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ABSTRACT

This report contains assessments of the conditions of groundfish and squid in the eastern Bering Sea and Aleutian Islands region management area. The assessments are based on single species analyses of commercial fishery and research vessel survey data available through August 1985. Estimates of maximum sustainable yields and equilibrium yields are presented to guide management of the 1986 fishery. Table A summarizes results of these assessments.

Pacific cod, Gadus *macrocephalus*; yellowfin sole, *Limanda aspera*; other flatfish, and Atka mackerel, *Pleurogrammus monopterygius*, remain in excellent condition with current populations at high levels of abundance. Abundance of the walleye pollock, *Theragra chalcogramma*, stock also remains relatively high and recruitment appears better in 1985 than it has in recent past years. Poor recruitment is believed to have reduced the abundance of adult Greenland turbot, *Reinhardtius hippoglossoides*. There has been some improvement in sablefish, *Anoplopoma fimbria*, stocks but Pacific ocean perch, *Sebastes alutus* stocks remain at low levels with no signs of improvement. Estimates of equilibrium yield for the groundfish complex as a whole decreased slightly from 2.19 million metric tons (t) in 1985 to 1.91 million t in 1986. Most of this decrease was accounted for by lower estimates of equilibrium yields for Pacific cod and yellowfin sole.

Table A.--Estimated biomass, maximum sustainable yield (MSY) and equilibrium yield (EY) in thousands of metric tons (t), and views on stock condition of groundfish in the Eastern Bering Sea/Aleutian Islands Region from assessments in 1985[a].

Species	Estimated biomass	MSY	EY	Stock condition	Abundance trend
Walleye pollock	8,900	1,600	1,200		Abundance expected to decline but recruitment improved in 1985
(Eastern Bering Sea)	(7,900)	(1,500)	(1,100)	Fair	
(Aleutains)	(1,000)	(100)	(100)	Good	
Pacific cod	1,140	--	182	Very good	Abundance starting to decline from historic high
(Eastern Bering Sea)	(958)		(157.4)		
(Aleutians)	(182)		(24.5)		
Yellowfin sole	2,300	150-175	230	Very good	Abundance starting to decline from historic high
Turbots	535	58.3-69.7	55.0		
(Arrowtooth flounder)	(205)	(19.7)	(20.0)	Good	Abundance increasing
(Greenland turbot)	(330)	(38.6-50.0)	(35.0)	Fair	Abundance below average
Other flatfish	1,554	88-150	137.5		
(Alaska plaice)	(554)	(45-70)	(57.5)	Very good	Abundance above average
(Rock sole-flathead sole-other flatfish)	(1,000)	(43-80)	(80.0)	Very good	Abundance above average
Sablefish	121.3	15.1	6.0		
(Eastern Bering Sea)	(52.8)	<13.0	(2.6)	Improved	Although improved, below historic levels
(Aleutians)	(68.5)	>2.1	(3.4)	Improved	
Pacific Ocean perch	127.5	9.4-16.9	3.8-12.9		
(Eastern Bering Sea)	(13.6)	(2.8- 5.0)	(1.0- 3.8)	Poor	Abundance low and stable
(Aleutians)	(113.9)	(6.6-11.9)	(2.8- 9.1)	Poor	Abundance low and stable
Other rockfish	89.9	--	9.0		
(Eastern Bering Sea)	(11.5)	--	(1.2)	Unknown	Unknown
(Aleutians)	(78.4)	--	(7.8)	Unknown	Unknown
Atka mackerel	307	38.7	38.7	Good	Abundance above average
Squid	--	>10	10	--	Unknown
Other species	359	67.1	35.9	Fair	Abundance declining
TOTAL GROUNDFISH	15,434	2,037-2,143	1,908-1,917		

[a] Numbers in parentheses give estimates for individual management areas where applicable and for individual species making up a management unit species complex.

CONTENTS

INTRODUCTION

by

Richard G. Bakkala

The current conditions of groundfish and squid in the eastern Bering Sea and Aleutian Islands region are assessed in this report. These assessments, are based on single species analyses using data collected from the commercial fishery and research vessel surveys. Estimates of maximum sustainable yields (MSY) and equilibrium yields (EY) are presented to guide management of the 1986 fishery. This introduction to the report presents background information on the fishery and management which may be useful in evaluating the species assessments that follow.

Management Area

The management area for which assessments are made lies within the 200-mile U.S. fishery conservation zone of the eastern Bering Sea and Aleutian Islands (Fig. 1). International North Pacific Fisheries Commission (INPFC) statistical areas 1 to 5 are also illustrated in Figure 1. The portions of INPFC areas 1 and 2 within the U.S. fishery conservation zone encompass the eastern Bering Sea region, and INPFC area 5 encompasses the Aleutian Islands region. Some species, including walleye pollock, Theragra chalcogramma; sablefish, Anoplopoma fimbria; and rockfishes, Sebastes and Sebastolobus spp., are assumed to have independent stocks in the eastern Bering Sea and Aleutians and the populations in these two regions are therefore managed separately. Other species, most of which are mainly distributed in the eastern Bering Sea but range into the Aleutians, are managed as a single stock throughout these. regions. A small catch originating from Bowers Ridge in INPFC area 3 (Fig. 1) is included with catches from the Aleutians.

Species of Concern

The North Pacific Fisheries Management Council (NPFMC) has established four categories of finfishes and invertebrates for management of groundfish: target groundfish species, other species, nonspecified species, and prohibited species (Table 1). Assessments of the conditions of stocks and estimates of MSY and EY are required for each of the target species of groundfish and the category of "other species." This latter category accounts for species which are currently of slight economic value and not generally targeted, but have potential economic value or are important ecosystem components. The NPFMC establishes a total allowable catch for this group, and hence catch records for this species category must be maintained by the fishery.

The second category of noncommercial species, "nonspecified species," includes fish and invertebrates of no current or foreseeable economic value (Table 1). These species are only taken in the fishery as a by-catch of target fisheries. There is no quota for this category and the total allowable catch is any amount taken by the fishery, whether retained or discarded, while fishing for target species. If retained, catch records must be kept.

The fourth category is "prohibited species." These are species of special socioeconomic interest to U.S. fisheries which cannot be retained by groundfish fisheries and, therefore, must be returned to the sea.

