res. Board Can. Transl. Ser. 2805).

Statgraphics. 1985. Statistical Graphics Corporation. PLUS*WARE Products, STSC, Inc., 2115 East Jefferson St., Rockville, Maryland 20852.

Swartzman, G., R. Francis, A. Hollowed, and P. Sullivan. 1985. Adaptive environmental assessment and management of the Pacific coast *Sebastes* fishery. NWAFC Processed Rep. 85-09, 76 p. Available at Northwest and Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115.

Taggart, J. 1985. Status of the yellowtail rockfish stocks in the INPFC Vancouver and Columbia areas in 1985. In Status of the Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 6, 30 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Thomas, D. H. 1985. Status of California's bocaccio stock. In Status of Pacific coast groundfish fishery through 1986 and recommended ABC for 1987, Appendix 4, 9 p. Available from Pacific Fishery Management Council, Metro Center, Suite 420, 2000 SW First Ave., Portland, OR 97201.

Vaga, R. M., and E. K. Pikitch. 1987. West coast groundfish mesh size study. Report to Saltonstall-Kennedy Foundation. Available from E.K. Pikitch, Fisheries Research Institute, Univ. Washington, Seattle, WA 98195.

Weinburg, K. L., M. E. Wilkins, and T. A. Dark. 1984. The 1983 Pacific West coast bottom trawl survey of groundfish resources: estimates of distribution, abundance, age, and length composition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-70, 376 p.

Wendler, H. O. 1953. Length-weight relationships of the lingcod. Wash. Dep. Fish., Fish. Res. Pap. 1(1):25-32.

Westrheim, S. J. 1958. On the biology of the Pacific ocean perch, *Sebastodes alutus* (Gilbert). M.S.Thesis, Univ. Washington, Seattle, WA, 106 p.

Wilkins, M. E. 1980. Size composition, age composition, and growth of Chilipepper, *Sebastes goodei*, and bocaccio, *S. paucispinis*, from the 1977 rockfish survey. Mar. Fish. Rev. 42(3-4): 48-53.

Wilson, C. D. 1984. The effects of different otolith aging techniques on estimates of growth and mortality for two species of rockfishes, *Sebastes pinniger* and *Sebastes diploproa*. M.S. Thesis, Oregon State Univ., Corvallis, OR, 107 p.

Yoklavich, M., and E. K. Pikitch. 1988. Assessing changes in the fecundity and maturity of Dover Sole (*Microstomus pacificus*). Unpubl. manuscr., 23 p. Available from E. K. Pikitch, Fisheries Research Institute, School of Fisheries WH-10, University of Washington, Seattle, WA 98195.