NOAA Technical Memorandum NMFS F/NWC-166 Life History Characteristics of Commercially Important Groundfish Species Off California, Oregon, and Washington

by<br>Jean Beyer Rogers<br>and<br>Ellen K. Pikitch

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

by<br>Jean Beyer Rogers and Ellen K. Pikitch*<br>Department of Fisheries and Wildlife<br>Oregon State University<br>Mark O. Hatfield Marine Science Center<br>Newport, Oregon 97365

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#### 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).


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## 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) 1982 ${ }^{1} /$ ). 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]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, $1_{\mathrm{t}}$, is the von Bertalanffy (Gulland 1964) equation:

$$
\mathrm{l}_{\mathrm{t}}=\mathrm{L}_{\infty}\left(1-\mathrm{e}^{-\mathrm{K}\left(\mathrm{t}-\mathrm{t}_{0}\right)}\right)
$$

where $\mathrm{L}_{\infty}, \mathrm{K}$, and $\mathrm{t}_{\mathrm{o}}$ 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

Table l.-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 Beralanffy's equation ${ }^{1}$ |  |  | $\begin{aligned} & \text { Range } \\ & \text { (ages) } \end{aligned}$ | n | Ageing ${ }^{4}$ method | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Lo | k | $\mathrm{t}_{0}$ |  |  |  |  |
| Widow rockfish |  |  |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { CA, OR, } \\ & \text { WA } \end{aligned}$ | $\begin{aligned} & 80-82 \\ & 80-82 \end{aligned}$ | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ | $\begin{aligned} & 46.7394 \\ & 51.5690 \end{aligned}$ | $\begin{aligned} & 0.1650 \\ & 0.1501 \end{aligned}$ | $\begin{aligned} & -1.9355 \\ & -1.4109 \end{aligned}$ | $\begin{aligned} & 3.8-21 \\ & 3.8-23 \end{aligned}$ | $\begin{aligned} & 2184 \\ & 2003 \end{aligned}$ | $\begin{aligned} & \text { SS } \\ & \text { SS } \end{aligned}$ | $\begin{aligned} & \text { Lenarz } \\ & 1987 \end{aligned}$ |
| CA |  | Both | 49.748 | 0.21456 | -0.1148 | 0-14 | 151(921) | SC | $\begin{aligned} & \text { Phillips } \\ & 1964^{3} \end{aligned}$ |
| Canary rockfish |  |  |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { CA } \\ & \text { OR, WA } \end{aligned}$ | 80 | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ | $\begin{aligned} & 52.12 \\ & 57.70 \end{aligned}$ | $\begin{aligned} & 0.1878 \\ & 0.1624 \end{aligned}$ | $\begin{aligned} & 0.1693 \\ & 0.1435 \end{aligned}$ | $\begin{aligned} & 2-60 \\ & 2-34 \end{aligned}$ | $\begin{aligned} & 516 \\ & 363 \end{aligned}$ | $\begin{aligned} & \mathrm{SE} \\ & \mathrm{SE} \end{aligned}$ | $\begin{aligned} & \text { Wilson } \\ & 1984 \end{aligned}$ |
| Columbia area | 80-82 | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ | $\begin{aligned} & 51.29 \\ & 57.32 \end{aligned}$ | $\begin{aligned} & 0.162 \\ & 0.152 \end{aligned}$ | $\begin{aligned} & -2.634 \\ & -1.221 \end{aligned}$ | $\begin{aligned} & 6.35 \\ & 6-35 \end{aligned}$ | $\begin{aligned} & 1311 \\ & 907 \end{aligned}$ | $\begin{aligned} & \mathrm{BB} \\ & \mathrm{BB} \end{aligned}$ | Golden and Demory 1984 |
| N. CA-WA | -77-78 | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ | $\begin{aligned} & 55.72 \\ & 66.11 \end{aligned}$ | $\begin{aligned} & 0.178 \\ & 0.118 \end{aligned}$ | $\begin{array}{r} 0.596 \\ -0.240 \end{array}$ |  | $\begin{aligned} & 817 \\ & 557 \end{aligned}$ | $\begin{aligned} & \text { SU } \\ & \text { SU } \end{aligned}$ | $\begin{aligned} & \text { Boehlert } \\ & 1980 \end{aligned}$ |
| OR | $72,74$ <br> (2 readings) | $\begin{aligned} & \mathrm{M} \\ & \mathrm{M} \\ & \mathrm{~F} \\ & \mathrm{~F} \end{aligned}$ | $\begin{aligned} & 53.60- \\ & 53.50 \\ & 60.95- \\ & 57.43 \end{aligned}$ | $\begin{aligned} & 0.185517- \\ & 0.183965 \\ & 0.146062- \\ & 0.177790 \end{aligned}$ |  | $2-22$ $3-23$ |  | $\begin{aligned} & \text { SU } \\ & \text { SU } \\ & \text { SU } \\ & \text { SU } \end{aligned}$ | Six and Horton 1977 |
| CA |  | Both | 63.34 | 0.12235 | -0.4021 | 0-16 | 143(1285) | SC | $\begin{aligned} & \text { Phillips } \\ & 1964^{3} \end{aligned}$ |

## Chilipepper

| CA | 77 | M | 38.66 | 0.30 | -0.15 | $2-11$ | 958 | SU | Wikkins |
| :--- | :--- | :--- | :--- | :--- | :--- | :---: | :---: | :---: | :--- |
| OR, WA |  | F | 53.19 | 0.18 | -0.43 | $2-15$ | 1194 | SU | 1980 |
| CA |  | Both | 52.018 | 0.18204 | -0.2283 | $0-15$ | $138(960)$ | SC | Phillips |
|  |  |  |  |  |  |  |  |  | $1964^{3}$ |

Bocaccio

| CA | 77 | M | 76.58 | 0.13 | -1.81 | $4-10$ | 199 | SU | Wilkins |
| :--- | :--- | :--- | :--- | :--- | :--- | :---: | :---: | :---: | :--- |
| OR, WA |  | F | 87.76 | 0.11 | -1.73 | $3-11$ | 187 | SU | 1980 |
| CA |  | Both | 76.342 | 0.14784 | -0.6439 | $0-16$ | $155(1008)$ | SC | Phillips |
|  |  |  |  |  |  |  |  |  | $19643^{3}$ |

Table 1 .-continued.