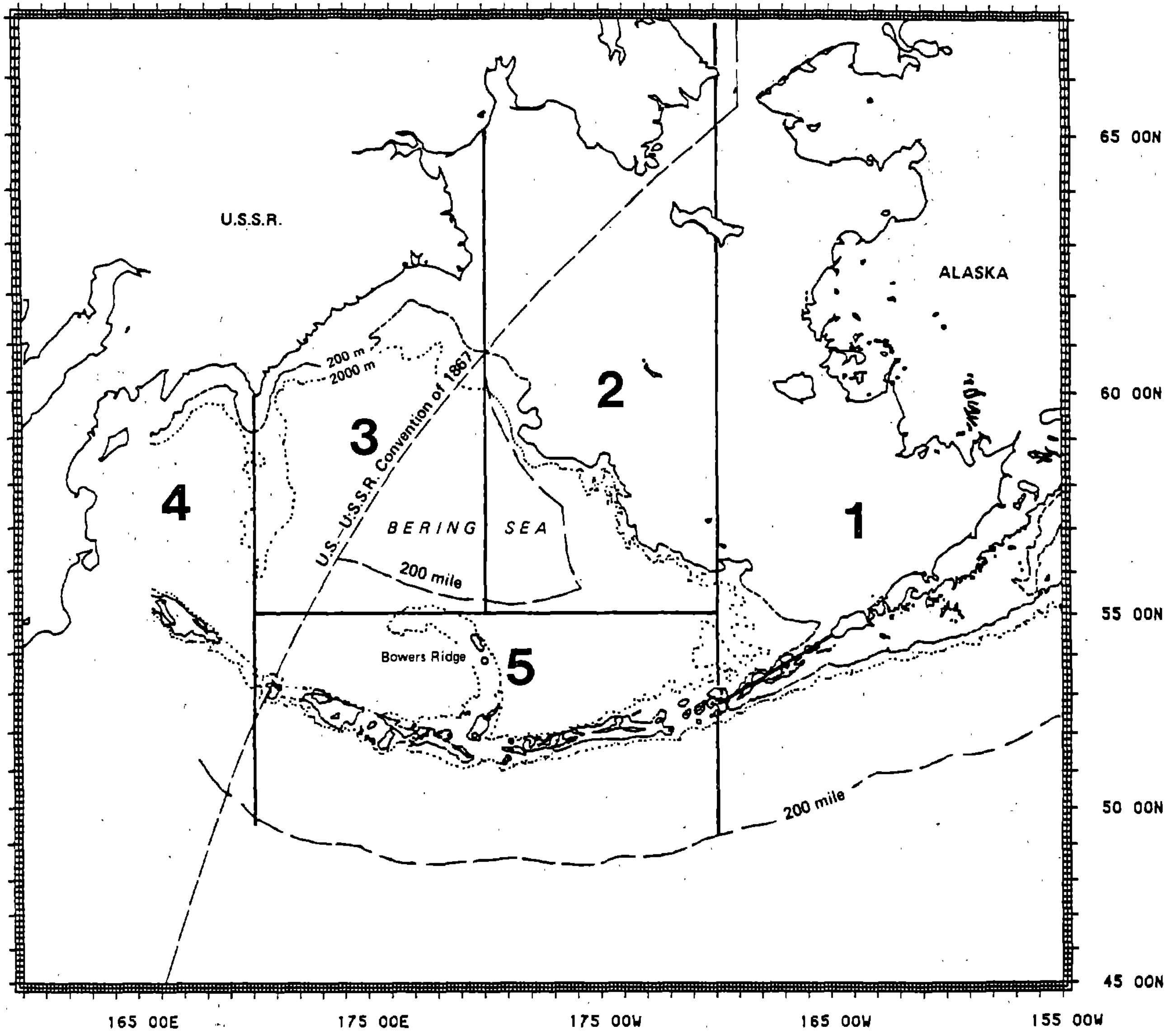

Figure 1.--Bering Sea showing U.S. 200-mile fishery conservation zone and eastern Bering Sea (areas 1 and 2) and Aleutian Islands region (area 5) management areas. Areas 1-5 are International North Pacific Fisheries Commission statistical areas.

Table 1.--Species categories which apply to the Bering Sea-Aleutians groundfish fishery. (North Pacific Fishery Management Council 1983).

Prohibited species[a]	Target species[b]	Other species[c]	Nonspecified species[d]	
FINFISHES				
Salmonids	Walleye pollock	Sculpins	Eelpouts (Zoarcidae)	
Pacific halibut	Cod	Sharks	Poachers (Agonidae) and alligator fish	
	Yellowfin sole	Skates	Snailfish, lumpfishes, lumpsuckers (Cyclopteridae)	
	Turbots	Smelts	Sandfishes (*Trichodon* sp.)	
	Other flatfishes		Rattails (Macrouridae)	
	Atka mackerel		Ronquils, searchers (Bathymasteridae)	
	Sablefish		Lancetfish (Alepisauridae)	
	Pacific ocean perch		Pricklebacks, cockscombs, warbonnets, shanny	
	Other rockfish		Prowfish (*Zaprora silenus*)	
			Hagfish (*Eptatretus* sp.)	
			Lampreys (*Lampetra* sp.)	
			Blennys, gunnels, various small bottom dwelling fishes of the families Stichaeidae and Pholidae	
INVERTEBRATES				
King crab	Squids	Octopuses	Anemones	Jellyfishes
Snow (Tanner) crab			Starfishes	Tunicates
Coral			Egg cases	Sea cucumbers
Shrimp			Sea mouse	Sea pens
Clams			Sea slugs	Isopods
Horsehair crab			Sea potatos	Barnacles
Lyre crab			Sand dollars	Polychaetes
Dungeness crab			Hermit crabs	Crinoids
			Mussels	Crabs - unident.
			Sea urchins	Misc. - unident.
			Sponge-unident.	

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[a] Must be returned to the sea.

[b] Optimum yield established for each species.

[c] Aggregate optimum yield established for the group as a whole.

[d] List not exclusive; includes any species not listed under Prohibited, Target, or "Other" categories.

Historical Catch Statistics

Although groundfish fisheries operated in the eastern Bering Sea prior to World War II (Forrester et al. 1978), they were minor in nature compared to the modern-day fishery which started in 1954. Since the inception of groundfish fisheries in the Bering Sea, distant water fleets from Japan, the U.S.S.R., and the Republic of Korea have exclusively or predominately harvested these resources. Not until recent years, as will be described in individual species sections of the report, have U.S. domestic and joint venture fisheries taken a significant portion of the catch.

Historical catch statistics since 1954 are shown for the eastern Bering Sea in Table 2. In this region, the initial target species of fisheries from Japan and the U.S.S.R. was yellowfin sole, Limanda aspera. During this early period of the fisheries, total recorded catches of groundfish reached a peak of 674,000 metric tons (t) in 1961. Following a decline in abundance of yellowfin sole, other species were targeted, principally pollock, and total catches of groundfish in the eastern Bering Sea rose to much higher levels; reaching more than 2.2 million t in 1972. Catches have since declined to range from 1.2 to 1.5 million t as catch restrictions were placed on the fishery because of declining stock abundance of pollock and other species.

Catches in the Aleutian region (Table 3) have always been much smaller than those in the eastern Bering Sea and target species have generally been different. Pacific ocean perch, Sebastes alutus, was the initial target species in the Aleutians and during early stages of exploitation of this species, overall catches of groundfish reached a peak of 112,000 t. With a decline in abundance of Pacific ocean perch, the fishery diversified to other species including turbots, Reinhardtius hippoglossoides and Atheresthes stomias; Atka mackerel, Pleurogrammus monopterygius; Pacific cod, Gadus macrocephalus; and pollock, and overall catches declined to less than 100,000 t annually. Starting in 1980, catches of pollock increased markedly in the Aleutian region; as a result, the overall catch has again exceeded 100,000 t in some recent years. A good portion of the recent pollock catches in the Aleutian region have come from the pelagic population in the Aleutian Basin prior to and during the spawning season in winter and spring.

