STATUS AND FUTURE PROSPECTS FOR THE PACIFIC OCEAN PERCH RESOURCE IN WATERS OFF WASHINGTON AND OREGON AS ASSESSED IN 1986

by

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ABSTRACT

The status of Pacific ocean perch, *Sebastes alutus*, stocks off Washington and Oregon was reassessed in 1986. The history of the fishery for Pacific ocean perch and earlier stock assessments were reviewed. The most recent trawl survey of this resource was conducted in 1985 and indicated that the stocks in the International North Pacific Fisheries Commission Vancouver and Columbia areas continue to be depressed and have apparently declined since a previous trawl survey in 1979. Recent improved methods of aging rockfish (breaking and buring otoliths before aging) indicate instantaneous natural mortality rates for this species are approximately 0.05, compared to values of 0.10 to 0.15 that had been estimated from surface readings of otoliths. Virtual population analysis and stock reduction analysis were performed using this lower natural mortality rate. These analyses indicate that the stocks in the Vancouver and Columbia areas were once similar in size and should be rebuilt to about 25,000 t if the maximum sustainable yield is to be realized. Finally, a delay-difference population model was used to estimate stock rebuilding rates under a variety of recruitment and fishing rate scenarios.

CONTENTS

INTRODUCTION

In 1981 the Pacific Fishery Management Council (PFMC) adopted a 20-year plan to rebuild the depleted Pacific ocean perch (Sebastes alutus) resource in waters off the Washington and Oregon coast. This plan was based, for the most part, on the results of two studies. The first study employed a cohort analysis of 1966-76 catch and age composition data as a basis for examining various schedules of rebuilding (Gunderson 1979). This report was later updated with four additional years of catch and age information (Gunderson 1981). The second study provided an evaluation of alternative trip limits as a management tool for the Pacific ocean perch fishery (Tagart et al. 1980). Trip limits are now used by the Council as a means of curbing directed Pacific ocean perch fishing.

A significant amount of information useful for stock assessments has become available since the Council adopted its Pacific ocean perch rebuilding plan. For example, a National Marine Fisheries Service (NMFS) trawl survey of west coast Pacific ocean perch stocks was completed in the spring of 1985 and only recently has this information become available for analysis. Also, recent aging information suggests that the instantaneous natural mortality rates used in Gunderson's (1979, 1981) cohort analyses may have been too high. These analyses should be re-evaluated using a natural mortality rate more in line with current longevity estimates. And finally, a new method of stock assessment called stock reduction analysis (SRA) has proven useful for assessments of Pacific ocean perch stocks in waters off Alaska (Balsiger et al. 1985). Stock reduction analysis provides much useful assessment information, including estimates of historical biomass and maximum sustainable yield. This new assessment technique, however, has yet to be attempted for stocks off the Washington and Oregon coast.

A re-appraisal of the two major Pacific ocean perch stocks off the west coast is now warranted. This report attempts to evaluate the status of these stocks using a variety of assessment methods. First, Pacific ocean perch trawl surveys are used to examine recent trends in abundance and productivity. Next, Gunderson's (1979, 1981) catch-at-age data are re-evaluated using virtual population analysis (VPA) with a lower estimate of natural mortality. Stock reduction analysis is then applied to these stocks for the first time. Finally, our best SRA population parameter estimates are entered into the delay-difference equation (Schnute 1985) in order to estimate future stock sizes under a variety of recruitment and fishing rate scenarios.

BACKGROUND INFORMATION

History of the Fishery

Prior to 1965, the Pacific ocean perch resource in the Vancouver and Columbia areas (Fig. 1) of the International North Pacific Fisheries Commission (INPFC) were harvested almost entirely by Canadian and U.S. vessels. Most of these vessels were of multipurpose design and used in other fisheries (e.g., salmon and herring) when not engaged in the groundfish fishery (Forrester et al. 1978). Generally under 200 gross tons and less than 33 m in length, these vessels had very little at-sea processing capabilities. These characteristics restricted, for the most part, the distance from home ports the vessels could fish and limited the size of their landings. Landings from 1956 to 1964 averaged 2,018 and 1,980 metric tons (t) in the Vancouver and Columbia areas, respectively (Table 1).

Catches increased dramatically after 1964 with the introduction of large distant-water fishing fleets from the Soviet Union and Japan. Both nations

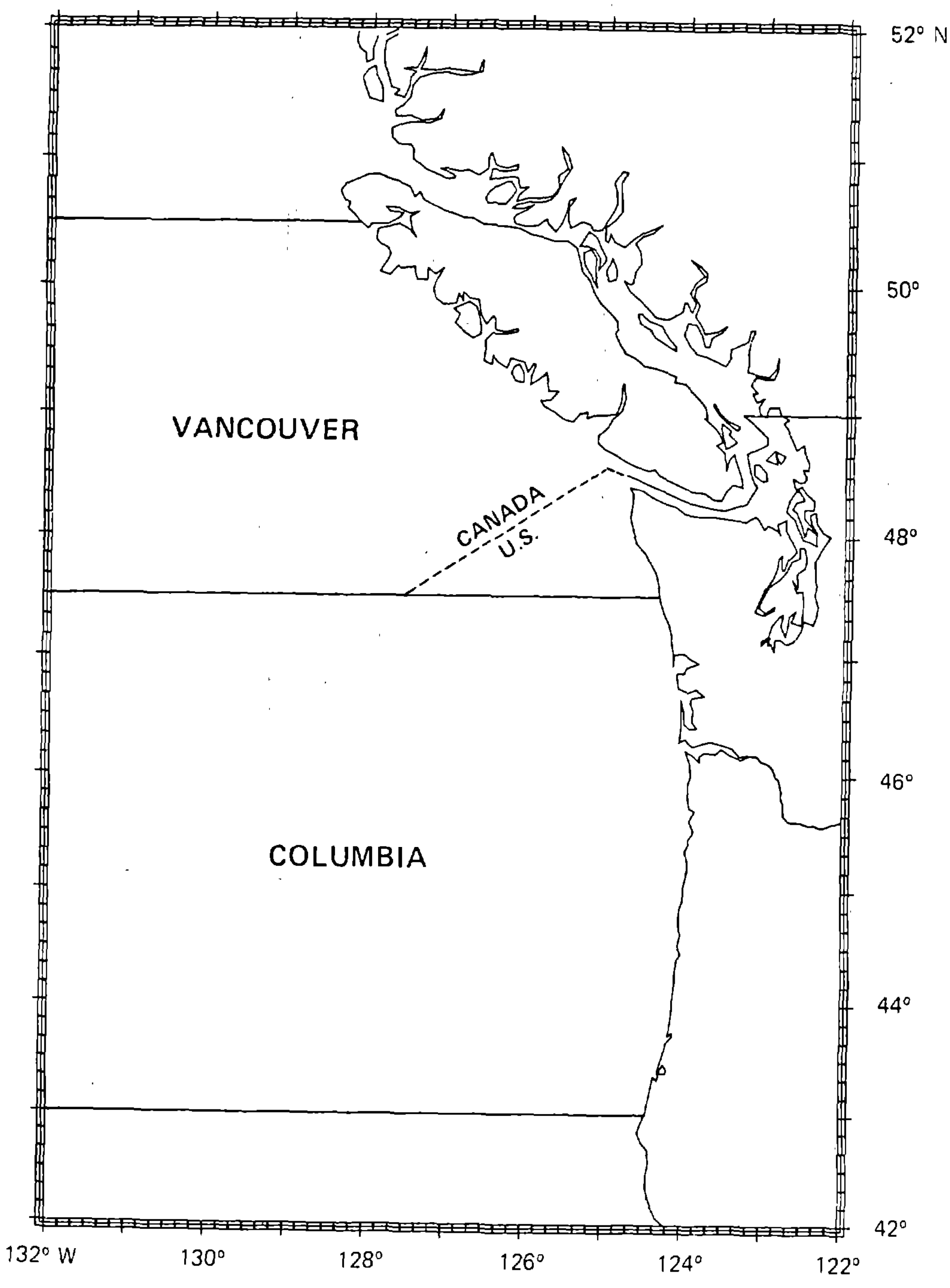

Figure 1 .--Boundaries of the International North Pacific Fisheries Commission areas, Vancouver and Columbia.

Table 1.--Estimated landings of Pacific ocean perch (metric tons, domestic and foreign combined) from INPFC* Vancouver and Columbia areas, 1956-85.

Year	INPFC Vancouver	INPFC Columbia
1956	1,084	1,306
1956	1,154	1,454
1957	675	1,002
1959	968	1,134
1960	1,575	1,065
1961	2,485	2,060
1962	3,857	2,610
1963	3,867	3,549
1964	2,499	3,643
1965	3,546	5,375
1966	16,358	11,270
1967	13,483	23,976
1968	10,417	11,562
1969	3,410	2,496
1970	4,323	2,842
1971	3,893	2,869
1972	2,605	2,619
1973	3,823	634
1974	1,473	305
1975	944	1,116
1976	1,397	1,500
1977	945	478
1978	1,014	1,099
1979	741	1,008
1980	835	1,535
1981	790	1,102
1982	830	623
1983	1,147	1,397
1984	886	1,028
1985	1,039	891

*International North Pacific Fisheries Commission.

employed large factory stern trawlers as their primary method for harvesting Pacific ocean perch. These vessels generally operated independently by processing and freezing their own catch, and the use of support vessels (e.g., refrigerated transports, oil tankers, supply ships, etc.) permitted the large stern trawlers to operate at sea for extended periods of time. Peak removals by all nations combined amounted to 16,358 t from the Vancouver area in 1966 and 23,976 t from the Columbia area 1 year later in 1967.

Immediately following these peak years, production declined very rapidly. Apparently, these stocks were far too limited to sustain the large removals during the mid 1960s. By 1969, the Pacific ocean perch stocks were severely depleted throughout the Oregon to Vancouver Island region (Gunderson 1977). Harvests within the past fifteen years (1971-1985) have averaged 1,491 and 1,214 t in the Vancouver and Columbia areas, respectively. Catches since 1979, however, have been restricted by the Pacific Fishery Management Council (PFMC).

Prior to 1977, Pacific ocean perch stocks in the northeast Pacific were managed by the Canadian government in its waters and by the individual states in waters off the United States. With implementation of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977, primary responsibility for management of groundfish stocks off Washington, Oregon, and California shifted from the states to the PFMC. At that time, however, a fishery management plan (FMP) for the west coast groundfish stocks had not yet been approved. In the interim, the state agencies worked with the PFMC to address conservation issues. Specifically, in 1981 the PFMC adopted a management strategy to rebuild the depleted Pacific ocean perch stocks to levels which would produce maximum sustainable yields within 20 years. On the basis of a cohort analysis (Gunderson 1979) the PFMC set acceptable biological catch

(ABC) levels at 600 t for the U.S. portion of the INPFC Vancouver area and 950 t for the Columbia area. To implement this strategy, the states of Oregon and Washington established landing limits for Pacific ocean perch caught in their waters. Trip limits have remained in effect to this day (Table 2). An FMP for the California, Oregon, and Washington groundfish fishery, which maintains the 20-year rebuilding schedule with above ABC levels, was implemented on September 30, 1982.

Previous Biomass Estimates

The condition of Pacific ocean perch stocks off British Columbia, Washington, and Oregon have been assessed periodically since the intense pulse of exploitation in 1966-68. The mean exploitable biomass in the Vancouver area during 1966-68 was estimated at about 34,000 t (Westrheim et al. 1972). Following the years of heavy fishing, catch per unit of effort (CPUE) for the Washington-based fleet in the Vancouver area dropped to 55% of the 1966-68 levels, indicating a decrease in biomass to 18,700 t during 1969-71 (Technical Subcommittee 1972). Catch rates declined further during 1972-74, lowering the estimated mean biomass during this period to 16,700 t (Gunderson et al. 1977). The mean weighted CPUE rose slightly in the period from 1975 to 1977, raising the biomass estimate to 17,800 t (Fraidenburg et al. 1978), although this estimate is probably biased toward the high side by the adoption of a new, more effective "high-rise" trawl net during that period.