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

Table 1 .-continued.

${ }_{2}^{2}(m)=\quad L_{\infty}\left[1 \cdot e_{b}^{-k}\left(\right.\right.$ age $\left.\left.-L_{0}\right)\right]$.
${ }_{3}^{2} \mathrm{FL}(\mathrm{cm})=$ a Age
${ }^{3}$ Sample size in parentheses ( n ) is number of back-calculations; TL converted to FL using equations from Echeverria and 4 Lenarz (1982).
${ }^{4}$ Ageing method:
$S \mathrm{U}=$ surface otoliths
SE = section otoliths
$\mathrm{BB}=$ break and burn otoliths
SC = scales
SS = surface with difficult to read otoliths sectioned
IO = interopercular bones.
total instantaneous mortality rate $(\mathrm{Z})$ and the instantaneous fishing mortality rate $(\mathrm{F})$ 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:

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

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:

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

| Area | $\begin{aligned} & \text { Years } \\ & \text { collected } \end{aligned} \quad \text { Sex }$ | Range (ages) | M | Z | $n$ | Ageing ${ }^{2}$ method | Data analysis method | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Widow rockfish |  |  |  |  |  |  |  |  |
|  |  |  | $\begin{aligned} & 0.15- \\ & 0.20 \end{aligned}$ |  | 10,000 | SU | catch curve of unfished population | Hightower and Lenarz 1986 |
| Yellowtail rockfish |  |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR, BC } \\ & \text { WA } \end{aligned}$ | 67.83 |  | $\begin{aligned} & 0.075- \\ & 0.10 \end{aligned}$ |  |  |  | most reasonable based on trials | Taggan 1985 |
|  |  |  | 0.125 |  |  |  | basis not stated | Swartzman et al. 1985 |
| OR | 78-80 | >5 |  | 0.548 |  | SU | calch curve (hook and line, recreation and research) | $\begin{aligned} & \text { McClure } \\ & 1982 \end{aligned}$ |
| WA | 75-77 | 13-18 | 0.25 |  | 58 | SU | catch curve of unfished population (trawl, commercial and research trawl, commercial) | Fraidenburg 1981 |
| OR | $\begin{aligned} & 73-74 \\ & \text { (2 readings) } \end{aligned}$ | 14-18 |  | $\begin{aligned} & .29- \\ & .40 \end{aligned}$ |  | SU | catch curve (com(mercial trawl) | Six and Horton 1977 |
| Canary rockfish |  |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR, } \\ & \text { WA } \end{aligned}$ | 80-84 | 15-35 |  | 0.115 |  | BB | catch curve <br> (rawl, commercial) | Golden and Demory 1984 |
| $\begin{aligned} & \text { CA, OR } \\ & \text { WA } \end{aligned}$ | $\begin{array}{lc} 80 & \mathrm{M} \\ & \mathrm{~F} \end{array}$ | $\begin{aligned} & 12-60 \\ & 12-34 \end{aligned}$ | $\begin{aligned} & 0.005 \\ & 0.091 \end{aligned}$ | $\begin{aligned} & 0.089 \\ & 0.178 \end{aligned}$ | $\begin{array}{r} 967 \\ 1464 \end{array}$ | $\begin{aligned} & \mathrm{SE} \\ & \mathrm{SE} \end{aligned}$ | catch curve (trawl,research) | $\begin{aligned} & \text { Wilson } \\ & 1984 \end{aligned}$ |
| OR | $\begin{aligned} & 73-74 \\ & \text { (2 readings) } \end{aligned}$ | 15-23 |  | $\begin{aligned} & 0.26-1 \\ & 0.27 \end{aligned}$ |  | 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) | $\begin{aligned} & \text { McClure } \\ & 1982 \end{aligned}$ |

Table 2.-Continued.

| Area | $\begin{aligned} & \text { Years } \\ & \text { collected } \end{aligned}$ | Sex | Range (ages) | M | Z | n | $\begin{aligned} & \text { Ageing }{ }^{2} \\ & \text { method } \end{aligned}$ | Data analysis method | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Canary rockfish - continued |  |  |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { CA, OR } \\ & \text { WA } \end{aligned}$ | 77 | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{aligned} & 14-19 \\ & 14-20 \end{aligned}$ |  | $\begin{aligned} & 0.564 \\ & 0.615 \end{aligned}$ |  | SU | catch curve <br> (trawl, research) | $\begin{aligned} & \text { Boehlert }{ }^{1} \\ & 1980 \end{aligned}$ |
| Chilipepper |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 0.20 |  |  |  | based on V-B growth (k = 0.18 ) and max age 29 years | Henry 1985 |

