

NOAA Technical Memorandum NMFS F/NWC-166

Life History Characteristics of Commercially Important Groundfish Species Off California, Oregon, and Washington

by Jean Beyer Rogers and Ellen K. Pikitch

August 1989

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

by

Jean Beyer Rogers and Ellen K. Pikitch* Department of Fisheries and Wildlife Oregon State University

Mark O. Hatfield Marine Science Center Newport, Oregon 97365

August 1989

^{*}Present address: Fisheries Research Institute, School of Fisheries WH-10, University of Washington, Seattle, WA 98195.

THIS PAGE INTENTIONALLY LEFT BLANK

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 stockrecruitment 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 thorneyhead (*Sebastolobus alascanus*), and longspined thorneyhead (*Sebastolobus altivelis*). THIS PAGE INTENTIONALLY LEFT BLANK

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
ACKNŎWLEĎGMENTS.	31
REFERENCES	33
	55

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 (PFMC) 1982¹/). 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, 1_t , is the von Bertalanffy (Gulland 1964) equation:

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

where L_{∞} , K, and t_o are model input parameters.

Another equation used to describe growth (Six and Horton 1977; McClure 1982) 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 (Six and Horton 1977; Kimura et al. 1979). However, growth parameter estimates are generally not greatly affected by the ageing method used; 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

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

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

Table 1 .-continued.

	Years (months)		von Be	rtalanffy's eq	uation ¹	Range Ageing ⁴			
Area	collected	Sex	 	k	to	(ages)	n	method	Source
Pacific ocea	n perch								
Columbia area	77	M F	45.74 49.53	0.110 0.100	-4.36 -4.24	6-18 6-18	621 548	SU SU	Golden et al. 1980
Vancouver a (100- 149m)	irea	М	42.30	0.170	-1.64	6-18	304	SU	39
(150- 199m)		М	46.17	0.080	-8.65	7-18	176	SU	**
19911)		F	49.39	0.097	-4.97	6-18	191	SU	**
WA	72	M F	43.15 48.47	0.1320 0.0908	-2.1186 -3.5041	2-22 2-24	836 843	SU SU	Gunderson 1977
Yellowtail r	ockfish								
CA OR, WA	77	M F	49.04 55.54	0.209 0.163	-0.185 -0.250	5-22 5-21	2684 1527	SU SU	Fraidenburg 1980 ^a
WA	75-77	M F Both	42.0 51.0 41.0	0.35 0.18 0.36	0.40 0.89 0.55	3-7 3-7 1-7	29 34 152	SU SU SU	Barker 1979
CA		Both	49.25	0.17249	-0.3219	0-17	140(1120)	SC	Phillips 1964
Lingcod									
N.CA	67-71	M F	85(TL) 154.6(TL)	0.214 0.087	-1.33 -1.70		126 112	SU SU	Miller and Geibel 1973
Sablefish									
WA OR	85	M F	67.588 79.509	0.13278 0.13171	6.082 -4.463	2-14 2-23	661 553		Parks and Shaw 1987
Rex sole									
OR	69, 71	M F	33.42(TL) 37.21(TL)	0.1778 0.1749	0.8551 0.5667	2-10 2-13	257 234	SU SU	Hosie 1975
OR	71-74 (6-9)	M F	31.10(TL) 38.50(TL)	0.2274 0.1454	-0.36 -1.19			SU SU	Demory et al. 1976

.

Table 1 .- continued.

Years (months)			von Be	rtalanffy's	equation ¹	Range		Ageing ⁴	
Area	collected	Sex	مرا	k	to	(ages)	n	method	Source
Dover sole									
OR	71-74	M F	44.08 60.70	0.2186 0.1110	-0.02 -0.18			SC	Demory et al. 1976
Petrale sole									
OR	71-74	M F	45.4 54.4	0.2018 0.2119	-1.82 0.08			SC	Demory et al. 1976
English sole	;								
OR	71-74	M F	36.3 42.6	0.256 0.265	-1.08 -0.40			IO	Demory et al. 1976
Arrowtooth	flounder								,
OR	71-74	M F	43.10 68.80	0.3481 0.1562	-1.37 -0.46			SU	Demory et al. 1976
Area	Years collected	Sex	Exp a	onential ec	uation ² b	Range (ages)	n	Ageing ⁴ method	Source
Yellowtail re	ockfish								
OR	78-80	Both	13.79	65	0.52966	3-8	77	SU	McClure 1982
OR (2 readings)	73-74	M M F F	27.99 28.41 25.08 23.66	62- 18 41- 46	0.18068- 0.17206 0.26386- 0.28150	6-21 6-21 6-20 6-20		SU SU SU SU	Six and Horton 1977