Columbia area biomass estimates since 1966 have been calculated by dividing landings by estimated exploitation rates. The mean biomass estimates declined from 23,000 t during 1966-68 to 7,300 t during 1969-72 and 4,300 t during 1973-74 (Gunderson et al. 1977). An area-swept extrapolation from commercial CPUE data in the Columbia area resulted in a biomass estimate

Table 2.--Summary of management regulations of the Pacific ocean perch fishery in the INPFC* Vancouver and Columbia areas (U.S. waters only). Weight restrictions are in metric tons.

Effective date	Area	Regulation
26 October 1978	Washington	Trip limit of 4.54 t or 25% of catch (whichever greater)
	Oregon	Trip limit of 9.07 t
1 January 1981	Washington and Oregon	Trip limit of 4.54 t or 10% of catch (whichever greater)
1 February 1982	Washington and Oregon	Trip limit of 2.27 t or 10% of catch (whichever greater)
10 November 1983	Columbia area	No landings permitted
1 January 1984	Washington and Oregon	Trip limit of 2.27 t or 10% of catch (whichever greater)
16 August 1984	Columbia area	No landings permitted
1 January 1985	Washington and Oregon	Trip limit of less than 20% of catch
28 April 1985	Washington and Oregon	Trip limit of 2.27 t or 20% of catch (whichever less)

*International North Pacific Fisheries Commission.

of between 8,000 and 9,600 t in 1977 (Fraidenburg et al. 1978). Since the commercial fishery operates mainly in areas of high abundance, these estimates are likely to be biased toward the high side.

Research surveys have been used to provide fishery independent assessments of the abundance, distribution, and biological characteristics of Pacific ocean perch. A coastwide survey of the rockfish resource was conducted in 1977 (Gunderson and Sample 1980) with the objective of defining the distribution and measuring the abundance of the major species taken in bottom trawls. Results of this survey indicated that the biomass of Pacific ocean perch was 10,304 t in the Vancouver area[1] (Fraidenburg et al. 1978) and 7,100 t in the Columbia area (Gunderson and Sample 1980).

The 1977 coastwide survey has since been repeated twice (with some modification of the survey design), in 1980 and 1983, yielding two more fishery-independent assessments of the resource. In 1980 the survey biomass estimates were 8,600 t in the Vancouver area and 3,340 t in the Columbia area, and by 1983 they had declined in both areas to 4,460 t and 2,950 t, respectively[2]. Pacific ocean perch was not a target species for the 1977, 1980, or 1983 surveys. The depth coverage of the surveys did, however, bracket the summer distribution of the species and should provide meaningful, if not precise, estimates of relative abundance.

The relative imprecision of biomass estimates derived for Pacific ocean perch from the 1977 rockfish survey prompted requests from the fishing

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[1] The estimate for the U.S. portion of the Vancouver area was expanded to the entire area by assuming that U.S. fishing patterns (75% of the 1972-76 landings were from the U.S. zone) were proportional to the actual stock distribution.

[2] T. A. Dark and M. E. Wilkins. Trends in groundfish populations off British Columbia-California based on resource surveys in 1977, 1980, and 1983. Manuscript in prep., Northwest and Alaska Fish. Cent., 7600 Sand Point NE. Seattle, WA 98115.

industry and resource managers for closer attention to the status of this resource. In response, the National Marine Fisheries Service (NMFS) coordinated a cooperative research survey of the Pacific ocean perch stocks off Washington and Oregon with the Washington Department of Fisheries and the Oregon Department of Fish and Wildlife from March through May 1979 (Wilkins and Golden 1983). This survey provided more precise biomass estimates indicating stock sizes similar to those calculated from the 1977 survey.

Another Pacific ocean perch survey was conducted in 1985 to determine the impact of 6 years of restrictive catch regulations on the status of these stocks. The 1979 and 1985 Pacific ocean perch surveys provide the most recent and precise estimates of abundance. Therefore, the current report will concentrate on these surveys.

STOCK ASSESSMENT METHODS

Trawl Surveys

The survey design used in 1985 was similar to that used in 1979 (Wilkins and Golden 1983), but was standardized to correct inconsistencies that arose during the 1979 field work. The two most serious inconsistencies were the use of three different trawls by four different vessels, and variable depth coverage (165-475 m off Washington and 165-420 m off Oregon). The 1985 survey was designed to correct these inconsistencies in a way that allowed these surveys to be comparable.

Sampling was done with the Noreastern trawl in all areas. In the Columbia South area (Fig. 2), which had been sampled exclusively with the Mystic trawl in 1979, half of the stations were sampled with the Noreastern and half with the Mystic. The relative fishing power of the two nets was used to adjust Noreastern trawl catch rates in that area to the fishing

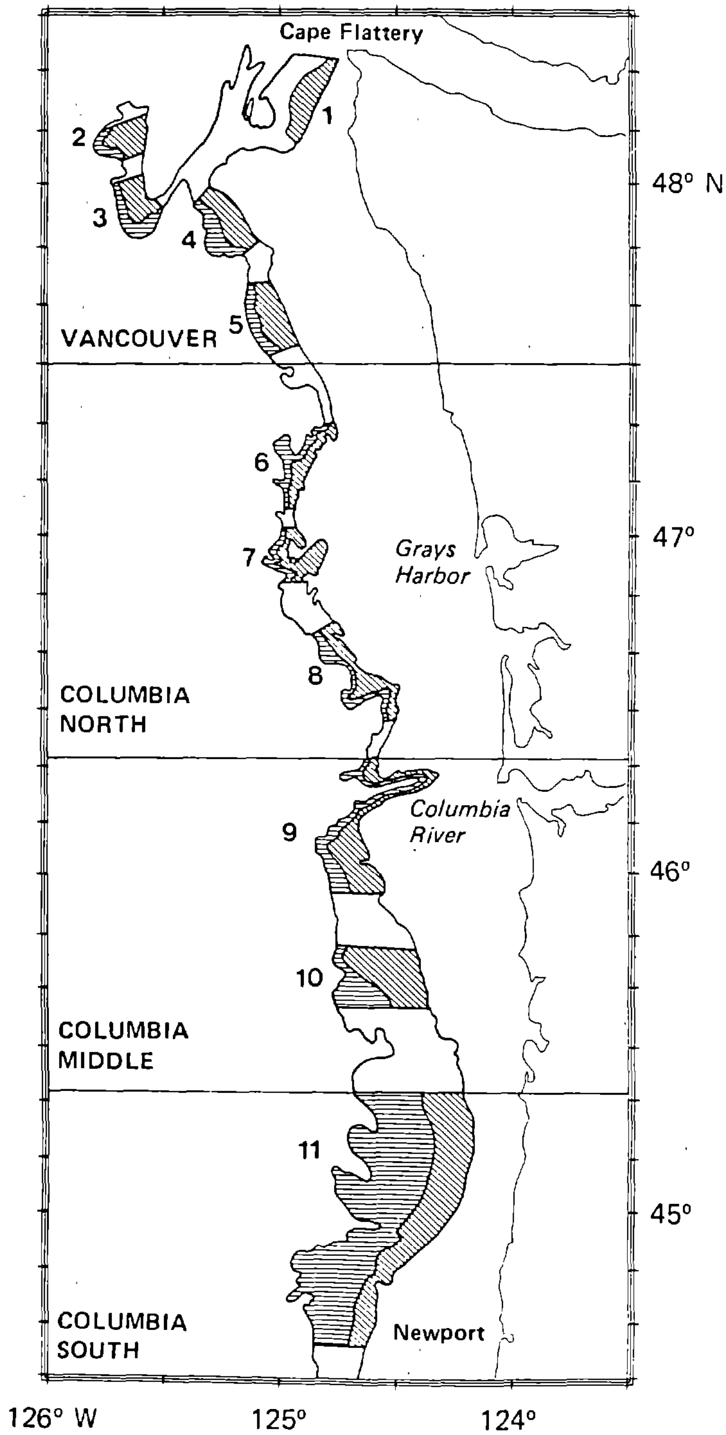


Figure 2. --The survey area, subareas, and high density sampling strata used in the design of the 1985 Pacific ocean perch survey.

efficiency of the Mystic trawl. In this way we were able to calculate, based on Mystic catch rates, abundance which could be compared with 1979 results in the southern-most subarea. No attempt was made to adjust fishing powers in the Columbia Middle area although a modified 400 eastern trawl was used there in 1979 and the Noreastern trawl was used in 1985. In calculating the 1985 Columbia South area abundance and size composition estimates for comparison with the 1979 results, hauls-deeper than 420 m in the Columbia Middle and South subareas were excluded from the data to conform with the 1979 depth coverage. Standardization of. the survey design had no effect on the survey pattern in the Vancouver or Columbia North areas.

Analytic Models

The population dynamics of Pacific ocean perch in the Vancouver and Columbia areas were examined using two analytic models, virtual population analysis (VPA) and stock reduction analysis (SRA). For both methods an instantaneous natural mortality rate of M=O.O5 was used. This mortality rate is consistent with the much older ages which result from the break-and-burn method of aging otoliths (Archibald et al. 1981). Hoenig's (1983) relationship estimates that if Pacific ocean perch longevity is between 70 and 90 yr (Beamish 1979, Chilton and Beamish 1982), M would be 0.059 and 0.046, respectively.

Virtual Population Analysis (VPA)

Virtual population analysis was carried out using Gulland's classic method (see Pope 1972). Since the age data were based on surface ages of otoliths, and the more correct break/burn ages coincide well with surface ages up through 17 yr, only ages 5-17 yr were used. The catch-at-age data (Tables 3 and 4) used in the current analysis were identical to those used by Gunderson (1981). Weight-at-age (Table 5) was estimated using a growth curve

Table 3.--Estimated number of Pacific ocean perch landed in the INPFC* Vancouver area, by age group, 1967-80.

Age	1967	1968	1969	1970	1971	1972
4						
5	26,707			10,296		6,389
6	26,707	34,022		20,591		12,778
7	213,653	68,045	30,911	82,366	47,547	44,721
8	213,653	102,067	61,822	329,464	152,149	127,776
9	454,012	238,156	30,911	1,070,758	656,143	281,106
10	961,436	510,335	175,161	741,294	1,179,156	594,157
11	1,629,100	918,602	453,358	555,970	656,143	900,818
12	1,949,579	1,701,116	896,413	473,604	475,466	357,772
13	2,563,830	1,735,138	896,413	422,126	351,845	204,441
14	2,136,525	1,633,071	607,912	473,604	351,845	185,275
15	1,388,741	1,496,982	649,127	411,830	332,826	159,720
16	1,308,622	1,224,803	278,197	494,196	294,789	159,720
17	1,201,795	918,602	72,125	329,464	237,733	102,220
18	667,664	714,469	103,036	226,506	114,112	121,387
19	507,425	544,357	41,214	123,549	104,603	63,888
20	240,359	442,290		61,774	57,056	25,555
21	80,120	238,156		20,591	28,528	25,555
22	106,826	136,089			9,509	19,166
23	26,707	34,022				6,389
24	26,707					
25						
25+						

Age	1973	1974	1975	1976	1977	1978
4					1,002	1,184
5	20,478	4,725	10,230	20,332	3,005	17,759
6	30,718	4,725	13,641	81,327	26,040	31,966
7	61,435	9,450	13,641	73,194	125,191	50,908
8	81,913	23,624	20,461	101,659	51,078	169,299
9	266,219	75,598	54,562	101,659	62,095	105,368
10	645,069	193,719	122,765	207,384	75,115	119,575
11	1,085,353	340,190	177,328	280,578	121,185	129,046
12	1,197,984	420,513	184,148	264,313	128,196	151,540
13	491,481	311,841	170,507	195,185	119,182	139,701
14	235,501	118,122	160,277	146,389	104,159	137,334
15	204,784	85,048	37,512	93,526	71,108	76,954
16	174,066	61,423	40,922	44,730	61,093	65,115
17	184,305	56,698	40,922	40,664	38,058	39,069
18	143,349	51,973	37,512	36,597	33,050	26,046
19	133,109	33,074	34,101	24,398	34,052	17,759
20	92,153	33,074	17,051	28,464	26,040	15,391
21	61,435	33,074	10,230	12,199	11,017	8,287
22	20,478	23,624	6,820	20,332	2,003	8,287
23	10,239	14,175	6,820	12,199	5,008	1,184
24		4,725	3,410	16,265	1,002	
25						
25+						

Table 3.--Continued.