Fishery Restrictions

Prior to implementation of U.S. extended jurisdiction and establishment of the 200-mile fishery conservation zone, a number of restrictions in the form of closed areas, catch quotas, and area-time closures were in effect for groundfish fisheries in the eastern Bering Sea and Aleutians (Forrester et al. 1983). These restrictions were the result of voluntary domestic regulations by Japan, bilateral agreements between the United States and user nations of the resources, and tripartite discussions within INPFC to minimize the impact of groundfish fisheries on the traditional North American setline fishery for Pacific halibut, Hippoglossus stenolepis. A number of these restrictions were retained by the NPFMC following implementation of extended jurisdiction in 1977.

Time-area restrictions currently applicable to non-U.S. groundfish fisheries in the two management areas are illustrated in Figure 2.

Table 2.--Annual catches of groundfish and squid in the eastern Bering Sea, 1954-84[a].

Year	Walleye pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Yellowfin sole	Turbots	Other flatfish	Atka mackerel	Squid	Other species	Total all species
1954						12,562						
1955						14,690						12,562
												14,690
1956						24,697						
1957						24,145						24,697
1958	6,924	171	6			44,153						24,145
1959	32,793	2,864	289			185,321					147	51,401
1960			1,861	6,100		456,103	36,843				380	222,647
												500,907
1961			15,627	47,000		553,742	57,348					
1962			25,989	19,900		420,703	58,226					673,717
1963			13,706	24,500		85,810	31,565	35,643				524,818
1964	174,792	13,408	3,545	25,900		111,177	33,729	30,604				191,224
1965	230,551	14,719	4,838	16,800		53,810	9,747	11,686			736	393,891
											2,218	344,369
1966	261,678	18,200	9,505	20,200		102,353	13,042	24,864			2,239	452,081
1967	550,362	32,064	11,698	19,600		162,228	23,869	32,109			4,378	836,308
1968	702,181	57,902	14,374	31,500		84,189	35,232	29,647			22,058	977,083
1969	862,789	50,351	16,009	14,500		167,134	36,029	34,749			10,459	1,192,020
1970	1,256,565	70,094	11,737	9,900		133,079	32,289	64,690			15,295	1,593,649
1971	1,743,763	43,054	15,106	9,800		160,399	59,256	92,452			33,496	2,157,326
1972	1,874,534	42,905	12,758	5,700		47,856	77,633	76,813			110,893	2,249,092
1973	1,758,919	53,386	5,957	3,700		78,240	64,497	43,919			55,826	2,064,444
1974	1,588,390	62,462	4,258	14,000		42,235	91,127	37,357			60,263	1,900,092
1975	1,356,736	51,551	2,766	8,600		64,690	85,651	20,393			54,845	1,645,232
1976	1,177,822	50,481	2,923	14,900		56,221	78,329	21,746			26,143	1,428,575
1977	978,370	33,335	2,718	6,600	1,678	58,373	37,162	14,393		4,926	35,902	1,173,457
1978	979,431	42,543	1,192	2,200	12,155	138,433	45,781	21,040	832	6,886	61,537	1,312,030
1979	913,881	33,761	1,376	1,700	10,048	99,017	42,919	19,724	1,985	4,286	38,767	1,167,464
1980	958,279	45,861	2,206	1,100	1,367	87,391	62,618	20,406	4,697	4,040	33,949	1,221,914
1981	973,505	51,996	2,604	1,200	1,111	97,301	66,394	23,428	3,028	4,179	35,551	1,260,297
1982	955,964	55,040	3,184	200	863	95,712	54,908	23,809	328	3,837	18,200	1,212,045
1983	982,363	83,212	2,695	200	460	108,385	53,659	30,454	116	3,455	11,062	1,276,061
1984	1,098,783	110,944	2,793	300	327	159,526	29,294	44,286	41	2,798	8,508	1,457,600

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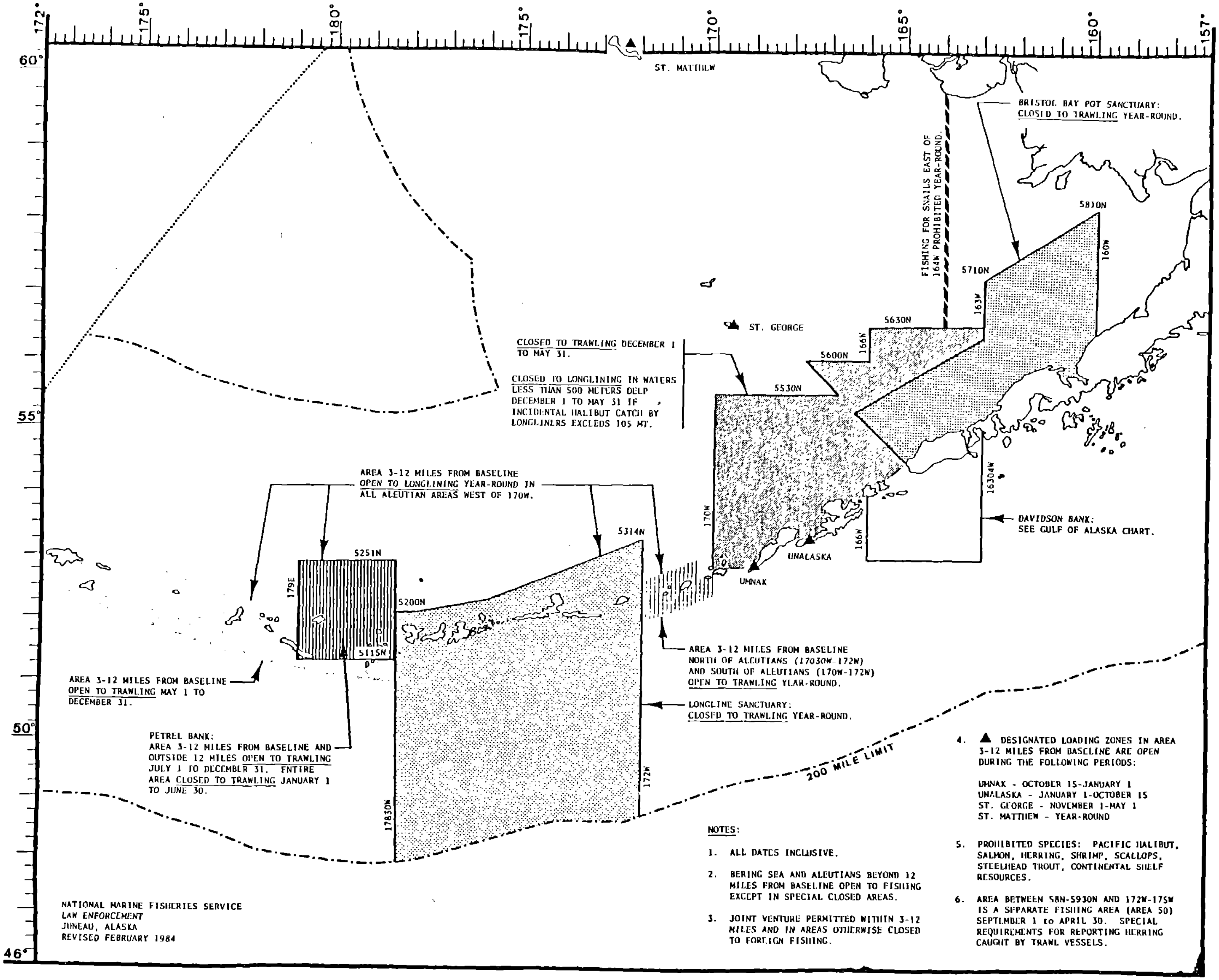
[a] See individual species sections of this report for details of the catch statistics.