⁴FL(cm) = $L_{\infty}[1-e^{-k} (age - t_0)]$. ³Sample size in parentheses (n) is number of back-calculations; TL converted to FL using equations from Echeverria and Lenarz (1982). ⁴Ageing 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:

Proportion mature at length
$$1 = \frac{1}{1 + e^{a1} + b}$$

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:

								Data	
Area	Years collected	Sex	Range (ages)	М	Z	n	Ageing ² method	analysis method	Source
Widow rock	kfish								
				0.15- 0.20		10,000	SU	catch curve of unfished popu- lation	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 popu- lation (trawl, commercial and research trawl, commercial)	Fraidenburg 1981
OR	73-74 (2 reading	gs)	14-18		.29- .40		SU	catch curve (com- (mercial trawl)	Six and Horton 1977
Canary roc	kfish								
OR, WA	80-84		15-35		0.115		BB	catch curve (trawl, com- mercial)	Golden and Demory 1984
CA, OR WA	80	M F	12-60 12-34	0.005 0.091	0.089 0.178	967 1464	SE SE	catch curve (trawl,research)	Wilson 1984
OR	73-74 (2 reading	gs)	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.-Natural mortality estimates (M) and instantaneous total mortality estimates (Z) for commercially important groundfish species found off the coasts of California, Oregon, and Washington.

Table 2.-Continued.

Area	Years collected	Sex	Range (ages)	М	Z	n	Ageing ² method	Data analysis method	Source
Canary ro	ckfish - conti	inued							
CA, OR WA	77	M F	14-19 14-20		0.564 0.615		SU	catch curve (trawl, research)	Boehlert ¹ 1980
Chilipepp	er								
				0.20				based on V-B growth (k = 0.18) and max age 29 years	Henry 1985
Bocaccio									
CA				0.25					Thomas 1985
Pacific oc	ean perch								
				0.05			BB	based on max age 70-90 years	Ito et al. 1986
WA	66-72			0.20			SU	catch curve (trawl, com- mercial and research)	Gunderson 1977
Lingcod									
WA	76			0.23- 0.31	0.40	35 41 tag	SU s	tagging and catch curve (recreation)	Barker 1979
Sablefish									
BC				0.10				basis not stated, estimate	McFarlane et al. 1985
Rex sole								usu.	
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)	М	Z	n	Ageing ² method	Data analysis method	Source
Dover sole									
				0.15					Demory et al. 1984
Petrale sole	e								
		M F		0.25 0.20					Demory 1984a
English so	le								
		M F		0.26 0.26					Demory 1984a
Arrowtoot	n flounder								
OR	71-74	M F	4-20 4-22		0.37 0.34		SU	catch curve	Demory et al. 1976
WA	75-76	M F	6-17 7-23		0.35-0.42 0.16-0.42		SU	catch curve	Barss et al. 1977
OR				0.20				life history	PFMC 1982

¹Data analyzed by Wilson (1984). ²Ageing method: SU = Surface otoliths SE = Sectioned otoliths BB = Break and bum otoliths.

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

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.

Table 3.-Continued.

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

.

.

Table 3.-Continued.

Area	Years (months) collected	Sex	<u>Consta</u>	nts ¹ b	n	A (cr 1st	verage leng n) at maturi 50%	th ty ² 100%	Source
	.1			<u>_</u>					
Dover s	ole								
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)	Наггу 1959
CA	49	M F			295 846	30(TL) 33(TL)	32(TL) 35(TL)	39(TL) 45(TL)	Hagerman 1952
Petrale :	sole								
OR	48-51	M F		,	267 1492	29(TL) 31(TL)	36(TL) 40(TL)	38(TL) 45(TL)	Harry 1959
CA	59-62	F				35(TL)		42(TL)	Porter 1964
English	sole								
OR	50-51	M F			27 2090	18(TL) 26(TL)	26(TL) 31(TL)	29(TL) 35(TL)	Harry 1959
Arrowto	oth flounder	•							
BC	80 (6)	M F			672	30 29	31 37	42 43	Fargo et al. 1981
OR							42		PFMC 1982
Longspi	ine thornyhe	ad							
Central CA	60	M F			32 18	25(TL) 27(TL)		28(TL) 28(TL)	Best 1964
OR	79-82	M F			23 20			25 25	Barss ⁵
Shortspi	ine thornyhe	ad							
OR	79-82	M F			500 600		<17 22	26 44	Barss ⁵