Age	1979	1980
4	461	
5	3,226	
6	8,756	3,478
7	15,668	8,696
8	39,170	17,391
9	100,919	27,826
10	82,947	60,869
11	80,183	64,347
12	94,007	78,260
13	91,242	93,912
14	78,800	83,478
15	67,740	71,304
16	65,436	81,739
17	45,621	80,000
18	35,944	50,434
19	25,345	31,304
20	13,825	43,478
21	11,981	24,348
22	6,912	12,174
23	3,226	6,956
24	461	13,913
25	461	1,739
25+	461	6,956

*International North Pacific Fisheries Commission.

Table 4.--Estimated number of Pacific ocean perch landed in the INPFC* Columbia area, by age group, 1966-80.

Age	1966	1967	1968	1969	1970	1971
3					6,061	
4			19,445			
5	11,773	17,318	29,168	18,329	12,122	
6	23,546	34,637	525,028	7,332	212,127	11,530
7	82,412	329,048	1,137,561	32,992	236,370	69,183
8	294,327	658,096	1,545,917	47,656	381,828	138,365
9	353,192	1,125,691	952,829	65,985	387,889	299,791
10	800,569	1,818,423	1,157,007	54,987	339,403	461,211
11	1,400,996	3,359,754	1,565,362	124,638	351,524	426,626
12	1,731,353	6,165,321	2,440,410	370,247	430,314	322,852
13	1,648,231	3,758,075	2,109,836	472,890	515,165	334,382
14	1,200,854	3,359,754	1,497,303	494,885	333,342	299,791
15,	1,424,542	3,134,616	1,205,621	410,571	406,071	334,382
16	1,342,131	2,286,018	826,434	307,928	206,066	276,730
17	812,342	1,298,874	398,633	142,967	60,608	299,791
18	588,654	658,096	223,623	80,648	42,425	138,365
19	259,008	484,913	106,950	29,326	24,243	115,304
20	117,731	138,547	77,782	7,332	12,122	92,243
21	35,319	34,637	9,723		6,061	46,122
22	11,773	34,637	9,723	3,666		11.530
23	11,773	17,318				
24						
25						
25+						

Age	1972	1973	1974	1975	1976	1977
3		2,192				203
4	4,041	8,770				2,554
5	24,246	8,770	1,326	76,706	179,901	4,019
6	52,532	13,155	9,279	74,188'	1,271,402	64,786
7	96,983	8,770	5,302	91,168	351,866	403,733
8	149,515	28,502	3,977	46,078	186,957	92,552
9	258,621	44,946	18,557	46,769	99,739	55,553
10	396,013	63,582	47,718	95,241	108,942	22,485
11	610,183	84,410	62,229	143,194	133,365	34,218
12	262,662	128,259	84,833	188,630	138,243	28,726
13	198,007	72,351	58,323	219,307	102,275	22,001
14	234,375	43,849	23,859	90,358	101,137	17,548
15	266,703	37,272	21,208	59,701	39,349	11,845
16	242,457	43,849	17,232	35,959	16,845	10,322
17	274,785	48,234	9,272	45,263	20,780	3,447
18	149,515	43,849	13,255	32,874	22,959	3,646
19	72,737	13,155	7,953	19,596	20,423	1,490
20	64,655	13,155	3,977	15,080	20,390	575
21	32,328	10,962	1,326	12,612	2,829	993
22	12,123	4,385	1,326	4,961	4,650	352
23	12,123	5,481			195	
24				814	2,829	
25						
25+						

Table 4.--Continued.

Age	1978	1979	1980
3			
4	979		
5	4,898	4,612	3,613
6	16,280	8,407	19,729
7	43,762	18,535	44,316
8	163,652	48,114	141,997
9	77,388	155,680	317,667
10	75,555	108,398	290,186
11	79,434	85,342	150,096
12	127,066	101,492	110,875
13	124,015	87,091	103,587
14	158,838	91,529	116,960
15	137,724	96,153	104,751
16	104,761	80,893	84,582
17	67,074	77,982	66,331
18	42,170	62,903	56,258
19	15,357	47,444	28,264
20	15,101	30,361	25,174
21	8,396	19,820	15,033
22	2,726	13,900	10,413
23	1,666	15,261	9,259
24		1,945	6,561
25		3,132	4,728
25+			5,299

*International North Pacific Fisheries Commission.

Table 5.--Estimated length (cm) and weight (g) at age for Pacific ocean perch, ages 5-17 yr.

Age (yr)	Length (cm)[a]	Weight (g)[b]
5	26.1	240.4
6	28.0	301.9
7	29.8	366.8
8	31.4	433.8
9	32.9	501.9
10	34.2	570.1
11	35.5	637.8
12	36.6	704.2
13	37.6	768.9
14	38.6	831.4
15	39.4	891.4
16	40.2	948.7
17	40.9	1,003.3

[a] $L_t = 48.47\ (1 - e\ [-0.0908\ (t + 3.5041)])$ (Gunderson 1977)

[b] $W_t = 0.0078571\ L_t\ 3.16734$ (Westrheim and Thomson 1971)

fitted by Gunderson (1977) and a weight-length relationship published by Westrheim and Thomson (1971). Recruitment to the fishing grounds is not complete until age 16 (Gunderson 1977). Therefore, ages 16 and 17 yr were assumed to be fully recruited so that the instantaneous fishing mortality rate in years previous to the final catch year could be "linked" to provide initial F values for earlier cohorts.

Initial F values for the final year were tuned using a variant of a method described by Tagart (1982). For this method, it is assumed that the portion of fish at each age recruited to the fishable biomass is the same in all years. If we denote the average instantaneous fishing mortality rate on age j fish (taken over years) as Fj, and the average exploitation rate as Uj=Fj*(l-eXp(-M-Fj))/(M+Fj), the proportion of age j fish recruited to the fishable population relative to some age group J, assumed to be fully recruited, can be estimated using rj=Uj/UJ. Hence, for the final catch year, initial F values for the year class represented by j-yr olds can be estimated by soiving rj*UJ1 for F.l. In our computer program, the initial F value for the fully recruited ages in the final catch year (F_J^1) was fixed, so U_J^1 was also fixed. The rj values were initially assumed to be 1, but were iterated using the formulas described here. This estimation process was found to be stable and converged very rapidly. In the VPA analysis, initial F_J^1 values of 0.05, 0.10, 0.15, 0.20, 0.25, and 0.30, were used.

Stock Reduction Analysis (SRA)

Stock reduction analysis (Kimura and Tagart 1982, Kimura et al. 1984, Kimura 1985) was carried out using Schnute's (1985) version of the delay-difference equation. Growth parameters for the delay-difference equation were estimated using data from Archibald et al. (1983). Assuming an age at recruitment of k=lO yr, the estimated Ford growth parameters were RHO=0.97

and OMEGA=0.94. A Cushing stock-recruitment relationship was also used (Kimura et al. 1984). The SRA analysis was tuned as much as possible to the the 1985 survey biomass estimates.

When examining results from SRA it is important to understand the important role the Cushing recruitment coefficient (r) plays in the stock assessment. Under the assumption of the Cushing recruitment model, if a stock declines to some proportion of the virgin biomass, the recruitment from that stock will decline to some predictable fraction of that present in the virgin stock. If virgin biomass is denoted by B_o, recruitment to the virgin biomass by R_o, the age at recruitment by k-yr, biomass at time t-k by B_t-k, and the Cushing recruitment coefficient by r, current recruitment is assumed to be R_t = %*(Bt-k/Bo)**r. This relationship is graphed in Figure 3 for r = 0.0, 0.125, 0.250, and 0.500, the values employed in the current study. In Figure 3, all of these r values appear to be plausible; yet the correct r parameter is critical for determining possible yields, rate of rebuilding, and the target biomass for rebuilding.

STOCK ASSESSMENT RESULTS AND DISCUSSION

Trawl Surveys

The biomass of Pacific ocean perch estimated from results of the 1979 survey was 5,516 t in the U.S. portion of the Vancouver area and 10,528 t in the Columbia area. The comparable 1985 estimates were 2,028 t in the U.S.-Vancouver area and 8,668 t in the Columbia area (Table 6). These estimates represent an apparent decline of 33% in biomass and 37% in numbers in the total survey area between 1979 and 1985 (Table 6, Fig. 4). The largest decline (63% less biomass and 57% fewer fish) was seen. in the U.S.-Vancouver area. Results of trawl surveys conducted in the Canadian portion of the

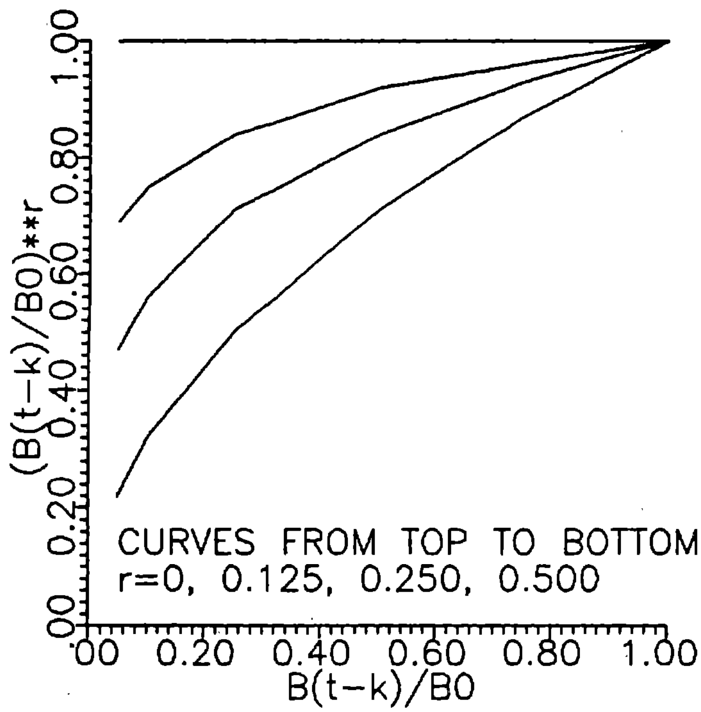


Figure 3.--Stock-recruitment relationship for the Cushing recruitment model. The relationship between stock size and recruitment is Rt = R, * (Bt-k/bo) **r.

Table 6.-- Pacific ocean perch abundance estimates from an analysis of the 1979a/ and 1995b/ survey data.

Area	Biomass (t)	90% Confidence limits (t) lower	upper	% of B	Population (x1000)	Mean weight (kg)	Mean length (cm)
U.S.-Vancouver							
1979							
165-319 m	4573.3	443.6	8703.0	(± 90%)	5281	0.9	
320-475 m	956.3	83.2	1829.5	(± 91%)	1466	0.7	
165-475 m	5515.8	1397.6	9633.9	(± 75%)	6736	0.8	37.7
1985							
165-319 m	1709.5	574.2	2844.8	(± 66%)	2484	0.7	34.5
320-475 m	318.0	145.7	490.4	(± 54%)	413	0.8	37.9
165-475 m	2027.5	880.6	3174.5	(± 57%)	2897	0.7	35.0
Columbia North							
1979							
165-319 m	1794.5	128.2	3460.8	(± 93%)	2037	0.9	
320-475 m	123.4	0	398.0	(± 223%)	143	0.9	
165-475 m	1917.9	249.6	3586.2	(± 87%)	2180	0.9	38.6
1985							
165-319 m	2739.4	1889.2	3589.5	(± 31%)	3390	0.8	37.2
320-475 m	76.0	50.6	101.3	(± 33%)	87	0.9	39.9
165-475 m	2815.3	1964.8	3665.8	(± 30%)	3477	0.8	37.2
Columbia Middle							
1979							
165-319 m	1905.1	0	4239.2	(± 123%)	3044	0.6	
320-420 m	45.2	6.6	83.9	(± 86%)	61	0.7	
165-420 m	1950.3	0	4284.7	(± 120%)	3105	0.6	35.2
1985							
165-319 m	2327.9	783.5	3872.4	(± 66%)	2989	0.8	36.7
320-420 m	136.8	0	335.8	(± 145%)	185	0.7	37.2
165-420 m	2464.7	918.6	4010.8	(± 63%)	3174	0.8	36.7
Columbia South							
1979							
165-319 m	2968.1	853.9	5082.3	(± 71%)	5695	0.5	
320-420 m	3691.3	1082.9	6299.7	(± 71%)	5416	0.7	
165-420 m	6659.4	3359.1	9959.7	(± 50%)	11112	0.6	34.6
1985							
165-319 m	1229.2	533.9	1924.6	(± 57%)	2323	0.5	31.8
320-420 m	2143.6	1114.6	3172.5	(± 48%)	2724	0.8	35.0
165-420 m	3372.8	2153.1	4592.5	(± 36%)	5046	0.7	35.0
Columbia Total							
1979							
165-319 m	6667.7	3266.4	10069.0	(± 51%)	10776	0.6	
320-420 m or 475 m	3859.9	1269.8	6450.0	(± 67%)	5620	0.7	
165-420 m or 475 m	10527.6	6323.9	14731.3	(± 40%)	16397	0.6	35.2
1985							
165-319 m	6296.5	4441.3	8151.8	(± 29%)	8701	0.7	35.6
320-420 m	2371.5	1339.8	3403.2	(± 44%)	3015	0.8	37.8
165-420 m	8668.0	6577.6	10758.5	(± 24%)	11716	0.7	36.1

a/ 1979 estimates based on survey depths of 165-475 m north of the Columbia River and 165-420 m south of the Columbia River; Noreastern trawl catch rates were used north of the river, 400 Eastern trawl catch rates between the river and 45°22' N lat., and Mystic trawl catch rates south of 45°22' N lat.