Bocaccio

$$
\begin{array}{ll}
\mathrm{CA} & 0.25
\end{array}
$$

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) | $\begin{aligned} & \text { Gunderson } \\ & 1977 \end{aligned}$ |
| Lingcod |  |  |  |  |  |  |  |  |  |
| WA | 76 |  |  | $\begin{aligned} & 0.23- \\ & 0.31 \end{aligned}$ | 0.40 | $\begin{gathered} 35 \\ 41 \text { tags } \end{gathered}$ | SU | tagging and catch curve (recreation) | $\begin{aligned} & \text { Barker } \\ & 1979 \end{aligned}$ |
| Sablefish |  |  |  |  |  |  |  |  |  |
| BC |  |  |  | 0.10 |  |  |  | basis not stated, estimate used | McFarlane et al. 1985 |
| Rex sole |  |  |  |  |  |  |  |  |  |
| OR | 71-74 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 6-16 \\ & 6-16 \end{aligned}$ |  | $\begin{aligned} & 0.64 \\ & 0.51 \end{aligned}$ |  | SU | catch curve | $\begin{aligned} & \text { Hosie } \\ & 1975 \end{aligned}$ |
| OR | 71-74 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 7-16 \\ & 7.18 \end{aligned}$ |  | $\begin{aligned} & 0.56 \\ & 0.50 \end{aligned}$ |  | SU | catch curve | Demory et al. 1976 |
| WA | 75-76 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 5-18 \\ & 5.14 \end{aligned}$ |  | $\begin{aligned} & 0.41-0.58 \\ & 0.43-0.55 \end{aligned}$ |  | SU | catch curve | Barss et al. 1977 |
| OR |  |  |  | 0.20 |  |  |  | life history | PFMC 1982 |

Table 2.-Continued.

| Area | Years collected | Sex | Range <br> (ages) | M | Z | n | Ageing ${ }^{2}$ method | Data analysis method | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Dover sole |  |  |  |  |  |  |  |  |  |
|  |  |  |  | 0.15 |  |  |  |  | Demory et al. 1984 |
| Petrale sole |  |  |  |  |  |  |  |  |  |
|  |  | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ |  | $\begin{aligned} & 0.25 \\ & 0.20 \end{aligned}$ |  |  |  |  | Demory 1984a |
| English sole |  |  |  |  |  |  |  |  |  |
|  |  | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ |  | $\begin{aligned} & 0.26 \\ & 0.26 \end{aligned}$ |  |  |  |  | Demory 1984a |
| Arrowtooth flounder |  |  |  |  |  |  |  |  |  |
| OR | 71-74 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 4-20 \\ & 4-22 \end{aligned}$ |  | $\begin{aligned} & 0.37 \\ & 0.34 \end{aligned}$ |  | SU | catch curve | Demory et al. 1976 |
| WA | 75-76 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{array}{r} 6-17 \\ 7-23 \end{array}$ |  | $\begin{aligned} & 0.35-0.42 \\ & 0.16-0.42 \end{aligned}$ |  | SU | catch curve | Barss et al. 1977 |
| OR |  |  |  | 0.20 |  |  |  | life history | PFMC 1982 |

${ }_{2}^{1}$ Data analyzed by Wilson (1984).
${ }^{2}$ Ageing method:
SU = Surface otoliths
$\mathrm{SE}=$ Sectioned otoliths
$\mathrm{BB}=$ Break and bum 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 | $\stackrel{M}{\mathrm{M}}$ | $\begin{array}{r} -0.3390 \\ -0.8372 \end{array}$ | $\begin{aligned} & 15.4551 \\ & 33.8270 \end{aligned}$ | 2467 | 58.5(TL) | 58.5(TL) |  | Echeverria $1987{ }^{3}$ |
| CA | 77-82 | $\underset{\mathrm{F}}{\mathrm{M}}$ |  |  | $\begin{aligned} & 1237 \\ & 1165 \end{aligned}$ | $\begin{aligned} & 25 \\ & 25 \end{aligned}$ | $\begin{aligned} & 32 \\ & 33 \end{aligned}$ | $\begin{aligned} & 46 \\ & 46 \end{aligned}$ | Barss and Echeverria 1987 |
| OR | 79-80 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ |  |  | $\begin{aligned} & 688 \\ & 646 \end{aligned}$ | $\begin{aligned} & 31 \\ & 35 \end{aligned}$ | $\begin{aligned} & 33 \\ & 38 \end{aligned}$ | $\begin{aligned} & 38 \\ & 43 \end{aligned}$ |  |
| CA |  | Both |  |  | 466 | 30 | 31 |  | Phillips $1964{ }^{3}$ |
| Yellowtail rockfish |  |  |  |  |  |  |  |  |  |
| CA | 80-82 | $\stackrel{M}{\mathrm{M}}$ | $\begin{aligned} & -0.4063 \\ & -0.4439 \end{aligned}$ | $\begin{aligned} & 12.8487 \\ & 14.7270 \end{aligned}$ | 2310 |  |  |  | Echeverria 19873 |
| WA | $\begin{aligned} & 77(9) \\ & 75-78 \\ & (12-4) \end{aligned}$ | $\stackrel{\mathrm{M}}{\mathrm{~F}}$ | $\begin{aligned} & -0.3684 \\ & -0.5315 \end{aligned}$ | $\begin{aligned} & 14.9884 \\ & 23.9411 \end{aligned}$ | $\begin{aligned} & 199 \\ & 186 \end{aligned}$ |  |  |  | Gunderson et al. 1980 |
| CA |  | Both |  |  |  | 450 | 27 | 32 | Phillips $1964{ }^{3}$ |
| Canary rockfish |  |  |  |  |  |  |  |  |  |
| CA | 80-82 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & -0.3036 \\ & -0.6310 \end{aligned}$ | $\begin{aligned} & 12.3699 \\ & 13.984 \end{aligned}$ | 1205 |  |  |  | Echeverria 19873 |
| OR | $\begin{aligned} & 78-80 \\ & (6-9) \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ |  |  |  | $\begin{aligned} & 39 \\ & 43 \end{aligned}$ | $\begin{aligned} & 39 \\ & 43 \end{aligned}$ |  | McClure 1982 |
| WA | $\begin{aligned} & 77(9) \\ & 75-78 \\ & (1-4) \end{aligned}$ | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{aligned} & -0.4694 \\ & -0.6171 \end{aligned}$ | $\begin{aligned} & 18.5360 \\ & 30.3776 \end{aligned}$ | $\begin{aligned} & 199 \\ & 186 \end{aligned}$ |  |  |  | Gunderson et al. 1980 |
|  | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ |  |  |  | 613 | 24 | $\begin{aligned} & 34 \\ & 34 \end{aligned}$ |  | Phillips $1964{ }^{3}$ |
| Chilipepper |  |  |  |  |  |  |  |  |  |
| CA | 80-82 | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{array}{r} -0.3218 \\ -0.3953 \end{array}$ | $\begin{array}{r} 7.0105 \\ 11.3170 \end{array}$ | 2568 |  |  |  | Echeverria 19873 |