¹Proportion mature at length = $\frac{1}{1 + e^{ax} + b}$

where x=FL(cm).

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

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

⁴Columbia area.

⁵Barss, W., personal communication, March 1987, Oregon Dep. Fish Wildl.. Newport, OR (unpubl. data).

$$\mathbf{E} = \mathbf{a}(\mathbf{l})^{\mathbf{b}}$$

where E is number of eggs, 1 is length, and a and b are constants. Some sources used the linear equation:

$$\mathbf{E} = \mathbf{a} + \mathbf{b}(\mathbf{l})$$

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, 1 is length, and a and b are constants.

	Month(s)	Year(s)	Expon	ential equation ¹		Range in fork	
Area	collected	collected	a	b	n	lengths $(mm)^2$	Source
Widow n	ockfish						
CA	10-12	58-59	0.002693	4.98789	20	309-503	Phillips 1964 ³
OR	12-1	80-81	0.001	5.431	64	333-520	Boehlert et al. 1982
Yellowta	ul rockfish						
CA	10-1	58-61	0.007834	4.691782	15	287-519	Phillips 1964 ³
Canary re	ockfish						
CA	10-12	58-60	0.123946	4.013613	10	469-653	Phillips 1964 ³
Chilipep	per						
CA	10-12	58-60	0.013358	4.360991	23	292-539	Phillips 1964 ³
Bocaccio							
CA	10-2	58-60	0.001878	4.878193	24	359-724	Phillips 1964 ³
Pacific or	cean perch						
OR-WA	11-3	67-68	0.131x10 ⁻⁵	4.98838	171		Snytko 1971
WA	9-11	51-52	4.8556x10-15	6.33454	13		Westrheim 1958
OR WA	8-9	73	0.193x10 ⁻⁹	7.32506	41		Gunderson 1977
Lingcod							
BC		38-42	0.2831	3.0011	55	741-1175	Hart 1967
Sablefish	ı						
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 so	le						
n. or	12	85	0.3892	3.19	57	345-500	Yoklavich and Pikitch 1988
Petrale so	ole						
OR	8,12	63	-1.9346	3.980	50	305-510	Porter 1964 ³
English s	sole						
OR		49-50	0.620811	3.60802	15	300-430	Harry 1959 ³

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.

Table 4.—Continued.

	Month(s)	Year(s)	Linea	r equation ⁴		Range in fork	
Area	collected	collected	а	b	n	lengths $(mm)^2$	Source
Widow	rockfish						
OR	12-1	80-81	-1,999,220	59,182.4	64	333-520	Boehlert et al. 1982
Yellowt	ail rockfish						
WA	9	77	-3,235,161	82,721.8	49	440-570	Gunderson et al. 1980
Canary r	rockfish						
CA WA	8-9	77	-2,330,029	64,221.3	56	490-640	Gunderson et al.1980
Chilipep	per						
N. CA C. CA	8	77	-870,717 -658,047	24,297.4 20,809.4	22 61	380-520 380-510	Gunderson et al. 1980
Bocaccio	D						
CA	1-4	61	-901,943	24,299	13		MacGregor 1970 ³
Dover se	ole						
OR	10-12	42-57	-338463	9420	22	420-570	Натту 1959
Petrale s	sole						
OR	8	63	-356,503	2310	12	410-510	Porter
OR CA	12	63 63	-1,665,654 -2,526,700	5030 7500	38 30	305-500 320-520	1964
Area	Month(s) collected	Year(s) collected	Num	ber of eggs	n	Range in fork lengths (mm) ³	Source
Dover s		<u> </u>					
CA		49	37,18	38-229-615	8	362-504	Hagerman 1952
Petrale	sole						
OR 98,000 at 36-40 cm TL						PFMC 1982	
Arrowto	ooth flounder						
OR 1,000,000 at 42 cm						PFMC 1982	

 ${}^{1}F(eggs) = a (FL (cm))^{b}$. ${}^{2}TL$ converted to FL as needed using equations from Echeverria and Lenarz (1982). ${}^{3}Equation calculated from data in publication.$ ${}^{4}F(eggs) = a + b (FL(cm)).$

.