b/ This analysis of the 1985 data incorporates adjustments to make the results as closely comparable to the 1979 results as possible. Survey depths used in the analysis were 165-475 m north of the Columbia River and 165-420 m south of the river. Noreastern trawl catch rates were used in all areas except the Columbia South where Noreastern trawl catch rates were adjusted to Mystic trawl catch rates by multiplying them by 2.64. Consequently, the Columbia Total estimates also reflect the use of Mystic trawl catch rates in the Columbia South area.

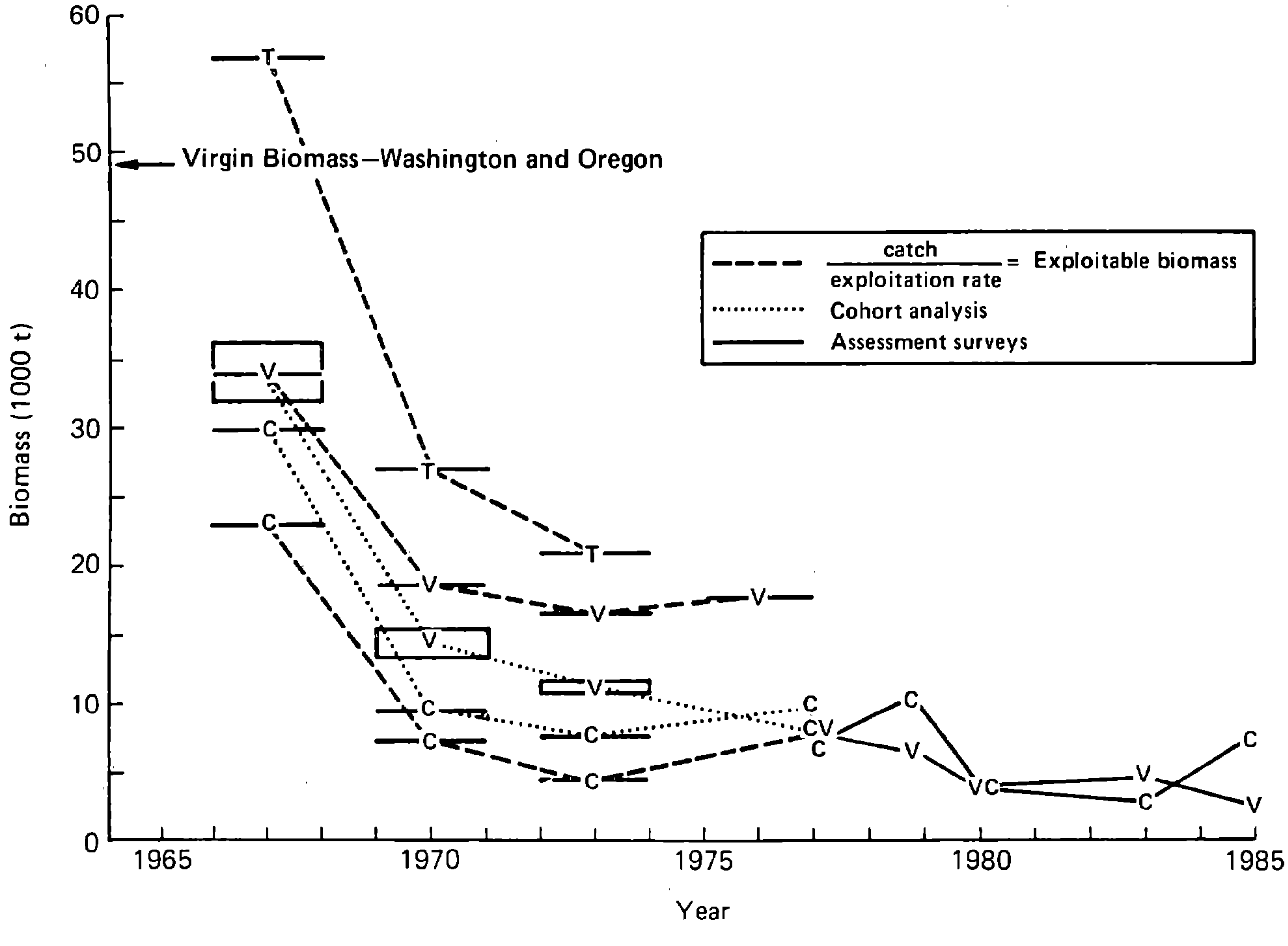


Figure 4.--Summary of various estimates of biomass for the stocks of Pacific ocean perch in the International North Pacific Fisheries Commission areas, Vancouver (V) and Columbia (C). The different methods used to derive biomass estimates are indicated by different line patterns.

Vancouver area by the Canadian Department of Fisheries and Oceans also reflect a similar decline in biomass of Pacific ocean perch (down 56%) between the fall of 1979 (4,200 t) and the fall of 1985 (1,850 t) (Bruce M. Leaman, Pacific Biological Station, Nanaimo, B.C., Canada, personal communication). Stocks in the Columbia area decreased by 18% in terms of biomass and 29% in numbers of fish. Although these differences appear large, differences in the estimates for the 2 years were not statistically significant due to the wide confidence intervals of the 1979 results (Table 6). The Z-statistics for the U.S.-Vancouver and Columbia areas were -1.48 and -0.66, respectively, neither of which exceeds the test value of 1.96 (alpha = 0.05).

The depth distribution of the population was similar in both survey years. Approximately 85-95% of the estimated population occurred in the shallow zone except in the Columbia South subarea where only 35-45% of the population was in the shallow stratum. This subarea is different from the others in that the deep stratum is larger than the shallow. The depth distribution in 1985 was smoother than in 1979 when examined by 20 m depth intervals (Fig. 5). The population was also distributed more evenly latitudinally in 1985 (Fig. 6).

The 1985 survey yielded more precise biomass estimates than the 1979 survey (Table 6). The 90% confidence intervals around the area-depth biomass estimates ranged from ±24 to ±66% with one exception of ±145% in the deep zone of the Columbia Middle subarea. The more even latitudinal and depth distribution of the population and more consistent data collection procedures were undoubtedly major factors in this improvement.

Major differences are evident between the population size composition estimates from the two surveys (Fig. 7). The majority of the 1979 population

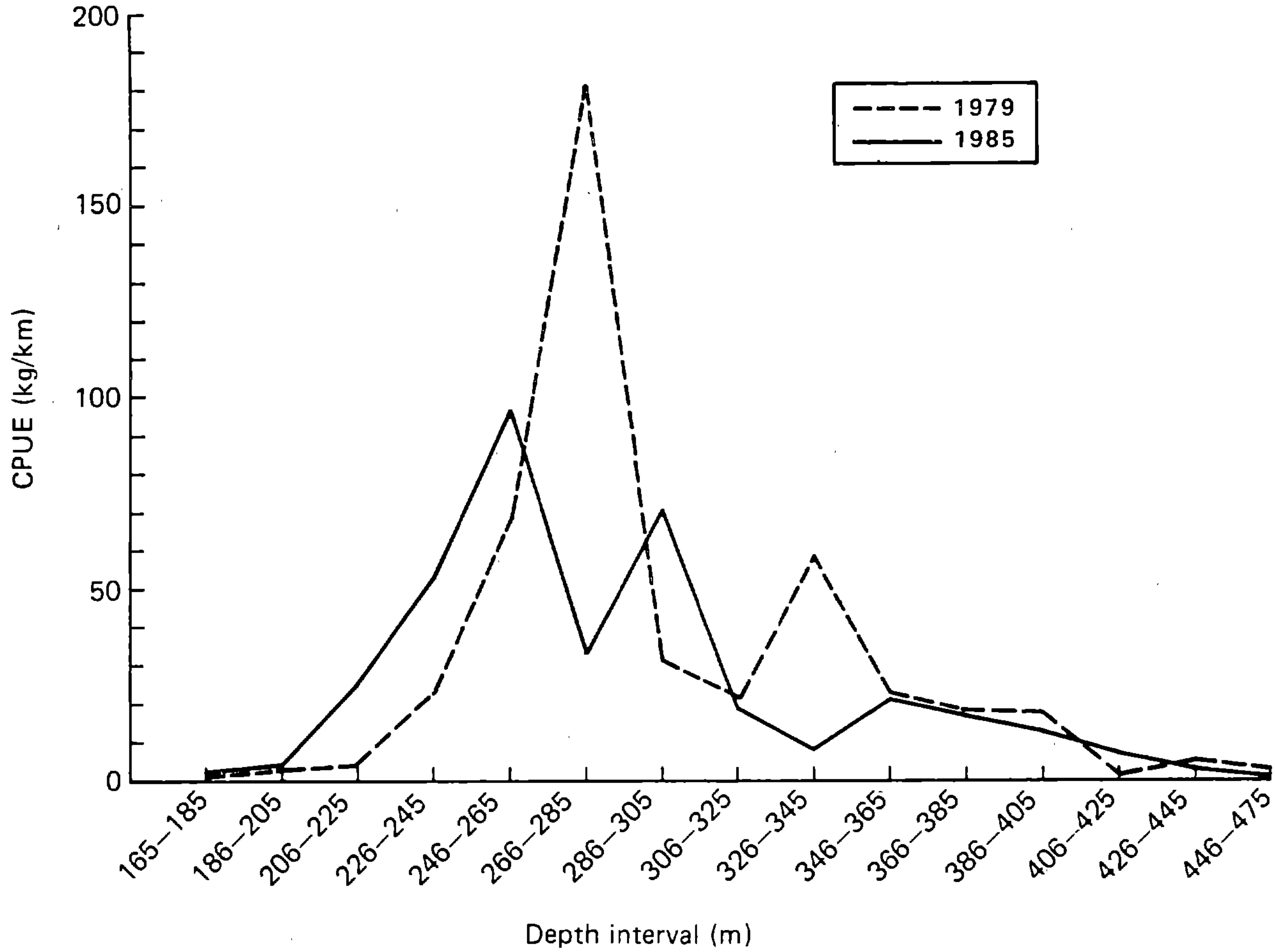


Figure 5.--The depth distribution of Pacific ocean perch in 1979 and 1985 (survey results) shown by mean catch per unit effort by 20 m depth intervals.