Table 3.-Continued.

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

Table 3.-Continued.

| Area | Years (months) collected | Sex | Constants ${ }^{1}$ |  | n | Average length $(\mathrm{cm})$ at maturity ${ }^{2}$ |  |  | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | a | b |  | 1st | 50\% | 100\% |  |
| Dover sole |  |  |  |  |  |  |  |  |  |
| Col. A | $\begin{aligned} & 85-86 \\ & (12-1) \end{aligned}$ | F |  |  | 370 | 24(TL) |  | 32(TL) | Yoklavich and Pikitch 1988 |
| Col. A | 80-81 |  |  |  |  |  |  | 37(TL) | Demory et al. 1984 |
| OR | $\begin{aligned} & 48-50 \\ & (5-10) \end{aligned}$ |  |  |  | 2086 | 33(TL) | 38(TL) | 42(TL) | Наrry 1959 |
| CA | 49 | $\begin{gathered} \mathbf{M} \\ \mathrm{F} \end{gathered}$ |  |  | $\begin{aligned} & 295 \\ & 846 \end{aligned}$ | $\begin{aligned} & 30(\mathrm{TL}) \\ & 33(\mathrm{TL}) \end{aligned}$ | $\begin{aligned} & 32(\mathrm{TL}) \\ & 35(\mathrm{TL}) \end{aligned}$ | $\begin{aligned} & 39(\mathrm{TL}) \\ & 45(\mathrm{TL}) \end{aligned}$ | Hagerman 1952 |
| Petrale sole |  |  |  |  |  |  |  |  |  |
| OR | 48-51 | $\begin{gathered} \mathbf{M} \\ \mathrm{F} \end{gathered}$ |  |  | $\begin{array}{r} 267 \\ 1492 \end{array}$ | $\begin{aligned} & 29(\mathrm{TL}) \\ & 31(\mathrm{TL}) \end{aligned}$ | $\begin{aligned} & 36(\mathrm{TL}) \\ & 40(\mathrm{TL}) \end{aligned}$ | $\begin{aligned} & 38(\mathrm{TL}) \\ & 45(\mathrm{TL}) \end{aligned}$ | Harry 1959 |
| CA | 59-62 | F |  |  |  | 35(TL) |  | 42(TL) | Porter 1964 |
| English sole |  |  |  |  |  |  |  |  |  |
| OR | $50-51$ | $\begin{aligned} & \mathrm{M} \\ & \mathrm{~F} \end{aligned}$ |  |  | $\begin{array}{r} 27 \\ 2090 \end{array}$ | $\begin{aligned} & 18(\mathrm{TL}) \\ & 26(\mathrm{TL}) \end{aligned}$ | $\begin{aligned} & 26(T L) \\ & 31(T L) \end{aligned}$ | $\begin{aligned} & \text { 29(TL) } \\ & 35(\mathrm{TL}) \end{aligned}$ | Harry 1959 |
| Arrowtooth flounder |  |  |  |  |  |  |  |  |  |
| $\mathrm{BC}$ | $80$ <br> (6) | $\begin{gathered} \mathbf{M} \\ \mathbf{F} \end{gathered}$ |  |  | 672 | $\begin{aligned} & 30 \\ & 29 \end{aligned}$ | $\begin{aligned} & 31 \\ & 37 \end{aligned}$ | $\begin{aligned} & 42 \\ & 43 \end{aligned}$ | Fargo et al. 1981 |
| OR |  |  |  |  |  |  | 42 |  | PFMC 1982 |
| Longspine thomyhead |  |  |  |  |  |  |  |  |  |
| Central CA | $60$ | $\begin{gathered} \mathbf{M} \\ \mathbf{F} \end{gathered}$ |  |  | 32 18 | $\begin{aligned} & 25(\mathrm{TL}) \\ & 27(\mathrm{TL}) \end{aligned}$ |  | $\begin{aligned} & 28(\mathrm{TL}) \\ & 28(\mathrm{TL}) \end{aligned}$ | Best 1964 |
| OR | 79-82 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ |  |  | $\begin{aligned} & 23 \\ & 20 \end{aligned}$ |  |  | $\begin{aligned} & 25 \\ & 25 \end{aligned}$ | Barss ${ }^{5}$ |
| Shortspine thornyhead |  |  |  |  |  |  |  |  |  |
| OR | 79.82 | $\begin{gathered} \mathbf{M} \\ \mathbf{F} \end{gathered}$ |  |  | $\begin{aligned} & 500 \\ & 600 \\ & \hline \end{aligned}$ |  | $\begin{array}{r} <17 \\ 22 \end{array}$ | $\begin{aligned} & 26 \\ & 44 \end{aligned}$ | Barss ${ }^{5}$ |