Table 3.--Annual catches of groundfish and squid in the Aleutian Islands region, 1962-84.[a]

Year	Walleye pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Turbots	Atka mackerel	Squid	Other species	Total all species
1962			-	200						200
1963			664	20,800		7				21,471
1964		241	1,541	90,300		504			66	92,652
1965		451	1,249	109,100		300			768	111,868
1966		154	1,341	85,900		63			131	87,589
1967		293	1,652	55,900		394			8,542	66,781
1968		289	1,673	44,900		213			8,948	56,023
1969		220	1,673	38,800		228			3,088	44,009
1970		283	1,248	66,900		559	949		10,671	80,610
1971		2,078	2,936	21,800		2,331			2,973	32,118
1972		435	3,531	33,200		14,197	5,907		22,447	79,717
1973		977	2,902	11,800		12,371	1,712		4,244	34,006
1974		1,379	2,477	22,400		11,983	1,377		9,724	49,340
1975		2,838	1,747	16,600		3,754	13,326		8,288	46,553
1976		4,190	1,659	14,000		3,437	13,126		7,053	43,465
1977	7,625	3,262	1,897	5,900	9,587	4,488	20,975	1,808	16,170	71,712
1978	6,282	3,295	821	5,300	8,737	6,548	23,418	2,085	12,436	68,922
1979	9,504	5,593	782	5,500	14,543	12,847	21,279	2,252	12,934	85,234
1980	58,156	5,788	274	4,700	1,361	8,299	15,793	2,332	13,004	109,707
1981	55,516	10,462	533	3,600	1,397	8,040	16,661	1,762	7,274	105,245
1982	57,978	11,526	955	1,000	2,792	8,732	19,546	1,201	5,167	108,897
1983	59,026	9,955	673	300	1,147	7,869	11,610	524	3,193	94,297
1984	81,834	22,216	1,043	600	292	3,275	36,013	326	1,669	147,268

[a] See individual species sections of this report for details of the catch statistics.



BRISTOL BAY POT SANCTUARY: CLOSED TO TRAWLING YEAR-ROUND.

FISHING FOR SNAILS EAST OF 164W PROHIBITED YEAR-ROUND.

CLOSED TO TRAWLING DECEMBER 1 TO MAY 31.

CLOSED TO LONGLINING IN WATERS LESS THAN 500 METERS DEEP DECEMBER 1 TO MAY 31 IF INCIDENTAL HALIBUT CATCH BY LONGLINERS EXCEEDS 105 MT.

AREA 3-12 MILES FROM BASELINE OPEN TO LONGLINING YEAR-ROUND IN ALL ALEUTIAN AREAS WEST OF 170W.

DAVIDSON BANK: SEE GULF OF ALASKA CHART.

AREA 3-12 MILES FROM BASELINE NORTH OF ALEUTIANS (17030W-172W) AND SOUTH OF ALEUTIANS (170W-172W) OPEN TO TRAWLING YEAR-ROUND.

LONGLINE SANCTUARY: CLOSED TO TRAWLING YEAR-ROUND.

AREA 3-12 MILES FROM BASELINE OPEN TO TRAWLING MAY 1 TO DECEMBER 31.

PETREL BANK: AREA 3-12 MILES FROM BASELINE AND OUTSIDE 12 MILES OPEN TO TRAWLING JULY 1 TO DECEMBER 31. ENTIRE AREA CLOSED TO TRAWLING JANUARY 1 TO JUNE 30.

NOTES:

1. ALL DATES INCLUSIVE.
2. BERING SEA AND ALEUTIANS BEYOND 12 MILES FROM BASELINE OPEN TO FISHING EXCEPT IN SPECIAL CLOSED AREAS.
3. JOINT VENTURE PERMITTED WITHIN 3-12 MILES AND IN AREAS OTHERWISE CLOSED TO FOREIGN FISHING.
4. ▲ DESIGNATED LOADING ZONES IN AREA 3-12 MILES FROM BASELINE ARE OPEN DURING THE FOLLOWING PERIODS:

UMNAK - OCTOBER 15-JANUARY 1
UNALASKA - JANUARY 1-OCTOBER 15
ST. GEORGE - NOVEMBER 1-MAY 1
ST. MATTHEW - YEAR-ROUND

5. PROHIBITED SPECIES: PACIFIC HALIBUT, SALMON, HERRING, SHRIMP, SCALLOPS, STEELHEAD TROUT, CONTINENTAL SHELF RESOURCES.
6. AREA BETWEEN 58N-5930N AND 172W-175W IS A SEPARATE FISHING AREA (AREA 50) SEPTEMBER 1 to APRIL 30. SPECIAL REQUIREMENTS FOR REPORTING HERRING CAUGHT BY TRAWL VESSELS.

NATIONAL MARINE FISHERIES SERVICE
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JUNEAU, ALASKA
REVISED FEBRUARY 1984

Figure 2.--Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions.

Estimated Yields

Optimum yields (OY) estimated by the NPFMC since implementation of extended jurisdiction in 1977 are given in Table 4. The overall OY for all species combined has steadily increased from 1.4 million t in 1977 to 2.0 million t in 1984 and 1985. Species accounting for the major part of this increase have been pollock, yellowfin sole, and Pacific cod.

Table 4.--Optimum yields (t) for groundfish of the eastern Bering Sea and Aleutian Islands region 1977-1986.