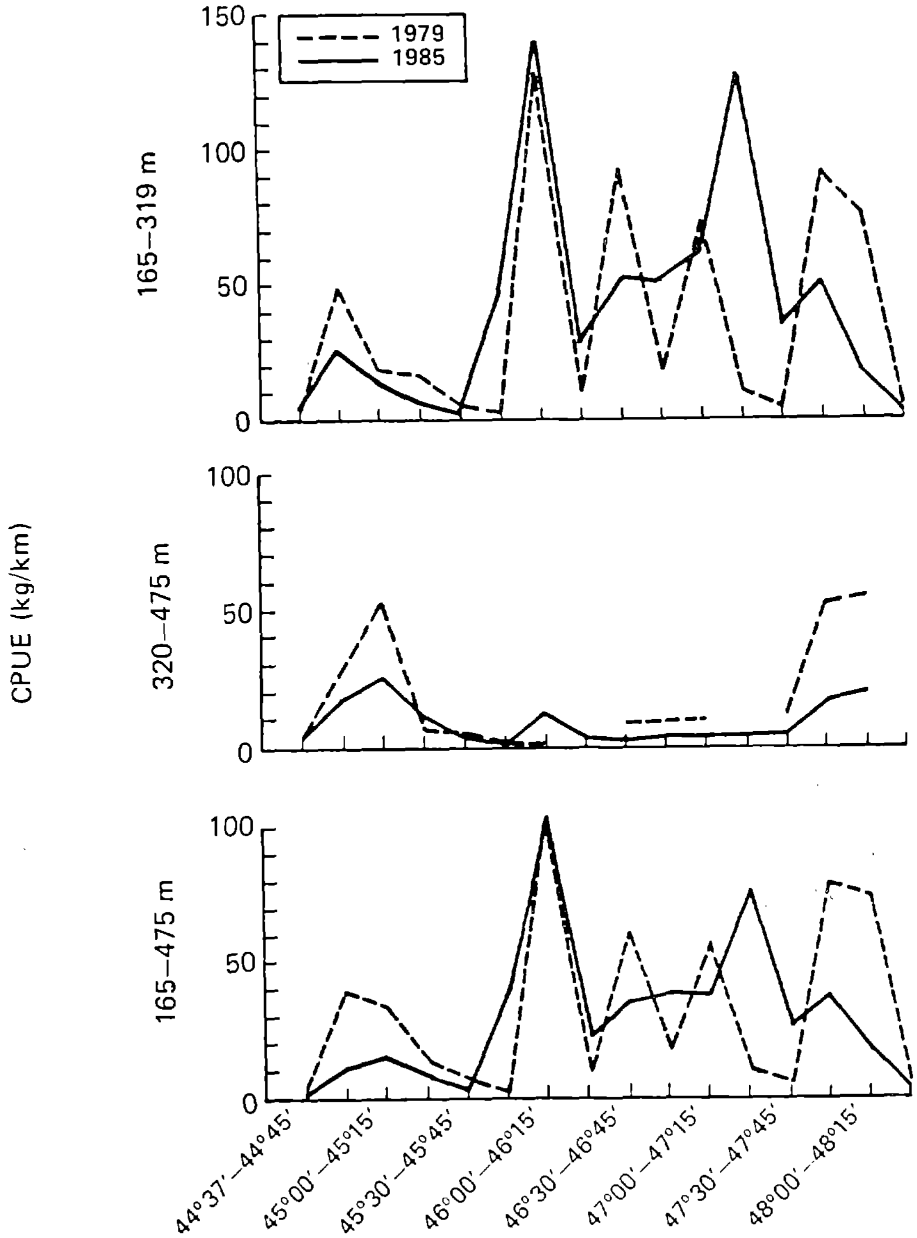


Figure 6.--The latitudinal distribution of Pacific ocean perch in 1979 and 1985 (survey results) shown by mean catch per unit effort by 15 minute latitude intervals.

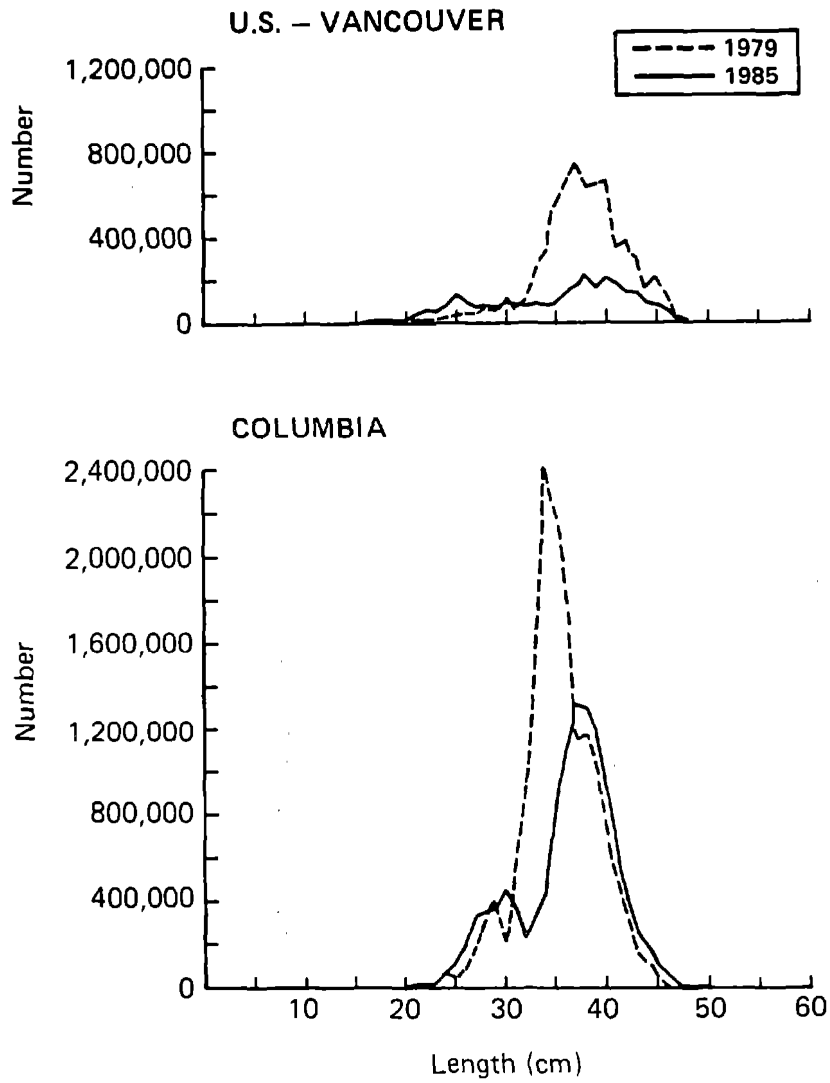


Figure 7.--The population size composition of Pacific ocean perch in 1979 and 1985 (survey results) in the International North Pacific Fisheries Commission Vancouver (U.S. portion) and Columbia areas. The 1985 results have been adjusted to Mystic trawl catch rates in the Columbia South subarea and depth coverage to 420 m off Oregon for comparison with the results of the 1979 survey.

in the U.S.-Vancouver area was included in a single large mode at 34-42 cm. The 1985 population was spread relatively evenly across all lengths between 22 and 46 cm. The population size composition in the Columbia area was bimodal in 1985 with a major mode at 34-42 cm and a smaller mode at 27-31 cm. The large mode of fish at 34 cm seen in 1979 appears still to be relatively strong 6 years later as larger fish. There were more small fish (20-30 cm) in both areas during 1985 than there were in 1979, suggesting somewhat stronger recruitment, or fewer large fish, than in recent years. Larger fish dominated the size composition in the deep strata consistently in both years and all areas, a pattern which is consistent with the distribution of most rockfish species.

The sex ratio of the population changed notably between 1979 and 1985. The population was 47.8% male in 1979 and 53.8% male in 1985. This shift toward a higher proportion of males was consistent in all strata (Table 7). The proportion of males was higher in all shallow strata of the Columbia area than in the deep strata, although the opposite trend was found in the U.S.-Vancouver area. This pattern occurred during both survey years. The dissimilarities in sex ratio and size composition between Pacific ocean perch in these two INPFC areas supports the approach of managing them as separate stocks.

All resource assessment results show the dramatic decline of Pacific ocean perch stocks during and after the intensive fishing in 1966-68 (Fig. 4). Managers of groundfish resources responded to the situation by restricting foreign catches of this species to incidental levels in 1977 when extended jurisdiction took effect in Canadian and U.S. waters. When U.S. trawlers were prohibited from fishing in Queen Charlotte Sound in l977, the groundfish stocks off the Washington and Oregon coasts were subjected to

Table 7.--Sex ratios (percent males) of Pacific ocean perch populations in the INPFC* Vancouver and Columbia areas (U.S. waters only) from results of the 1985 Pacific ocean perch survey by survey subarea and depth zone. Values in parentheses represent results of the analysis which adjusted 1985 estimates for comparison with 1979 results (depths to 420 m and catch rates adjusted to the Mystic trawl in the Columbia South subarea).

	1979	1985
U.S.-Vancouver area		
165-319 m	46.54	47.70
320-475 m	46.67	51.57
165-475 m	46.57	48.25
Columbia North subarea		
165-319 m	51.70	54.19
320-475 m	43.03	36.05
165-475 m	51.13	53.74
Columbia Middle subarea		
165-319 m	44.17	58.73
320-475 m	33.05	48.02 (48.77)
165-475 m	43.96	57.66 (58.15)
Columbia South subarea		
165-319 m	53.17	57.17 (57.16)
320-475 m	46.26	54.06 (53.42)
165-475 m	49.80	55.56 (55.14)
Columbia area		
165-319 m	49.63	56.42 (56.55)
320-475 m	45.91	51.46 (52.61)
165-475 m	48.54	55.63 (55.53)
Total survey area		
165-319 m	48.45	54.20 (54.58)
320-475 m	46.13	51.48 (52.49)
165-475 m	47.84	53.78 (54.09)

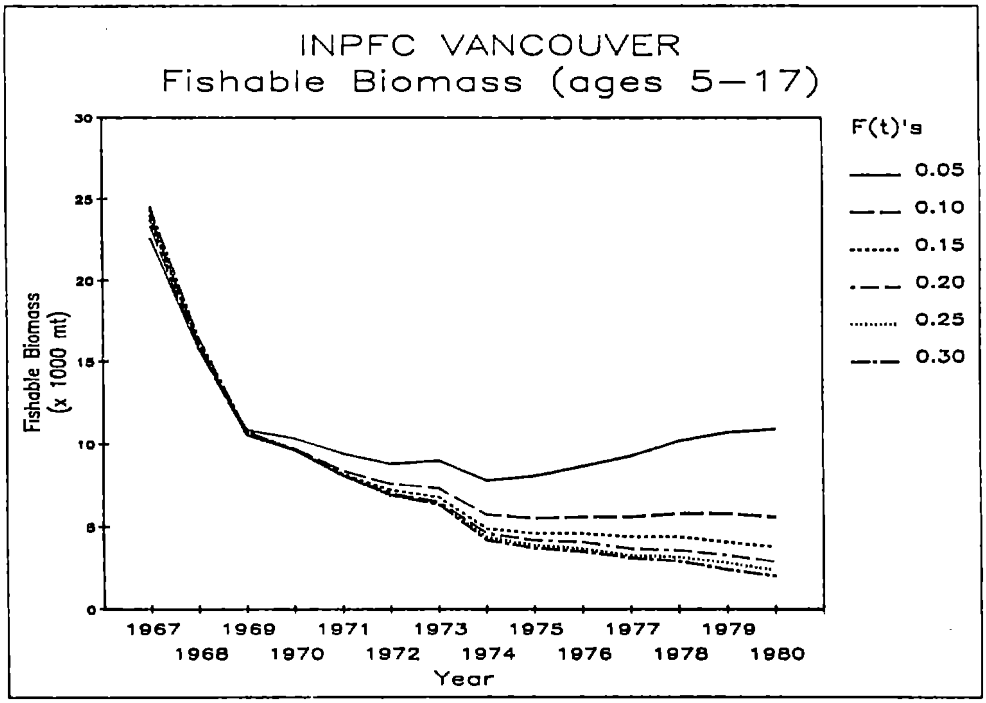
*International North Pacific Fisheries Commission.

increased fishing pressure. Trip limits for Pacific ocean perch were imposed on domestic trawlers in late 1978 to control Landings and promote the Pacific Fishery Management Council's goal of rebuilding the stocks off Washington and Oregon. Gunderson (1979) estimated through cohort analysis that these stocks could be rebuilt in approximately 20 yr to a level which they would produce maximum sustainable yields. This strategy required limiting acceptable biological catches (ABC) to 600 t and 950 t in the U.S.-Vancouver and Columbia areas, respectively (Pacific Fishery Management Council 1980).