${ }^{1}$ Proportion mature at length $=\frac{1}{1+e^{a x+b}}$
where $\mathrm{x}=\mathrm{FL}(\mathrm{cm})$.
${ }^{2}$ 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).
${ }^{4}$ Columbia area.
${ }^{5}$ Barss, W., personal communication, March 1987, Oregon Dep. Fish Wildl.. Newport, OR (unpubl. data).

$$
\mathrm{E}=\mathrm{a}(1)^{\mathrm{b}}
$$

where E is number of eggs, 1 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:

$$
\mathrm{W}=\mathrm{a}(\mathrm{~L})^{\mathrm{b}}
$$

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:

$$
g_{j}=a\left(l_{j}\right)+b
$$

where g is girth or width, 1 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.

| Area | Month(s) collected | Year(s) collected | Exponential equation ${ }^{1}$ |  |  | Range in fork lengths (mm) ${ }^{2}$ | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | a | b | n |  |  |
| Widow rockfish |  |  |  |  |  |  |  |
| 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 |
| Yellowtail rockfish |  |  |  |  |  |  |  |
| CA | 10-1 | 58-61 | 0.007834 | 4.691782 | 15 | 287-519 | Phillips $1964{ }^{3}$ |
| Canary rockfish |  |  |  |  |  |  |  |
| CA | 10-12 | 58-60 | 0.123946 | 4.013613 | 10 | 469-653 | Phillips $1964{ }^{3}$ |
| Chilipepper |  |  |  |  |  |  |  |
| 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 ocean perch |  |  |  |  |  |  |  |
| OR-WA | 11-3 | 67-68 | $0.131 \times 10^{-5}$ | 4.98838 | 171 |  | Snytko 1971 |
| WA | 9-11 | 51-52 | $4.8556 \times 10^{-15}$ | 6.33454 | 13 |  | Westrheim 1958 |
| $\begin{aligned} & \text { OR } \\ & \text { WA } \end{aligned}$ | 8-9 | 73 | $0.193 \times 10^{-9}$ | 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 ${ }^{3}$ |
| English sole |  |  |  |  |  |  |  |
| OR |  | 49-50 | 0.620811 | 3.60802 | 15 | 300-430 | Harry 1959 ${ }^{3}$ |

Table 4.-Continued.

| Area | Month(s) collected | Years ) collected | Linear equation ${ }^{4}$ |  |  | Range in fork lengths (mm) ${ }^{2}$ | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | a | b | n |  |  |
| 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 |  |  |  |  |  |  |  |
| $\begin{aligned} & \text { CA } \\ & \text { WA } \end{aligned}$ | 8-9 | 77 | -2,330,029 | 64,221.3 | 56 | 490-640 | Gunderson et al. 1980 |
| Chilipepper |  |  |  |  |  |  |  |
| N. CA C. CA | 8 | 77 | $\begin{aligned} & -870,717 \\ & -658,047 \end{aligned}$ | $\begin{aligned} & 24,297.4 \\ & 20,809.4 \end{aligned}$ | $\begin{aligned} & 22 \\ & 61 \end{aligned}$ | $\begin{aligned} & 380-520 \\ & 380-510 \end{aligned}$ | Gunderson et al. 1980 |
| Bocaccio |  |  |  |  |  |  |  |
| CA | 14 | 61 | -901,943 | 24,299 | 13 |  | $\begin{aligned} & \text { MacGregor } \\ & 1970^{3} \end{aligned}$ |
| Dover sole |  |  |  |  |  |  |  |
| OR | 10-12 | 42-57 | -338463 | 9420 | 22 | 420-570 | Harry 1959 |
| Petrale sole |  |  |  |  |  |  |  |
| OR OR | $\begin{gathered} 8 \\ 12 \end{gathered}$ | 63 63 | $\begin{aligned} & -356,503 \\ & -1,665,654 \end{aligned}$ | 2310 5030 7500 | 12 38 | $410-510$ $305-500$ $320-520$ | $\begin{aligned} & \text { Porter } \\ & 1964 \end{aligned}$ |
| CA | 10 | 63 | -2,526,700 | 7500 | 30 | $320-520$ |  |
| Area | Month(s) collected | Year(s) collected |  | of eggs | n | Range in fork lengths (mm) ${ }^{3}$ | Source |
| Dover sole |  |  |  |  |  |  |  |
| CA |  | 49 |  | -229-615 | 8 | 362.504 | Hagerman 1952 |
| Petrale sole |  |  |  |  |  |  |  |
| OR |  |  |  | at $36-40 \mathrm{~cm}$ |  |  | PFMC 1982 |
| Arrowtooch flounder |  |  |  |  |  |  |  |
| OR |  |  |  | 00 at 42 cm |  |  | PFMC 1982 |
| ${ }^{1} \mathrm{~F}(\mathrm{eggs})=\mathrm{a}(\mathrm{FL}(\mathrm{~cm}))^{\mathrm{b}} .$ <br> ${ }^{2}$ TL converted to FL as needed using equations from Echeverria and Lenarz (1982). <br> ${ }^{3}$ Equation calculated from data in publication. ${ }^{4} \mathrm{~F}(\mathrm{eggs})=\mathrm{a}+\mathrm{b}(\mathrm{FL}(\mathrm{~cm})) .$ |  |  |  |  |  |  |  |