	1977	1978	1979	1980	1981	1982	1983	1984	1985
Eastern Bering Sea[a]									
Walleye pollock	950,000	950,000	950,000	1,000,000	1,000,000	1,000,000	1,000,000	1,200,000	1,200,000
Yellowfin sole	106,000	126,000	126,000	117,000	117,000	117,000	117,000	230,000	226,900
Turbots	-	-	-	90,000	90,000	90,000	90,000	59,610	42,000
Other flounders[b]	100,000	159,000	159,000	61,000	61,000	61,000	61,000	111,490	109,900
Pacific cod	58,000	70,500	70,500	70,700	78,700	78,700	120,000	210,000	220,000
Sablefish	5,000	3,000	3,000	3,500	3,500	3,500	3,500	3,740	2,625
Pacific ocean perch	6,500	6,500	6,500	3,250	3,250	3,250	3,250	1,780	1,000
Other rockfish	-	-	-	7,727	7,727	7,727	7,727	1,550	1,120
Herring	21,000	18,670	18,670	-[c]	-	-	-	-	-
Squid	10,000	10,800	10,000	10,000	10,000	10,000	10,000	8,900	10,000
Other species	59,600	66,600	66,600	74,249	74,249	74,249	77,314	40,000	37,580
Aleutians[a]									
Walleye pollock	-	-	-	100,000	100,000	100,000	100,000	100,000	100,000
Sablefish	2,400	1,500	1,500	1,500	1,500	1,500	1,500	1,600	1,875
Pacific ocean perch	15,000	15,000	15,000	7,500	7,500	7,500	7,500	2,700	3,800
Other rockfish	-	-	-	-	-	-	-	5,500	5,500
Atka mackerel	-	24,800	24,800	24,800	24,800	24,800	24,800	23,130	37,700
Other species	34,000	34,000	34,000	-	-	-	-	-	-
Total all areas	1,367,500	1,486,370	1,485,570	1,571,226	1,579,226	1,579,226	1,623,591	2,000,000	2,000,000

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[a] Optimum yields are for the eastern Bering Sea and Aleutian Islands areas combined for pollock in 1977-79, other rockfish in 1980-83, other species in 1980-85, and in all years for yellowfin sole, turbot, other flounders, Pacific cod and squid.

[b] Excludes halibut but includes turbot until 1980.

[c] After 1979 herring no longer included with groundfish.

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WALLEYE POLLOCK

by

Richard G. Bakkala, Vidar G. Wespestad, and Jimmie J. Traynor

INTRODUCTION

The walleye pollock, Theragra chalcogramma, resource in the eastern Bering Sea supports the largest single-species fishery in the northeast Pacific Ocean. In 1978-83, catches of pollock ranged from 914,000 to 982,000 metric tons (t) and exceeded those (594,000 to 694,000 t) of all other species of groundfish in U.S. waters from off California to the Bering Sea (Bakkala et al. 1985b). Pollock became a highly sought-after species when mechanized processing of minced meat was successfully implemented on Japanese commercial vessels in the mid-1960s. As a result, catches increased more than ten-fold between 1964 and 1972 (from 175,000 t to nearly 1.9 million t; Table 5). Catches have since declined, ranging between 914,000 t and 1,099,000 t in 1977-84, due in part to catch restrictions placed on the fishery as a result of declining stock abundance. An additional 55,500 to 81,800 t were taken annually in 1980-84 in the Aleutian Islands region (Table 6).

Japanese fisheries have historically accounted for over 80% of annual catches since 1970, but their proportion has been declining and was 56% in 1984. Most of the remainder of the annual catches were taken by the U.S.S.R. until 1978, but in more recent years , catches by the Republic of Korea (R.O.K.) have been the second largest, reaching about 180,000 t in 1983 and 1984. However, catches by joint-venture operations between U.S. fishing vessels and processing vessels from Japan, Poland, the R.O.K., the Federal Republic of Germany (F.R.G.), and the U.S.S.R. have increased rapidly and were the second largest (237,000 t) in 1984.

CONDITION OF STOCKS

Relative Abundance

Trends in abundance shown by the various sources of catch and effort data are similar, indicating a rapid decline in abundance from the early to mid-1970s and then relative stability through 1982 (Table 7). All of the available catch per unit of effort (CPUE) estimates increased in 1983 and 1984 from those in 1982.

Trends in CPUE (Table 7) from large-scale Northwest and Alaska Fisheries Center (NWAFC) trawl surveys (Fig. 3) have been more variable than those from the fishery. This is believed to be the result of variability in the vertical distribution of pollock in the water column which would more severely influence abundance estimates from survey trawls with vertical openings of 1.5-2.3 m than fishery trawls with vertical openings of 7-12 m. The sharp decline in CPUE shown by survey data in 1980 represents an unrealistic fluctuation in

Table 5.--Annual catches of walleye pollock (t) in the eastern Bering Sea[a].

Year	Japan	U.S.S.R.	R.O.K.[b]	Taiwan	Poland	F.R.G.[c]	Portugal	Joint ventures[d]	U.S.	Total
					t					
1964	174,792									174,792
1965	230,551									230,551
1966	261,678									261,678
1967	550,362									550,362
1968	700,981		1,200							702,181
1969	830,494	27,295	5,000							862,789
1970	1,231,145	20,420	5,000							1,256,565
1971	1,513,923	219,840	10,000							1,743,763
1972	1,651,438	213,896	9,200							1,874,534
1973	1,475,814	280,005	3,100							1,758,919
1974	1,252,777	309,613	26,000							1,588,390
1975	1,136,731	216,567	3,438							1,356,736
1976	913,279	179,212	85,331							1,177,822
1977	868,732	63,467	45,227	944						978,370
1978	821,306	92,714	62,371	3,040						979,431
1979	749,229	58,880	83,658	1,952	20,162					913,881
1980	786,768	2,155	107,608	4,962	40,340	5,967		10,479		958,279
1981	765,287		104,942	3,367	48,391	9,580		41,938		973,505
1982	746,972		150,525	4,220		1,625		52,622		955,964
1983	654,939		170,007			10,038		146,467	912	982,363
1984	626,335	12,268	167,887		46,900	8,304	48	230,314	6,727	1,098,783

[a] Catch data for 1964-79 as reported by fishing nation (except 1967-76 R.O.K. catches which were based on U.S. surveillance reports). Non-U.S. and Joint-venture catch data for 1980-84 from U.S. observer estimates as reported by French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a. U.S. catches from Pacific Fishery Information Network (PACFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. 5th Ave., Portland, OR 97201.

[b] Republic of Korea

[c] Federal Republic of Germany

[d] Joint ventures between U.S. fishing vessels and R.O.K., Japanese,. Polish, F.R.G., and U.S.S.R. processors.

Table 6.--Annual catches of walleye pollock (t) in the Aleutian Islands region[a].

	Nation							
Year	Japan	U.S.S.R.	R.O.K.	Poland	Joint Ventures	U.S.	Others[b]	Total
1977	5,667	1,618	325				15	7,625
1978	5,025	1,193	64					6,282
1979	8,047	1,412	45					9,504
1980	46,052	1	6,256	5,806			41	58,156
1981	37,980		11,074	5,593			869	55,516
1982	33,379		8,117		1,983		14,499	57,978
1983	29,485		13,420		2,547		13,574	59,026
1984	38,598		12,027	5,171	6,694	3,891	15,453	81,834

[a] Catch data for 1977-79 as reported by fishing nations and for 1980-84 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a. U.S. catch data from Pacific Fishery Information Network (PACFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. 5th Ave., Portland, Or. 97201.