Analytic Models

Fishable biomass estimates calculated from VPA are shown in Figure 8. Table 8 provides estimates of total and fishable biomass for the first year of age data (1966 or 1967), the year Pacific ocean perch was fully surveyed (1979), and the final year of age data (1980). The estimates of early biomass (1966-67) are largely unchanged for the different values of F(start). These are approximately 36,000 t total, 23,000 t fishable for the Vancouver area, and 50,000 t total and 30,000 t fishable in the Columbia area. For M=O.l, Gunderson (1981) estimated a fishable biomass of 32,019 t for the Vancouver area, and 29,873 t for the Columbia area. Clearly the main difference is in the Vancouver area, where the present study provides significantly lower estimates of 1967 biomass.

The SPA fits based on catch-in-biomass data (Table 1) are summarized in Table 9 for the Vancouver area and Table 10 for the Columbia area. Given an assumed virgin biomass, and a value for the Cushing stock-recruitment coefficient (r), the SPA fit to the catch data is completely determined. Because the 1985 U.S. and Canadian trawl surveys estimated biomass to be approximately 4,000 t in the Vancouver area and 10,000 t in the Columbia area, virgin biomass in 1956 is estimated to be approximately 68,000-72,500 t



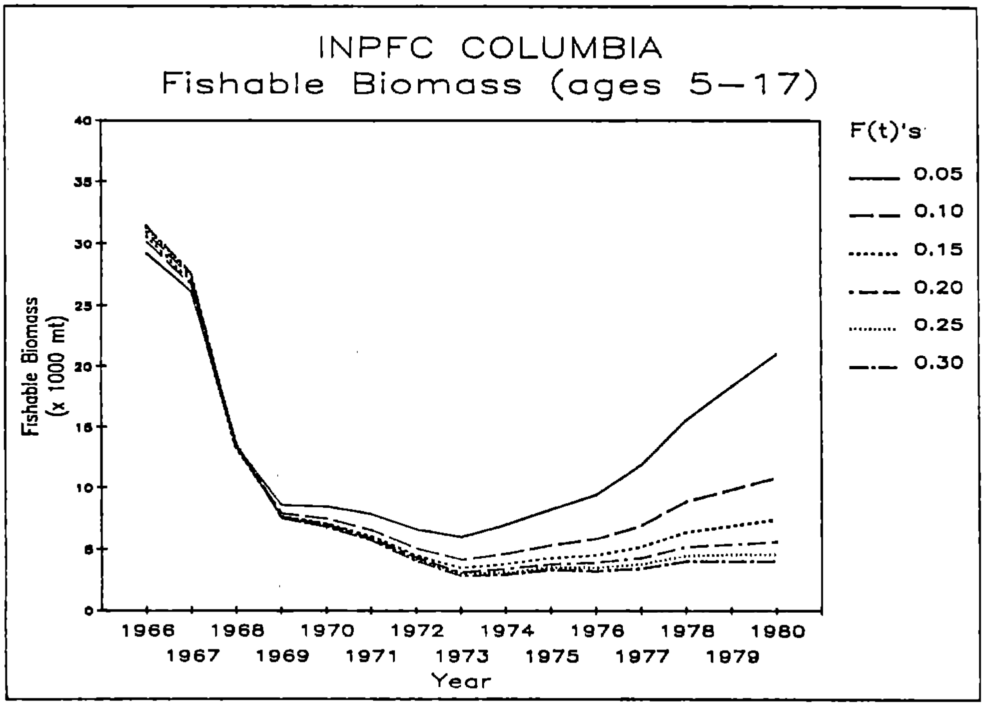


Figure 8. --Virtual population analysis estimates of fishable biomass by year for Pacific ocean perch in the International North Pacific Fisheries Commission Vancouver and Columbia areas using a range of initial F-values from 0.05 to 0.30 and a natural mortality rate of M = 0.05.

Table 8.--Virtual population analysis estimates of total and fishable biomass (metric tons, ages 5-17 combined) for INPFC* Vancouver and Columbia areas. Estimates are for selected years, based on M=0.05 and various F(start) levels.

	INPFC Vancouver			INPFC Columbia		
F(start)	1967	1979	1980	1966	1979	1980
Total biomass						
0.05	38,826	19,363	18,669	51,430	47,928	51,676
0.10	36,946	9,270	8,535	49,994	22,918	23,910
0.15	36,320	6,231	5,521	49,515	15,273	15,563
0.20	36,006	4,790	4,102	49,276	11,610	11,598
0.25	35,819	3,596	3,283	49,133	9,474	9,298
0.30	35,694	3,414	2,754	49,037	8,080	7,802
Fishable biomass						
0.05	22,593	10,742	10,919	29,207	18,394	21,025
0.10	23,270	5,792	5,595	30,135	9,773	10,773
0.15	23,713	4,124	3,821	30,659	6,878	7,358
0.20	24,034	3,286	2,936	31,016	5,426	5,653
0.25	24,284	2,782	2,405	31,282	4,554	4,632
0.30	24,485	2,446	2,052	31,493	3,972	3,952

*International North Pacific Fisheries Commission.

Table 9.--Stock reduction analysis (SRA) fits to the INPFC[a/] Vancouver area catch data. The SRA solutions are completely determined for given values of virgin biomass and the Cushing recruitment coefficient (r). Underlined values are those that best fit the survey data.

Assumed virgin biomass	Cushing recruitment coefficient (r)			
	0.000	0.125	0.250	0.500
Final biomass at the beginning of 1986				
67,000	No solution			
68,000	13,035	8,020	4,235	n.s.[b/]
70,000	15,518	10,913	7,304	2,236
72,500	18,467	14,187	10,730	5,666
75,000	21,302	17,248	13,900	8,844
Biomass at the beginning of 1967				
68,000	32,706	32,702	32,698	n.s.
70,000	34,706	34,702	34,698	34,691
72,500	37,206	37,202	37,198	37,191
75,000	39,706	39,702	39,699	39,691
Maximum sustainable yield assuming F=0.05				
68,000	1,382	1,224	1,041	n.s.
70,000	1,423	1,260	1,071	608
72,500	1,473	1,305	1,110	629
75,000	1,524	1,350	1,148	651
Equilibrium biomass at MSY assuming F=0.05				
68,000	29,043	25,720	21,872	n.s.
70,000	29,900	26,479	22,518	12,772
72,500	30,968	27,424	23,322	13,228
75,000	32,035	28,369	24,126	13,683
Maximum sustainable yield assuming F unconstrained	(F=0.49)			
68,000	1,890	1,411	1,086	n.s.
70,000	1,946	1,452	1,118	632
72,500	2,015	1,504	1,158	654
75,000	2,085	1,556	1,198	677
Equilibrium biomass at MSY assuming F unconstrained				
68,000	4,992	10,377	14,476	n.s.
70,000	5,139	11,389	14,904	21,908
72,500	5,322	11,795	15,436	22,690
75,000	5,506	12,202	15,968	23,471

a/Iternational North Pacific Fisheries Commission.
b/n.s. = no solution.

Table 10.--Stock reduction analysis (SRA) fits to the INPFC[a/] Columbia area catch data. The SRA solutions are completely determined for given values of virgin biomass and the Cushing recruitment coefficient (r). Underlined values are those that best fit the survey data.

Assumed virgin Biomass	Cushing recruitment coefficient (r)			
	0.000	0.125	0.250	0.500
Final biomass at the beginning of 1986				
69,000	No Solution-------------------------------			
70,000	14,914	9,473	5,450	n.s.[b/]
72,500	17,976	13,073	9,267	3,998
75,000	20,877	16,310	12,654	7,369
77,500	23,676	19,348	15,806	10,519
Biomass at the beginning of 1966				
70,000	48,893	48,893	48,893	n.s.
72,500	51,393	51,393	51,393	51,393
75,000	53,894	53,894	53,894	53,894
77,500	56,394	56,394	56,394	56,394
Maximum sustainable yield assuming F=0.05				
70,000	1,423	1,260	1,071	n.s.
72,500	1,473	1,305	1,110	629
75,000	1,524	1,350	1,148	651
77,500	1,575	1,395	1,186	673
Equilibrium biomass at MSY assuming F=0.05				
70,000	29,900	26,479	22,518	n.s.
72,500	30,968	27,424	23,322	13,228
75,000	32,035	28,369	24,126	13,683
77,500	33,102	29,314	24,929	14,139
Maximum sustainable yield assuming F unconstrained	(F=0.49)			
70,000	1,946	1,452	1,118	n.s.
72,500	2,015	1,504	1,158	654
75,000	2,085	1,556	1,198	677
77,500	2,154	1,608	1,238	699
Equilibrium biomass at MSY assuming F unconstrained				
70,000	5,139	10,638	14,904	n.s.
72,500	5,322	11,795	15,436	22,690
75,000	5,506	12,202	15,968	23,471
77,500	5,689	12,608	16,500	24,253

a/International North Pacific Fisheries Commission.
b/n.s. = no solution.

in the Vancouver area and 70,000-77,500 t in the Columbia area. Figure 9 graphs the biomass trends for the SRA fits most consistent with the 1985 survey estimates.

Although VPA shows that recruitment is gradual and not knife-edged (Table 11), it is useful to examine the number of l0-yr-olds as an index of recruitment strength (Table 12). Recruitment in the Vancouver and Columbia areas shows a dramatic decline. Both areas show a large initial decline, as the earlier recruitment values are from near virgin biomass levels. However, the Vancouver area shows a continued decline in recent years, while the Columbia area gives some indication of stabilized recruitment and the promise of a strong 1970 year class.

Comparing our recruitment estimates with F(start)=O.lO (average 1,538 t for the Vancouver area, and 1,909 t for the Columbia area) with those calculated by Gunderson (1981) (average 3,297 t for the Vancouver area and 2,326 t in the Columbia area), we see that our estimates of recruitment are lower especially in the Vancouver area. The 1979 survey estimates of fishable biomass, 9,716 t in the Vancouver area and 10,528 t in the Columbia area, favor F(start)=0.05 in the Vancouver area and F(start)=O.lO in the Columbia area (Table 12). Thus, annual recruitment in both areas appears to have averaged approximately 2,000 t.

The SRA assumed knife-edged recruitment to the fishable biomass at age 10 yr. This approximation is intended to account for the fact that many fish younger than age 10 yr are recruited to the fishable stock, while fish 10 yr and older are not fully recruited. The age-at-recruitment would affect the SRA analysis by changing the Ford growth parameters (RHO, OMEGA), and the time delay between stock size and subsequent recruitment. Both changes would be gradual, and one would not expect a radical change in the analysis if the