Area (year)			Constants		Range in fork			
collected	Sex	a	b	n	lengths (cm) ¹	Source		
Widow rockfi	ish			<u> </u>				
CA	Both	0.0045	3.34091	45	10-51	Phillips 1964 ²		
Yellowtail ro	ckfish							
OR (78-80)	Both	0.0510	2.646	17 M 40 F	20-54 25-54	McClure 1982		
N. CA- BC (75-77)	M F	0.0173 0.0092	2.97 3.14	949	30-55	Fraidenburg 1980 ^b		
WA (75-77)	Both	0.0044	3.20728	145	8-43	Barker 1979		
Canary rockfi	ish							
Combined Area	M F Both	0.0848 0.0652 0.0623	2.596 2.665 2.677	1294 776 2214		Golden and Demory 1984		
OR (78-80)	M F Both	0.0564 0.0222 0.0127	2.707 2.958 3.120	138 196 334	15-59 20-59	McClure 1982		
CA	Both	0.0117	3.10728	67	10-71	Phillips 1964 ²		
Chilipepper								
CA	Both	0.0072	3.19899	47	9-52	Phillips 1964 ²		
Bocaccio								
CA	Both	0.0079	3.1067	711	17-78	Phillips 1964 ²		
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 F	0.0852 0.0303	3.24 3.12	59 150	(TL)55-87 (TL)53-109	Wendler 1953		

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

Table 5.-Continued.

Area (year)			Constants		Range in fork			
collected	Sex	a	b	n	lengths (cm) ¹	Source		
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 (69-72)	M F	0.0097 0.00100	3.4782 3.4743	950 1121	11-50	Hosie 1975 ³		
OR (71-74)	M F	0.00088 0.00090	3.5428 3.5269		(TL) (TL)	Demory et al. 1976		
WA (75-76)	M F	0.00098 0.00081	3.51367 3.57285		(TL) (TL)	Barss et al. 1977		
Dover sole								
OR (71-74)	M F	0.0134 0.0102	2.8911 2.9655		(TL) (TL)	Demory et al. 1976		
N. OR (85)	F	0.00595	3.083	115	28.7-55(TL)	Yoklavitch and Pikitch 1988		
WA (75-76)	M F	0.0108 0.0075	2.95833 3.06697			Barss et al. 1977		
N. CA	М	0.0111	2.945861	488	33-52(TL)	Hagerman 1952 ³		
(40-49)	F	0.0108	2.972811	(19 averages) 1,738 (32 averages)				
Petrale sole								
OR (71-74)	M F	0.0040 0.0030	3.2812 3.3760		(TL) (TL)	Demory et al. 1976		
WA (75-76)	M F	0.0077 0.0036	3.135 3.348			Barss et al. 1977		
English sole	e							
OR (71-74)	M F	0.0078 0.0022	3.0132 3.4003		(TL) (TL)	Demory et al. 1976		
WA (75-76)	M F	0.0155 0.0080	2.83217 3.04795			Barss et al. 1977		

Area (year)			Constants	R	ange in fork			
collected	Sex	a	b	n le	engths (cm) ¹	Source		
Arrowtooth flo	under							
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 thomyhead								
CA (60)	Both	0.00211	2.90152	50	(TL)	Best 1964		

¹Length measurements are fork lengths, FL, except where indicated by TL (total length). ²Data reanalyzed to convert to g and FL(cm). ³values 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) survey²/ 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 Sebastolubus 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 $R_i = R_1 (B_{i-k}/B_1)^r$ (1)