[b] Federal Republic of Germany and Republic of China (Taiwan).

Table 7.--Relative indices of walleye pollock stock abundance in the eastern Bering Sea, 1964-85.

	Japanese pair trawl data			
Year	U.S. method[a] (t/1,000s of horsepower hours)	Japanese method[b] (t/h)	INPFC[a] workshop method[d] (% of 1975 value)	Large-scale NWAFC surveys (kg/ha)
1964	9.5	--	--	--
1965	18.3	--	--	--
1966	23.6	--	--	--
1967	21.3	--	--	--
1968	23.8	--	130	--
1969	31.5	--	132	--
1970	18.7	--	145	--
1971	14.2	--	152	--
1972	14.2	--	184	--
1973	8.6	13.7	164	--
1974	9.9	10.4	115	--
1975	9.2	9.8	100	66.0
1976	10.0	9.8	98	--
1977	8.7	9.2	97	--
1978	9.2	9.7	100	--
1979	9.9	9.8	103	63.5
1980	9.7	9.3	92	32.2
1981	6.4	9.6	95	57.6
1982	6.0	10.9	100	58.7
1983	9.3	11.5	121	133.0
1984	9.2	--	173	98.7
1985	--	--	--	97.2

[a] Alton and Fredin (1974).
[b] Okada et al. (1982).
[c] International North Pacific Fisheries Commission.
[d] Low and Ikeda (1980).

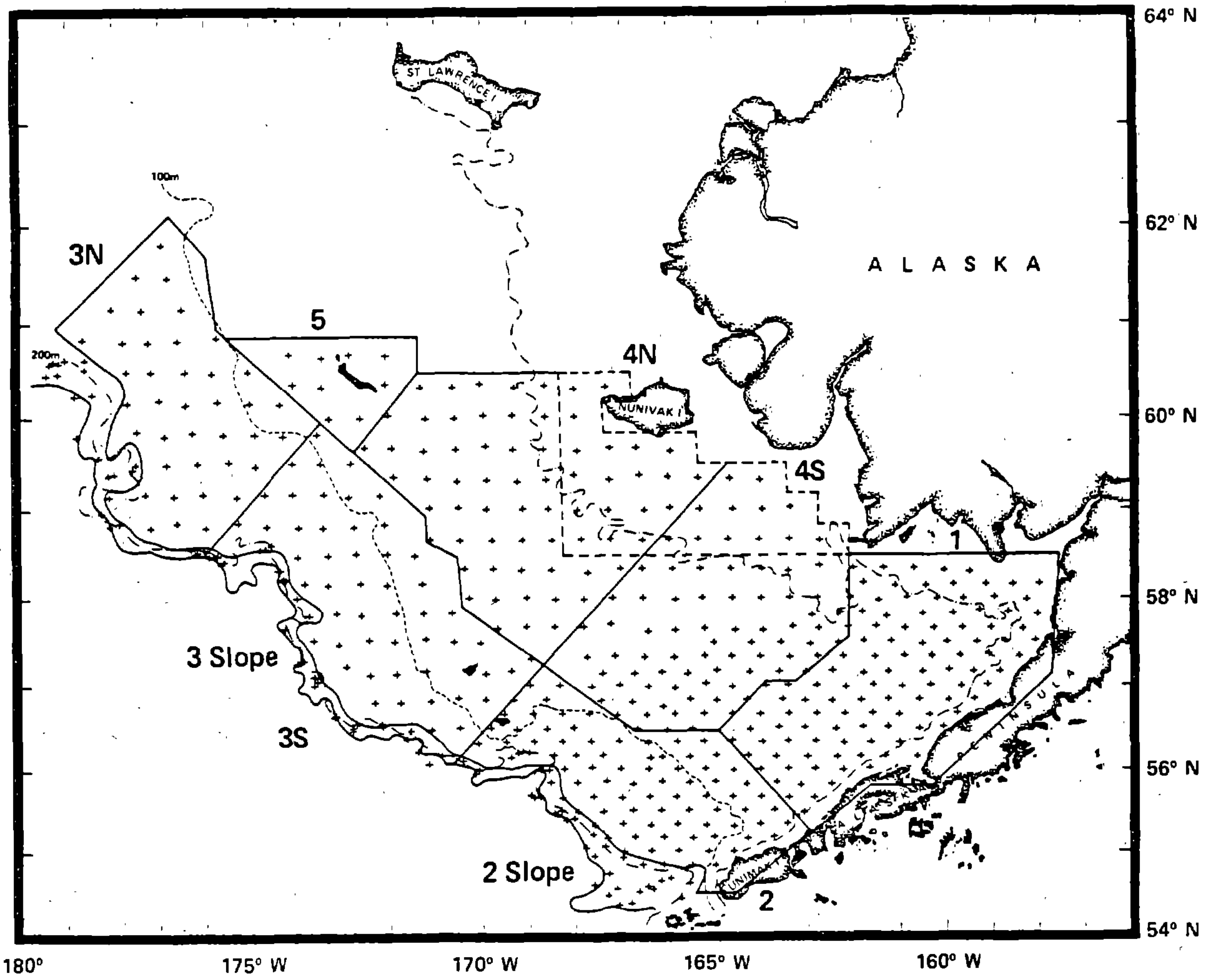

Figure 3.--Area of the eastern Bering Sea generally sampled during large-scale surveys by the Northwest and Alaska Fisheries Center in 1975 and 1979-85. Survey subareas are delineated by the solid lines and subarea numbers are shown adjacent to the subareas. Area within the dashed lines in the vicinity of Nunivak Island was not sampled during the 1981 survey.

abundance, and the fishery CPUE data is believed to more accurately reflect the condition of the stock in that year. The 1983-84 survey data indicates a major increase in abundance which is believed to represent an increase in abundance of older age groups (as will be described later) which are more vulnerable to the survey bottom trawls (Bakkala and Traynor 1984) rather than to an actual increase in abundance of the overall population. Corresponding increases in CPUE from the 1983 and 1984 fisheries are also believed to reflect the greater availability of these large pollock to the fishery.

The CPUE from the 1984 and 1985 surveys (99 and 97 kg/ha) were lower than that from the 1983 survey (133 kg/ha), but still much higher than the values (58-66 kg/ha) usually derived from the survey data since 1975. The again relatively high CPUE value in 1985 indicates that the abundance of large pollock remains high in the eastern Bering Sea.

Biomass Estimates

Survey Based Estimates

Biomass estimates from NWAFC surveys are derived from two methods. In most years, the estimates are based on bottom trawl survey data which only sample the portion of the pollock populations available to the trawls near bottom. Every third year since 1979, hydroacoustic surveys have been conducted in conjunction with the bottom trawl surveys to provide assessments of the midwater portion of the population which are combined with the bottom trawl data to produce an overall assessment of the pollock population. Additionally, during these triennial surveys as well as in 1981, a cooperating Japanese research vessel has comprehensively sampled continental slope waters of the eastern Bering Sea to supplement the estimates from continental shelf waters. A comprehensive triennial survey was again conducted in 1985, although at the time this report was prepared, estimates were only available from the NWAFC bottom trawl survey on the continental shelf.