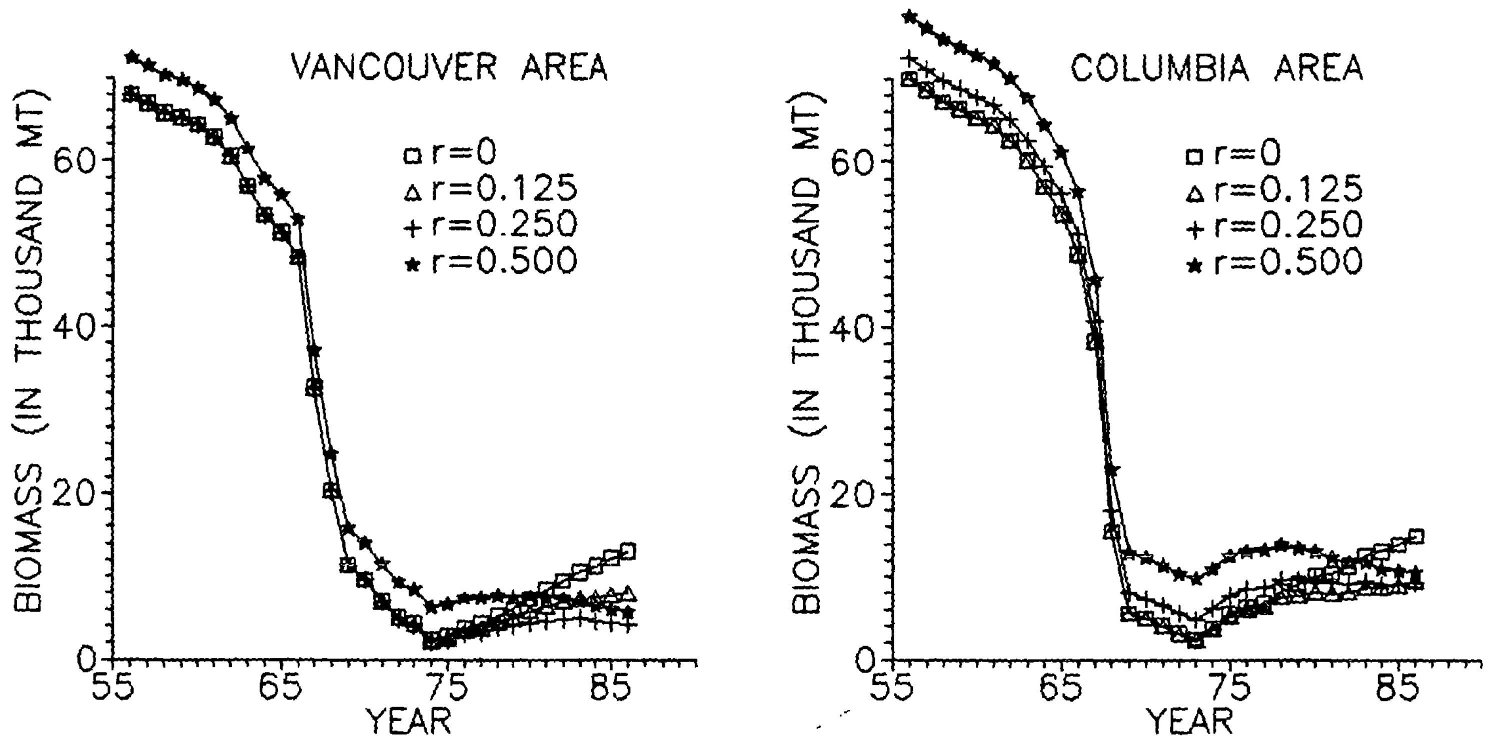


Figure 9.--Stock reduction analysis estimates of biomass by year for Pacific ocean perch in the International North Pacific Fisheries Commission Vancouver and Columbia areas based on various Cushing recruitment coefficients (r).

Table 11 .--Virtual population analysis estimates of vulnerablity coefficients for ages 5 through 17 in the INPFC* Vancouver and Columbia area stocks under M=0.05 and various F(start) levels.

	F(start) levels					
INPFC Vancouver						
Age	0.05	0.10	0.15	0.20	0.25	0.30
5	0.0082	0.0146	0.0207	0.0263	0.0316	0.0365
6	0.0199	0.0331	0.0443	0.0541	0.0627	0.0705
7	0.0587	0.0820	0.0995	0.1136	0.1253	0.1353
8	0.1050	0.1376	0.1608	0.1790	0.1939	0.2065
9	0.2278	0.2651	0.2889	0.3068	0.3212	0.3331
10	0.4125	0.4584	0.4843	0.5023	0.5159	0.5268
11	0.5999	0.6535	0.6796	0.6961	0.7078	0.7167
12	0.7635	0.8182	0.8423	0.8565	0.8660	0.8730
13	0.7786	0.8330	0.8581	0.8732	0.8834	0.8909
14	0.7496	0.8008	0.8268	0.8432	0.8548	0.8635
15	0.7930	0.8201	0.8335	0.8418	0.8477	0.8521
16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
INPFC Columbia						
Age	0.05	0.10	0.15	0.20	0.25	0.30
5	0.0086	0.0133	0.0169	0.0199	0.0224	0.0247
6	0.0618	0.0864	0.1030	0.1156	0.1256	0.1338
7	0.1310	0.1590	0.1767	0.1899	0.2005	0.2092
8	0.2525	0.2755	0.2883	0.2974	0.3045	0.3102
9	0.2618	0.2911	0.3062	0.3163	0.3239	0.3300
10	0.3500	0.3807	0.3964	0.4069	0.4148	0.4211
11	0.5139	0.5483	0.5645	0.5747	0.5820	0.5876
12	0.7018	0.7348	0.7495	0.7583	0.7643	0.7688
13	0.6676	0.7094	0.7287	0.7403	0.7482	0.7539
14	0.6856	0.7259	0.7471	0.7608	0.7706	0.7781
15	0.8744	0.8974	0.9088	0.9158	0.9207	0.9243
16	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
17	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

*International North Pacific Fisheries Commission.

Table 12.--Virtual population analysis estimates of recruitment of 10 year olds (metric tons) to the INPFC* Vancouver and Columbia area stocks by year class under M=0.05 and various F(start) levels.

INPFC Vancouver

Yr class	F(start) levels 0.05	0.10	0.15	0.20	0.25	0.30
1957	3,080	2,884	2,818	2,785	2,766	2,753
1958	2,006	1,804	1,737	1,703	1,683	1,670
1959	1,645	1,453	1,389	1,357	1,338	1,325
1960	2,027	1,826	1,759	1,725	1,705	1,692
1961	3,142	2,835	2,733	2,681	2,651	2,630
1962	2,644	2,157	1,995	1,914	1,865	1,833
1963	2,381	1,712	1,496	1,386	1,320	1,276
1964	1,944	1,300	1,085	978	913	871
1965	1,861	1,163	938	828	763	719
1966	1,985	1,137	872	745	670	621
1967	1,863	988	717	586	510	460
1968	1,476	768	550	444	383	342
1969	1,399	684	466	361	301	261
1970	1,768	815	527	390	311	260
Mean	2,087	1,538	1,363	1,277	1,227	1,194

INPFC Columbia

Yr class	0.05	0.10	0.15	0.20	0.25	0.30
1956	5,532	5,383	5,334	5,309	5,294	5,284
1957	3,397	3,269	3,226	3,205	3,192	3,183
1958	2,053	1,827	1,751	1,713	1,691	1,676
1959	1,082	911	854	826	809	797
1960	1,061	929	885	863	850	841
1961	1,808	1,433	1,307	1,245	1,207	1,182
1962	1,858	1,300	1,115	1,022	966	929
1963	1,574	1,024	841	749	694	658
1964	1,773	1,106	884	773	707	662
1965	2,148	1,226	926	779	691	633
1966	2,722	1,434	1,028	831	715	639
1967	2,287	1,169	820	651	552	487
1968	2,188	1,120	782	617	520	455
1969	3,742	1,830	1,235	948	779	668
1970	9,932	4,679	3,069	2,297	1,846	1,552
Mean	2,877	1,909	1,604	1,455	1,368	1,310

*International North Pacific Fisheries Commission.

age at recruitment were increased only a few years. Nevertheless, total biomass estimates from VPA for the 1966-67 time period (Table 8) compare well with the fishable biomass estimates from SRA (Tables 9 and IO). The reason for this is not clear. It may be simply that the SRA definition of fishable population (i.e., total population greater than age 10 yr) is approximately equal to the VPA definition of total population (i.e., total population between 5 and 17 yr). Nevertheless, the estimated biomass of all 10 yr-olds from VPA (Table 12) is close to the annual recruitment estimated from SRA (1,989 t from a virgin biomass of 70,000 t). This would be expected in theory.

Because virgin biomasses in the Vancouver and Columbia areas were approximately the same, the SRA estimates of MSY from these areas are approximately the same. Assuming F_{max}-0.05, it is believed that both areas can sustain catches of around l,OOO-1,500 t annually (Tables 9 and 10). If higher fishing mortality rates are sustainable and r is zero, higher yields would appear possible. However, this scenario is unreasonable because it suggests a removal of about 2,000 t annually from a fishable biomass of only 5,000 t.

Currently, stock biomass is approximately 6% and 12% of the virgin biomass in the Vancouver and Columbia areas, respectively. Recruitment failure is viewed as a strong possibility at these low stock levels. In fact, it should be clear from Tables 9 and 10 that from the biological point of view, the stock should be rebuilt to around the 25,000 t level in both areas. The rebuilt stocks will result in larger yields than available from the current biomass. Also, this larger standing stock would likely result in stronger recruitment.

The weakness of the SRA approach applied to these Pacific ocean perch stocks is that probably none of the Cushing recruitment coefficients (r) apply properly to the long history of stock decline. For example, perhaps the population behaves as a constant recruitment model (r=O.O) when B is greater than some threshold level; but when B is below this threshold level, there may be a strong stock recruitment relationship (e.g., r=0.50). Under these circumstances, the r=O.O scenarios would overestimate the stocks rate of rebuilding, while all scenarios would probably underestimate recruitment in the rebuilt stock and therefore underestimate the potential MSY.

REBUILDING SCENARIOS

It is clear that the current stock condition of Pacific ocean perch in the INPFC Vancouver and Columbia areas is very poor. Therefore, it is desirable to know what can be done to rebuild the population to more optimal levels. One way this can be done is to use Schnute's (1985) form of the delay-difference equation to project future population biomass. The SRA fits provide a convenient starting point for such projections. Given a particular SRA fit, say M, RHO, OMEGA, B_o, and a Cushing recruitment coefficient (r), the future population biomass is a function of annual fishing intensity F. The rate of rebuilding is largely a function of r and F.

Figures 10 and 11 project future stock biomass from the SRA fits that agree most closely with the 1985 survey (Table 6). Obviously, rebuilding is most rapid for scenarios with small r's and F's. However, the question arises as to which r is most appropriate. Tables 9 and 10 indicate the probability that r>O, since the SRA fits with r=O.O have difficulty fitting the 1985 survey results. Furthermore, Table 12 indicates that recruitment has decreased substantially with the decrease in stock biomass. Let us consider some rough figures: Virgin stock was approximately 70,000 t in both

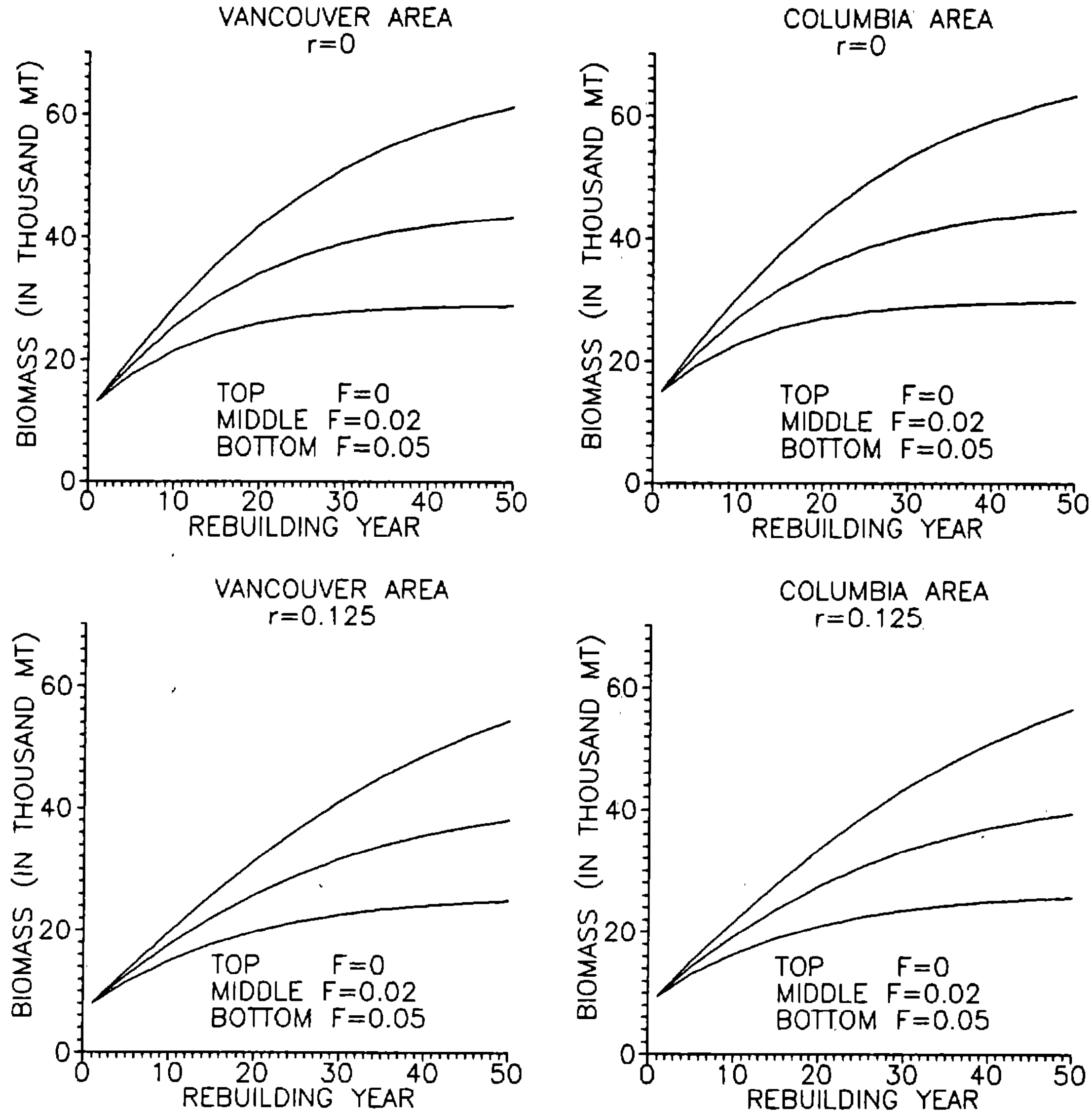


Figure 10.--Biomass projections for Pacific ocean perch in the International North Pacific Fisheries Commission Vancouver and Columbia areas based on Cushing recruitment coefficients (r) of 0.0 and 0.125 and F levels of 0.0, 0.02, and 0.05.