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

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

		Constants			
Species	Sex	a	b		
Widow	F	0.6777	-2.5353		
rockfish	М	0.6616	-2.0517		
Yellowtail	F	0.7297	-3.0721		
rockfish	M	0.7678	-4.3694		
Canary	F	0.7087	-0.2662		
rockfish	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	F	0.3283	-1.4664		
sole	M	0.3238	-1.1350		
Petrale	F	0.4831	-3.6229		
sole	M	0.4547	-2.5211		
English	F	0.3679	-1.2906		
sole	M	0.3460	-0.7984		
Arrowtooth	F	0.3313	-0.9756		
flounder	M	0.2795	2.3167		
Shortspine	F	0.5587	-8.8290		
thornyhead	M	0.6308	-29.0228		

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	Area for which original biomass esti- mates were derived	Adjustment factor ¹	r(0.5) ₂ (1.0)	<u>Recruitment p</u> Beverton-Holt A	arameters_ ³ Cushing r	Columbia area virgin biomass B ₁	<u>Virgin</u> <u>Mill</u> Females	<u>ecruitme</u> ions Males	nt 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 ⁴
Yellowtai rockfish	l Columbia arca	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
Chilipepp	er CA	-	0.9	0.889	0.15					3	0.20	Henry ⁵
Pacific ocean perc	Columbia h 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 ⁶
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. 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.

Table 7 - Continued.

Species	Area for which original biomass esti- mates were derived	Adjustment factor ¹	$r(0.5)_2$ (1.0)	<u>Recruitment p</u> Beverton-Holt A	parameters_ ³ Cushing r	Columbia area virgin biomass B1	<u>Virgin</u> Mill Females	recruitme lions Males	nt R1 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, OF	1.35 R	0.70	0.75	0.083	15,744- ⁷ 16,376			2,157- 2,244	10	0.20	Present study
Arrowtoo flounder	th Cape Blanco- Col R, OF	1.35 R	0.999	0.999	0.002	10,207- ⁷ 10,475			582- 597	4	0.20	Present study

¹Multiplier 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.

³A 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.

⁴Hightower, J.E., personal communication, February 1987, National Marine Fisheries Service, Tiburon, CA.

⁵Henry, F.D., personal communication, February 1987, California Department of Fish and Game, Menlo Park, CA.

⁶McDivitt, S., personal communication, February 1987, National Marine Fisheries Service, 7600 Sand Point Way, Seattle, WA 98115-6349. ⁷Demory 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 sole, and English sole, they were extrapolated based on relative geographic area. That is:

$$\mathbf{B}_{col} = \mathbf{B}_{\mathbf{A}} \left(\mathbf{G}_{col} / \mathbf{G}_{\mathbf{A}} \right) \tag{3}$$

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 GA 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_iR_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:

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

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

$$W_{k+j} = W_{k-1} + (W_k - W_{k-1})(1-\rho^{1+j})/(1-\rho) \text{ for } j \ge 0$$
(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: p, W_{k-1} , and Wk. The parameter w was derived by dividing the estimate for W_{k-1} by the estimate for Wk. 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 w and p 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 as 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

$$r = e^{-0.0623} \sqrt{eggs}$$
 $n = 30$ $r^2 = 0.79.$ (7)

							r
	Length	at 50% maturity		Fecundity a	at 50% maturity	Derived from	Estimate from
Species	Length (cm)	Source	No. eggs	3√eggs	Source	equation 7	
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 ²	Fujiwara 1985	92,182	45	Mason et al. 1983	0.060	0.15
Dover sole	27 ²	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	Натту 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	

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

¹See Table 7 for literature sources for each species. ²Approximate 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 Cushing (1971) considers flatfish to have such high fecundities that there would be virtually no effect on recruitment if the stock were reduced, our equation predicts that the two flatfish species, Dover sole and rex sole, would experience the greatest effects of such a reduction.

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 w was 0.79 and for p was 0.979; for arrowtooth flounder, w was equal to 0.684 and p was 0.899; for rex sole, w was 0.88 and p 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) was close to the proportions we used for those species.

29

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 fox-i-nation 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). The estimate of Ito et al. (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, 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.

THIS PAGE INTENTIONALLY LEFT BLANK

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. Penn. 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 &bastes 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.

Preceding page blank

- 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-100,181 p.
- 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.

- For-rester, 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., 31 p. Available from Oregon Dept. Fish and Wildlife, Marine Region, 2030 Marine Science Drive, Bldg. 3, Newport, OR 97365.
- 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), Groundflsh 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(Sup. 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.