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

| Area (year) collected | Sex | Constants |  |  | Range in fork lengths (cm) ${ }^{1}$ | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | a | b | $\pi$ |  |  |
| Widow rockfish |  |  |  |  |  |  |
| CA | Both | 0.0045 | 3.34091 | 45 | 10-51 | Phillips $1964{ }^{2}$ |
| Yellowtail rockfish |  |  |  |  |  |  |
| OR <br> (78-80) | Both | 0.0510 | 2.646 | $\begin{array}{r} 17 \mathrm{M} \\ 40 \mathrm{~F} \end{array}$ | $\begin{aligned} & 20-54 \\ & 25-54 \end{aligned}$ | $\begin{aligned} & \text { McClure } \\ & 1982 \end{aligned}$ |
| N. CA- <br> BC <br> (75-77) | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0173 \\ & 0.0092 \end{aligned}$ | $\begin{aligned} & 2.97 \\ & 3.14 \end{aligned}$ | 949 | 30-55 | Fraidenburg $1980^{b}$ |
| WA $(75-77)$ | Both | 0.0044 | 3.20728 | 145 | 8-43 | $\begin{aligned} & \text { Barker } \\ & 1979 \end{aligned}$ |
| Canary rockfish |  |  |  |  |  |  |
| Combined Area | $\begin{gathered} \mathbf{M} \\ \text { F } \\ \text { Both } \end{gathered}$ | $\begin{aligned} & 0.0848 \\ & 0.0652 \\ & 0.0623 \end{aligned}$ | $\begin{aligned} & 2.596 \\ & 2.665 \\ & 2.677 \end{aligned}$ | $\begin{array}{r} 1294 \\ 776 \\ 2214 \end{array}$ |  | Golden and <br> Demory 1984 |
| OR <br> (78-80) | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \\ \text { Both } \end{gathered}$ | $\begin{aligned} & 0.0564 \\ & 0.0222 \\ & 0.0127 \end{aligned}$ | $\begin{aligned} & 2.707 \\ & 2.958 \\ & 3.120 \end{aligned}$ | $\begin{aligned} & 138 \\ & 196 \\ & 334 \end{aligned}$ | $\begin{aligned} & 15-59 \\ & 20-59 \end{aligned}$ | 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 | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0852 \\ & 0.0303 \end{aligned}$ | $\begin{aligned} & 3.24 \\ & 3.12 \end{aligned}$ | $\begin{array}{r} 59 \\ 150 \end{array}$ | $\begin{aligned} & \text { (TL) } 55-87 \\ & \text { (TL) 53-109 } \end{aligned}$ | Wendler 1953 |

Table 5.-Continued.

| Area (year) collected | Sex | Constants |  |  | Range in fork lenght (cm) ${ }^{1}$ | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | a | b | n |  |  |
| Sablefish |  |  |  |  |  |  |
| $\begin{aligned} & \text { WA } \\ & \text { OR(85) } \end{aligned}$ | Both | 0.00366 | 3.24316 | 1270 | 10-95 | Parks and Shaw 1987 |
| $\begin{aligned} & \text { CA } \\ & (80-82) \end{aligned}$ | Both | 0.00203 | 3.39 | 414 |  | Fujiwara 1985 |
| Rex sole |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR } \\ & (69-72) \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0097 \\ & 0.00100 \end{aligned}$ | $\begin{aligned} & 3.4782 \\ & 3.4743 \end{aligned}$ | $\begin{array}{r} 950 \\ 1121 \end{array}$ | $11-50$ | Hosie 19753 |
| $\begin{aligned} & \text { OR } \\ & (71-74) \end{aligned}$ | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{aligned} & 0.00088 \\ & 0.00090 \end{aligned}$ | $\begin{aligned} & 3.5428 \\ & 3.5269 \end{aligned}$ |  | (TL) <br> (TL) | Demory et al. 1976 |
| $\begin{aligned} & \text { WA } \\ & (75-76) \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.00098 \\ & 0.00081 \end{aligned}$ | $\begin{aligned} & 3.51367 \\ & 3.57285 \end{aligned}$ |  | $\begin{aligned} & \text { (TL) } \\ & \text { (TL) } \end{aligned}$ | Barss et al. 1977 |
| Dover sole |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR } \\ & (71-74) \end{aligned}$ | $\underset{\mathbf{F}}{\mathbf{M}}$ | $\begin{aligned} & 0.0134 \\ & 0.0102 \end{aligned}$ | $\begin{aligned} & 2.8911 \\ & 2.9655 \end{aligned}$ |  | $\begin{aligned} & \text { (TL) } \\ & \text { (TL) } \end{aligned}$ | Demory et al. 1976 |
| $\begin{aligned} & \text { N. OR } \\ & (85) \end{aligned}$ | F | 0.00595 | 3.083 | 115 | 28.7-55(TL) | Yoklavitch and <br> Pikitch 1988 |
| $\begin{aligned} & \text { WA } \\ & (75-76) \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0108 \\ & 0.0075 \end{aligned}$ | $\begin{aligned} & 2.95833 \\ & 3.06697 \end{aligned}$ |  |  | Barss et al. 1977 |
| $\begin{aligned} & \text { N. CA } \\ & (48-49) \end{aligned}$ | M | 0.0111 0.0108 | 2.945861 2.972811 | $\begin{gathered} 488 \\ \text { (19 averages) } \\ 1,738 \\ \text { (32 averages) } \end{gathered}$ | 33-52(TL) | Hagerman 1952 ${ }^{3}$ |
| Petrale sole |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR } \\ & (71-74) \end{aligned}$ | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{aligned} & 0.0040 \\ & 0.0030 \end{aligned}$ | $\begin{aligned} & 3.2812 \\ & 3.3760 \end{aligned}$ |  | $\begin{aligned} & \text { (TL) } \\ & \text { (TL) } \end{aligned}$ | Demory et al. 1976 |
| $\begin{aligned} & \text { WA } \\ & (75-76) \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0077 \\ & 0.0036 \end{aligned}$ | $\begin{aligned} & 3.135 \\ & 3.348 \end{aligned}$ |  |  | Barss et al. 1977 |
| English sole |  |  |  |  |  |  |
| $\begin{aligned} & \text { OR } \\ & \text { (71-74) } \end{aligned}$ | $\begin{gathered} \mathrm{M} \\ \mathrm{~F} \end{gathered}$ | $\begin{aligned} & 0.0078 \\ & 0.0022 \end{aligned}$ | $\begin{aligned} & 3.0132 \\ & 3.4003 \end{aligned}$ |  | $\begin{aligned} & \text { (TL) } \\ & \text { (TL) } \end{aligned}$ | Demory et al. 1976 |
| $\begin{aligned} & \text { WA } \\ & (75-76) \end{aligned}$ | $\underset{\mathrm{F}}{\mathrm{M}}$ | $\begin{aligned} & 0.0155 \\ & 0.0080 \end{aligned}$ | $\begin{aligned} & 2.83217 \\ & 3.04795 \end{aligned}$ |  |  | Barss et al. 1977 |