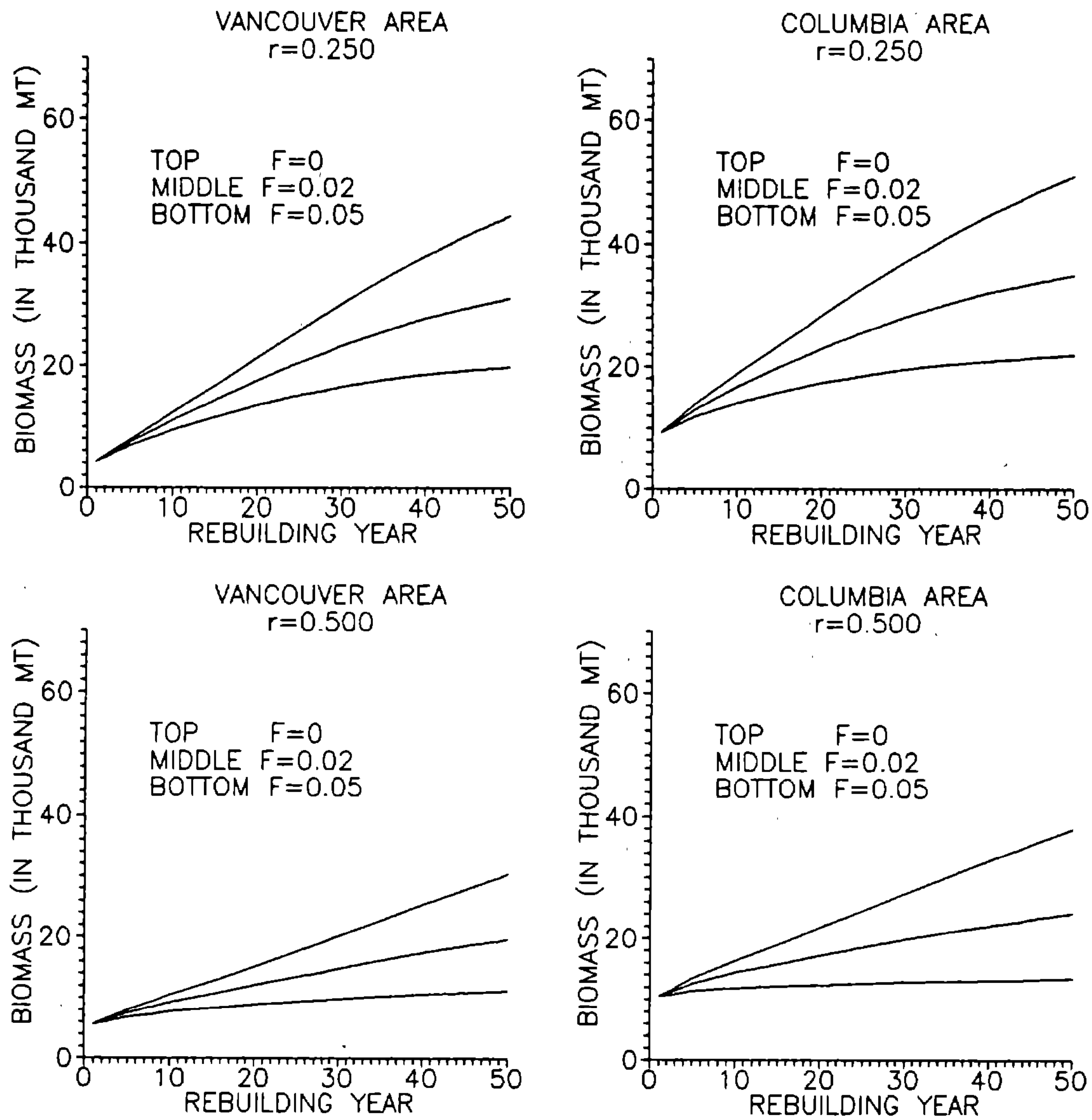


Figure 11 .--Biomass projections for Pacific ocean perch in the International North Pacific Fisheries Commission Vancouver and Columbia areas based on Cushing recruitment coefficients (r) of 0.25 and 0.50 and F levels of 0.0, 0.02, and 0.05.

areas, with current biomass approximately 10,000 t, and recruitment from the virgin biomass appears to have decreased to half that from the virgin stock. The applicable Cushing recruitment coefficient that solves 0.5=(1/7)**r is r=0.36. Hence, a realistic r might be in the 0.25-0.50 range.

Because SRA models with r=O.O or 0.125 could not always be accurately fitted to the 1985 survey data, the rebuilding trends in Figures 10 and 11 start from different initial biomass values. To correct somewhat for this bias, the rebuilding trends presented in these figures have been presented in a different and probably more usable form. Table 13 gives the number of years required to rebuild the stock a fixed amount, given the area, r, and a future instantaneous fishing mortality rate.

From Table 13 it appears that both the Vancouver and Columbia areas can be expected to rebuild at approximately the same rate, though Vancouver can be expected to be a little slower. With a middle estimate of r (r-=0.25), when there is no fishing (F=O.O), the stocks can be expected to rebuild at the rate of 5,000 t every 6 or 7 years; when F=0.02, the rate is 5,000 t every. 7 or 8 years; and when F=0.05 the rate is 5,000 mt every 10 or 11 years. With a stronger stock-recruitment relationship (r=0.50), F=O;O implies a rebuilding rate of 5,000 t every 9 to 11 years, and F=0.02 implies 5,000 t takes 15 to 16 years. With r=0.50, an F=0.05 implies there will be no rebuilding.

In 1979, survey biomass was roughly 10,000 t in both INPFC areas. Since 1979, annual catches have averaged approximately 1,000 t from both areas. Clearly the stocks in these areas cannot be expected to rebuild at annual fishing rates of F=O.l. In fact, there is the probability that further damage will be done to these stocks. Since the 1985 survey shows that the Vancouver area stock suffered a sharp decline, while the Columbia area stock

Table 13.--Estimated number of years to rebuild Pacific ocean perch stocks using the stock reduction analysis results that best fit the survey data (underlined in Tables 9 and IO). Rebuilding time is a function of both the Cushing recruitment coefficient (r) and the instantaneous fishing rate (F).

	Cushing recruitment coefficients (r)											
	0.000			0.125			0.250			0.500		
Estimated population increase	Fishing mortality rate (F)											
	.0	.02	.05	.0	.02	.05	.0	.02	.05	.0	.02	.05
	INPFC* Vancouver Area											
5,000	4	5	6	5	6	8	7	8	10	11	16	42
10,000	7	9	13	9	11	16	13	15	23	22	34	50+
15,000	10	13	33	13	17	33	18	23	45	32	50+	50+
20,000	14	19	50+	18	24	50+	24	33	50+	41	50+	50+
25,000	17	28	50+	22	33	50+	30	45	50+	50+	50+	50+
	INPFC Columbia Area											
5,000	4	5	6	5	6	7	6	7	11	9	15	50+
10,000	7	9	15	9	11	17	11	14	29	18	33	50+
15,000	10	13	50+	13	17	36	16	23	50+	27	50+	50+
20,000	13	19	50+	17	24	50+	21	33	50+	36	50+	50+
25,000	17	29	50+	21	33	50+	27	48	50+	46	50+	50+

*International North Pacific Fisheries Commission.

is roughly unchanged, the question arises as to why stocks did not suffer equally in the two areas? Our best guess would be that recruitment in the Vancouver area has been weaker than in the Columbia area (Table 12).

CONCLUSIONS AND RECOMMENDATIONS

From the study presented in this paper, it is clear that Pacific ocean perch stocks in the Vancouver and Columbia areas are in poor and perhaps worsening condition. These stocks have deteriorated to the point that acceptable biological catch (ABC), the catch which is justifiable from biological considerations only, should be set at a low level in both the Vancouver and Columbia INPFC areas. We have attempted to establish a range of ABC values for each area to be consistent with the groundfish management team's (GMT) definition of ABC: "ABC is the GMT's estimate of a catch or a range of catches that will result in the stock remaining at or approaching the maximum sustainable yield (MSY) level, or remaining constant if the stock is not at the MSY level."

We believe that the current biomass of Pacific ocean perch in both regions is well below the level which produces MSY. Based on the 1985 trawl surveys, stock biomass was estimated at about 3,900 t in the Vancouver area and approximately 8,700 t in the Columbia area. Our best estimate of the biomass which produces MSY is roughly 25,000 t for both stocks. If these stocks are to be rebuilt at the maximum rate, ABC should be set to zero. If rebuilding at the maximum rate is not desired, however, ABC can be any number between zero and our best estimate of equilibrium yield (EY).

We estimated EY from the previously calculated SRA solutions by examining levels of fishing mortality (F) that would stabilize the population at its current level. Only the SRA values of current biomass under Cushing recruitment coefficients of 0.25 and 0.50 were used (Tables 9 and 10, underlined values). These values were selected because they best approximated the 1985 survey biomass estimates and because current recruitment is thought to be affected by the low biomasses. The results of this analysis are summarized as follows:

	INPFC Vancouver		INPFC Columbia	
Cushing recruitment coefficient (r)	0.25	0.50	0.25	0.50
SRA estimates of current biomass	4,235	5,666	9,267	10,519
Equilibrium F	0.254	0.094	0.132	0.063
Equilibrium yield (EY)	928	494	1,120	629

Our best estimate of EY for both areas is the midpoint of the individual yields under the two recruitment scenarios (i.e., 711 and 874 t for the Vancouver and Columbia areas, respectively). The U.S. portion of the total Vancouver EY was estimated by multiplying the midpoint by the percentage of the 1985 survey biomass estimate in U.S. waters only (i.e., 52%). Therefore, our final recommendation for the 1987 ABC range is O-370 t for the U.S.-Vancouver area and O-874 t for the Columbia area.

It is important to understand the shortcomings of the stock assessment presented here. When a stock assessment is performed, usually a different level of credibility should be given to each portion of the analysis. For example, estimates of earlier population estimates, 1966-67 biomass from VPA, and 1956 virgin biomass from SRA, are probably fairly robust. Less certain, but still credible, are the range of estimates of maximum sustainable yield. Less credible still are the equilibrium biomasses corresponding to the MSY's. Least credible are the rebuilding schedules presented in this paper.

If one examines the previous paragraph it should be evident that uncertainty increases as the particular statistic depends more on the pattern of recruitment. Early biomass estimates and estimates of MSY ranges do not depend much on guessing the particular pattern of recruitment of a population. However, the equilibrium biomass of a population at a particular sustainable yield depends greatly on the particular stock-recruitment relationship, and the accuracy of any rebuilding schedule depends on the actual levels of future recruitment. Of course the latter is impossible to predict accurately in nature. However, the rebuilding schedule performs the useful service of providing a reasonable idea of what can be expected under optimistic and pessimistic recruitment scenarios and different levels of fishing intensity. It is easy to devise reasonable scenarios, both optimistic and pessimistic, that are not considered in our assessment. But it is nearly impossible to state probabilities for such conjectures.

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