In 1982, the second combined hydroacoustic-midwater trawl and bottom trawl survey was conducted in the eastern Bering Sea to sample the overall pollock population. Unlike the 1979 hydroacoustic survey which only covered a portion of the outer continental shelf. and slope (100-500 m), the 1982 survey covered the entire eastern Bering Sea shelf and slope from 37 to 500 m and northward to approximately 60° N, an area similar to that covered by the 1982 bottom trawl survey.

The total estimated biomass of pollock from the combined 1979 bottom trawl-hydroacoustic data was 11.1 million t (7.5 million t in midwater; 3.6 million t demersal) (Table 8). In 1982, the combined estimate was 8.8 million t (4.8 million t in midwater and 4.0 million t near bottom).

Estimated population numbers from the combined bottom trawl-hydroacoustic surveys in 1982 were less than observed in 1979 (Table 9). Most of the reduction was due to lower abundance of age 1 and 2 fish:

	Population estimates (billions)	
Year	Age 1 (year-class)	Age 2 (year-class)
1979	76.9 (1978)	46.9 (1977)
1982	1.0 (1981)	5.6 (1980)

Table 8.--Biomass estimates (t) for walleye pollock of the eastern Bering Sea based on bottom trawl and hydroacoustic data from research vessel surveys and the Japanese multi-vessel Danish seine and stern trawl survey.

	Research vessel surveys			Japanese
Year	Type of survey	Biomass estimates[a]	95% confidence interval	Multi-vessel survey
1975	U.S. bottom trawl	2,426,000	2,002,000- 2,851,000	--
1976	--	--	--	10,398,000
1977	--	--	--	10,971,200
1978	--	--	--	10,057,000
1979	U.S.-Japan bottom trawl	3,552,000	3,112,000- 3,993,000	8,215,800
	U.S. hydroacoustic	7,458,000	4,190,000-10,730,000	
1980	U.S. bottom trawl	1,509,000	1,085,000- 1,932,000	13,118,000
1981	U.S.-Japan bottom trawl	2,971,000	2,364,000- 3,579,000	9,337,400
1982	U.S.-Japan bottom trawl	4,040,000	2,161,000- 5,919,000	7,793,000
	U.S. hydroacoustic	4,778,300		
1983	U.S. bottom trawl	6,050,600	5,011,000- 7,090,000	10,684,400
1984	U.S. bottom trawl	4,585,400	3,681,000- 5,490,000	6,553,500
1985	U.S. bottom trawl	4,517,100	3,758,000- 5,276,000	--

[a] 1979 and 1982 values include estimates from the continental slope and from the area between St. Matthew and St. Lawrence Islands; the 1981 value includes estimates from the Japanese bottom trawl survey on the continental slope. For all other years the estimates are for continental shelf waters (20-200 m) from the approximate latitude at St. Matthews Island south to the Alaska Peninsula.

Table 9.--Population number (billions) estimates of walleye pollock derived from bottom and hydroacoustic-midwater trawl surveys in the eastern Bering Sea, 1979 and 1982.

Age (yr)	1979			1982		
	Midwater	Demersal	Total	Midwater	Demersal	Total
1	69.11	7.75	76.86	0.10	0.91	1.01
2	41.13	5.76	46.89	3.40	2.16	5.56
3	3.88	2.39	6.27	4.10	2.24	6.34
4	0.41	1.19	1.60	7.67	2.95	10.62
5	0.53	0.78	1.31	1.86	1.04	2.90
6+	0.35	0.88	1.23	0.80	0.41	1.21
Total	115.41	18.75	134.16	17.93	9.71	27.64

The extremely low values from the 1982 data indicate an almost complete failure of the 1981 year-class and low abundance of the 1980 year-class. The abundance of older fish (>age 2) was higher than that observed in 1979, particularly for age 4 (1978 year-class) and age 5 (1977 year-class) fish.

The biomass estimates from the 1983, 1984, and 1985 bottom trawl surveys were 6.1, 4.6, and 4.5 million t, respectively (Table 8), which were lower than the combined bottom trawl-hydroacoustic estimate in 1982 but far exceeded any of the previous estimates based solely on bottom trawl data. The reason for these larger estimates was believed to be the high abundance of large fish in the 1983-85 populations which are more vulnerable to survey trawls rather than to an increase in the overall population biomass.

Biomass estimates have also been produced by commercial Danish seine and stern trawl vessels of the Japanese mothership fleet which survey pollock from depths of about 80 to 300 m and from the southeastern Bering Sea to about 61°N in a period of approximately 2 weeks (Sasaki 1985a). An area swept method was used to derive the estimates (Table 8).

The 1979 estimate of 8.2 million t from the Japanese survey was less than the 11.0 million t estimate from the 1979 U.S. bottom trawl-hydroacoustic surveys, but in 1982 the estimates from the multi-vessel (7.8 million t) and research vessel (8.8 million t) surveys were similar. The increase in biomass (10.0 million t) shown by the 1983 Japanese survey apparently reflects, as aid other sources of abundance data, the greater vulnerability of older pollock to bottom trawling gear. The 1984 estimate from the multi-vessel survey dropped sharply to 6.6 million t or to 61% of the 1983 value. In comparison, the 1984 estimate from the U.S. bottom trawl survey declined to 76% of the 1983 value.

In 1980 and 1983, the NWAFC and Fisheries Agency of Japan conducted cooperative bottom trawl surveys in the Aleutian Islands region. Biomass estimates (t) from those surveys were as follows:

Year	Aleutian region (170°E-170°W)	Eastern Aleutian portion of INPFC, 1 (170°W-165°W)
1980	280,200	55,700
1983	539,400	282,700

The estimates indicate a major increase in abundance of pollock between 1980 and 1983, showing a doubling of the biomass in the Aleutian region and a four-fold increase in the Aleutian Islands portion of INPFC Area 1. Assuming that pollock occupy midwater in the Aleutians as they do in the eastern Bering Sea, these estimates may represent only a portion of the biomass in the region.

It should be noted that some of the commercial catch of pollock in the Aleutian region originates from midwater trawling in the Aleutian Basin. Japanese hydroacoustic surveys in the Basin have indicated that the biomass of the pelagic Basin population may range from about 1.3 to 5.4 million t (Okada 1983). Whether pollock in the Basin and Aleutians represent the same or independent populations is unknown.

Age Structured Model Based Estimates

Estimates of population numbers and biomass from eastern Bering Sea pollock have also been derived from cohort analyses (Bakkala et al. 1985b). These analyses have been based on the methods of Pope (1972) and have been updated and revised as new or improved data became available from the fishery. In this report two other age structured models are used to evaluate the results from the cohort analysis. These are the catch-age analysis (CAGEAN) of Deriso et al. (1985) which is based on the virtual population analysis (VPA) of Doubleday (1976) and the fishable biomass virtual population analysis (FBVPA) of Kimura (1985a). These latter methods are non-linear least square solutions to VPA and utilize auxiliary information such as abundance estimates from surveys to stabilize parameter estimates. The CAGEAN model also provides for the computation of variances around abundance estimates.