Table 5.-Continued.

| Area (year) <br> collected | Sex |  | Constants |  | Range in fork <br> lengths (cm) | Source |
| :--- | :---: | :---: | :---: | :---: | :---: | :--- |

${ }_{2}^{1}$ Length measurements are fork lengths, FL, except where indicated by TL (total length).
${ }_{3}^{2}$ Data reanalyzed to convert to g and $\mathrm{FL}(\mathrm{cm})$.
${ }^{3}$ 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 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 $i\left(R_{i}\right)$ is expressed as a function of the recruitment from an unfished, equilibrium (virgin) stock $\left(R_{1}\right)$, the proportion of the virgin biomass remaining at time i-k $\left(\mathrm{B}_{\mathrm{i}-\mathrm{k}} / \mathrm{B}_{1}\right)$, where $\mathrm{k}=$ age at recruitment, and the shape parameter $(\mathrm{r}$ or A$)$ :

$$
\begin{equation*}
\text { Cushing } \quad R_{i}=R_{1}\left(B_{i-k} / B_{1}\right)^{r} \tag{1}
\end{equation*}
$$

$$
\begin{equation*}
\text { Beverton-Holt } \quad R_{i}=R_{1}\left(B_{i-k} / B_{1}\right) /\left(1-A\left(1-B_{i-k} / B_{1}\right)\right) \tag{2}
\end{equation*}
$$

[^2]Table 6.-The relationship between length and the girth of roundfish or the width of flatfish (girth or width $(\mathrm{cm})=\mathrm{a}($ length $(\mathrm{cm}))+\mathrm{b})$ 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 thomyhead | 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 darived | Adjustment factor ${ }^{1}$ | $\frac{\mathrm{r}(0.5)_{2}}{(1.0)}$ | Recruitment parameters ${ }^{3}$ |  | Columbia area virgin biomass $\mathrm{B}_{1}$ | Virgin recruilment R1 |  |  | $\begin{aligned} & \text { Age at } \\ & \text { recruitment } \\ & \mathbf{k} \end{aligned}$ | Natural morality M | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Beverton-Holt A | Cushing <br> I |  | $\frac{\text { Mill }}{\text { Females }}$ | Males | Merric tons |  |  |  |
| Widow rockfish | CA-WA | . 56 | 0.9 | 0.889 | 0.15 | 90,720 | 00.00 | 00.00 | 14,280 | 5 | 0.15 | Hightower ${ }^{4}$ |
| Yellowtail rockfish | Columbia area | 1.0 | 0.84 | 0.81 | 0.25 | $\begin{aligned} & 55,500- \\ & 61,400 \end{aligned}$ |  |  | $\begin{aligned} & 3,089- \\ & 3,845 \end{aligned}$ | 10 | $\begin{aligned} & 0.075- \\ & 0.10 \end{aligned}$ | Taggart 1985 |
| Canary rockfish | Columbia area | 1.0 | 1.0 | 1.00 | 0.00 | $\begin{aligned} & 24,484- \\ & 47,309 \end{aligned}$ |  |  | $\begin{aligned} & 2,330- \\ & 4,502 \end{aligned}$ | 10 | 0.10 | Golden 1984 |
| Chilipepper | C CA | - | 0.9 | 0.889 | 0.15 |  |  |  |  | 3 | 0.20 | Henry ${ }^{5}$ |
| Pacific ocean perch | Columbia area | 1.0 | $\begin{aligned} & 0.71- \\ & 0.84 \end{aligned}$ | $\begin{aligned} & 0.59 \\ & 0.81 \end{aligned}$ | $\begin{aligned} & 0.25- \\ & 0.50 \end{aligned}$ | $\begin{aligned} & 70,000- \\ & 77,500 \end{aligned}$ |  |  | $\begin{aligned} & 5,284- \\ & 5,532 \end{aligned}$ | 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-Continued.

| Species | Area for which original biomass estimates were derived | Adjustment factor ${ }^{1}$ | $\frac{\mathrm{r}(0.5)_{2}}{(1.0)}$ | Recruitment parameters ${ }^{3}$ |  | Columbia area virgin biomass B1 | Virgin recruilment R1 |  |  | $\begin{gathered} \text { Age at } \\ \text { recruilment } \\ k \end{gathered}$ | Natural mortality M | Source |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Beverton-Holt A | Cushing <br> I |  | $\begin{gathered} \text { Milli } \\ \hline \text { Females } \end{gathered}$ | ions Males | Metric tons |  |  |  |
| 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 | $\begin{aligned} & 10,000- \\ & 11,000 \end{aligned}$ |  |  | $\begin{aligned} & 1,460 \\ & 1,606 \end{aligned}$ | 7 | 0.27 | Present study |
| Rex sole | Cape BlancoCol R, OR | 1.35 | 0.70 | 0.75 | 0.083 | $\begin{aligned} & 15,744.7 \\ & 16,376 \end{aligned}$ |  |  | $\begin{aligned} & 2,157 \\ & 2,244 \end{aligned}$ | 10 | 0.20 | Present study |
| Arrowtooth flounder | h Cape <br> Blanco- <br> Col R, OR | 1.35 | 0.999 | 0.999 | 0.002 | $\begin{aligned} & 10,207.7 \\ & 10,475 \end{aligned}$ |  |  | $\begin{aligned} & 582- \\ & 597 \end{aligned}$ | 4 | 0.20 | Present study |

${ }^{1}$ Multiplier applied to original biomass and recruitment estimates to obtain estimates for the Columbia area.
$2 \frac{\mathrm{r}(0.5)}{(1.0)}=$ 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 oblained by substituting $\frac{r(0.5)}{(1.0)}$ for $\frac{R_{i}}{R_{1}}$ in equations (1) and (2), respectively.
${ }^{4}$ Hightower, J.E., personal communication, February 1987, National Marine Fisheries Service, Tiburon, CA.
${ }^{5}$ Henry, F.D., personal communication, February 1987, California Department of Fish and Game, Menlo Park, CA.
${ }^{6}$ McDivitt, S., personal communication, February 1987, Nationa! Marine Fisheries Service, 7600 Sand Point Way, Seatte, WA 98115-6349.
${ }^{7}$ 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 sole, and English sole, they were extrapolated based on relative geographic area. That is:

$$
\begin{equation*}
\mathrm{B}_{\mathrm{col}}=\mathrm{B}_{\mathrm{A}}\left(\mathrm{G}_{\mathrm{col}} / \mathrm{G}_{\mathrm{A}}\right) \tag{3}
\end{equation*}
$$

where $\mathrm{B}_{\mathrm{co1}}$ is the biomass estimated for the Columbia Area, $\mathrm{B}_{\mathrm{A}}$ is the biomass estimated for the area given in the literature, $\mathrm{G}_{\mathrm{co1}}$ 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 $\left(\mathrm{R}_{\mathrm{i}} / \mathrm{R}_{1}\right)$ that is present when the virgin biomass is reduced by $50 \%\left(B_{i-k} / B_{1}=0.5\right)$. 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 $\left(\mathrm{R}_{\mathrm{i}} / \mathrm{R}_{1}\right)$ for a spawning stock biomass equal to one-half the virgin stock biomass. The conversion was accomplished by solving Equations (1) and (2), with $\mathrm{R}_{\mathrm{i}} \mathrm{R}_{1}$ equal for both equations and $\mathrm{B}_{\mathrm{i}-\mathrm{k}} / \mathrm{B}_{1}$ set equal to 0.5 , yielding the following relationship between the shape parameters:

$$
\begin{equation*}
A=2-(1 / 0.5 r) \tag{4}
\end{equation*}
$$

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:

$$
\begin{equation*}
R_{1}=B_{1}[[1-\exp (-M)]+\rho[\exp (-2 M)-\exp (-M)]] /[1-\rho(\omega) \exp (-M)] \tag{5}
\end{equation*}
$$

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):

$$
\begin{equation*}
W_{k+j}=W_{k-1}+\left(W_{k}-W_{k-1}\right)\left(1-\rho^{1+j}\right) /(1-p) \text { for } j \geq 0 \tag{6}
\end{equation*}
$$

where $\mathrm{W}_{\mathrm{i}}$ 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 $\left(\mathrm{W}_{\mathrm{k}+\mathrm{j}}\right)$, including ages greater than or equal to the age at recruitment $(\mathrm{k})$, using nonlinear least squares regression (Statgraphics 1985). Three parameters were estimated: $\mathrm{p}, \mathrm{W}_{\mathrm{k}-1}$, and Wk . The parameter w was derived by dividing the estimate for $\mathrm{W}_{\mathrm{k}-1}$ 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 ar 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

$$
\begin{equation*}
\mathrm{r}=\mathrm{e}^{-0.0623} 3 \sqrt{\mathrm{eggs}} \quad \mathrm{n}=30 \quad \mathrm{r}^{2}=0.79 \tag{7}
\end{equation*}
$$

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.

| Species | Length al $50 \%$ maturity |  | Fecundily al $50 \%$ malurily |  |  | 1 |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Dcrived from | Estimate from |
|  | Lengh (cm) | Source |  |  |  | No. eggs | $3 \sqrt{\text { eggs }}$ | Source | equation 7 | 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 | $55^{2}$ | 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 Pikich 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.
${ }^{2}$ 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 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.

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.

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[^0]:    *Present address: Fisheries Research Institute, School of Fisheries WH-10, University of Washington, Seattle, WA

[^1]:    ${ }^{1} /$ Available from PFMC, 12000 SW First Avenue, Portland, OR 97201.

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