The catch at age data used in all three models is shown in Table 10. The catch data used in 1971-79 was that reported by foreign nations and since 1980, that estimated from U.S. observer sampling of foreign catches. Length-frequency data, length-weight relationships, and age-length keys used to calculate catch at age in 1971-72 were those reported by Wespestad and Terry (1984), and in 1973-83 those collected by U.S. observers from the fishery. In estimating catch at age, length-frequency samples from the fishery were expanded to the total number in daily catches and summed within nation-vessel classes, areas, and sexes by quarter. For nation-vessel classes and area cells without length data, the most representative length-frequency information was used. Quarterly age-length keys combined over nation-vessel classes were applied to the quarterly length-frequencies to produce quarterly catches at age by area and sex which were then summed to provide annual estimates. Average weight at age data from Smith (1981) were used to convert numbers-at-age to weight at age. Age specific values of natural mortality as reported by Wespestad and Terry (1984) were used in the cohort analysis and a constant value of 0.3 in the other models.

Cohort analysis and the CAGEAN model were tuned using combined population estimates from hydroacoustic and bottom trawl survey data collected in 1979 and 1982. In the cohort analysis, natural mortality (M) and fishing mortality (F) were adjusted until the age composition of the cohort analysis approximated the age composition from the 1979 and 1982 surveys. Terminal F values were further adjusted so the trend in population numbers from the cohort anaysis was similar to that from the surveys.

In the CAGEAN model the survey data were used to estimate F for age 4 (the age first fully recruited) based on the numbers in the commercial catch and the total estimated numbers from the survey. This model also requires estimates of population numbers by age for the first year of the analysis and for the youngest age used in the analysis, estimates of fishing mortality for fully recruited ages in each year, and the relative selectivity for ages not fully recruited. These parameters were estimated from results of the cohort analysis.

The FBVPA model requires estimates of exploitation for the most recent years, annual catches at age, and natural mortality. The model iterates the deterministic VPA equation using a least squares solution. The exploitation rate used to initiate the FBVPA model was derived from the ratio of the 1982 catch and 1982 survey biomass estimate.

Table 10.--Catch at age in number of walleye pollock for the years 1971-1983.

AGE	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
2	229,666,346	357,629,989	652,036,435	3,121,491,256	833,663,705	884,555,706	1,073,816,172	722,678,783	958,318,125	1,120,060,875	76,514,479	25,378,068	96,175,159
3	1,168,437,203	1,590,330,458	730,835,166	1,403,040,336	3,817,149,225	1,618,900,824	1,195,774,141	1,097,359,561	1 235,419,499	1,041,523,325	1,442,684,307	214,940,910	187,229,665
4	1,826,504,748	1,480,190,788	1,903,951,588	421,051,278	458,942,403	1,355,235,503	847,525,659	944,443,475	682,467,001	430,156,165	662,889,545	1,466,504,870	429,962,151
5	592,724,763	780,048,019	999,247,867	484,369,344	53,732,729	128,829,194	274,558,181	391,272,633	540,965,602	228,463,365	149,673,091	389,070,688	912,078,907
6	40,210,943	92,862,859	473,409,030	248,429,057	84,055,063	47,727,250	74,979,679	94,394,232	231,774,924	153,058,035	74,749,419	62,695,091	207,847,468
7	6,186,299	14,253,369	262,396,559	156,877,923	95,631,209	55,630,057	32,114,379	26,330,318	53,803,793	75,204,515	45,412,822	21,177,588	32,995,774
8	1,933,218	3,023,442	228,998,835	127,981,544	70,129,796	57,155,435	45,992,258	17,719,477	22,826,600	51,415,520	38,000,626	23,989,227	13,305,595
9	386,644	431,920	87,177,468	133,712,886	53,429,920	38,315,592	41,234,111	19,145,347	29,169,814	21,146,821	23,281,868	14,936,765	9,054,704

Trends in pollock biomass from the three models were similar although the magnitude of biomass estimates, particularly in early years of the analyses, differed (Table 11, Fig. 4). Estimates from the CAGEAN and FBVPA models were similar throughout the period of the analysis. Biomasses were estimated at near 10 million t in the early 1970s, declined to about 6-7 million t in 1974-79, and then increased again to approximately 10 million t in the early 1980s. Estimates from the cohort analysis were higher over most of the period of the analyses approximating the upper end of the 95% confidence interval from the CAGEAN model in 1971-74, and ranging from near 14 million t in 1971 to 7.6 million t in 1978 and 1979. After 1979 there was good agreement between the estimates from the three methods, thus providing greater confidence in the more recent estimates.

Results since 1979 indicate that the biomass of pollock increased to about 10 million t in 1981 and 1982 and then declined moderately in 1983. The 1982 model results showing a range in mean values of 8.9 to 10.1 million t are in fairly good agreement with results from the combined bottom trawl-hydroacoustic survey data which produced a value of 8.8 million t. However, the trend in abundance of pollock as shown by the bottom trawl-hydroacoustic survey data between 1979 and 1982 (11.0 to 8.8 million t) is opposed to that shown by the models (6.4-7.6 million t to 8.9-10.1 million t). This difference can be partially explained by the unusually high abundance of age 1 fish in 1979 (from recruitment of the strong 1978 year-class) which accounted for 1.9 million t of the acoustic bottom trawl estimate, but which were not included in the estimates from the cohort analyses. The trends shown by the various CPUE values (Table 7) also differ from the modelling results, reflecting relatively stable abundance between 1979 and, 1982. The increase in abundance in 1979-82 as shown by the age-structured models appears to be the most logical trend because of recruitment of the strong 1978 year-class into the population during this period as will be discussed in the following section.

Age and Size Composition

Changes observed in the age structure of the pollock population in the eastern Bering Sea over the past few years show the effects of the recent highly variable recruitment (Fig. 5). From 1975 to 1981, the age compositions derived, from survey and fishery data were relatively consistent with survey catches composed primarily of ages 1-4 and fishery catches of ages 2-4 with age 3 fish usually predominating in the fishery catches. Age 5 and older fish were relatively rare in both survey and fisheries catches. Beginning in 1982 and continuing through 1984, the average age of the population increased. This change was the result of the strength of the 1978 year-class, which continued to dominate the age structure of the population at the relatively advanced ages of 4 - 6 years, and the low abundance of more recent year-classes.

Recruitment of the 1982 year-class appeared to be stronger than the 1979-81 year-classes based on the 1983 survey age data (Fig. 5). Cohort analysis indicates that the strength of the 1982 year-class at age 1 was above average. However, the 1984 age data indicated that the strength of the 1982 year-class at age 2 may have been below average.

Table 11.--Biomass estimates (million t) for walleye pollock in the eastern Bering Sea based on cohort analysis[a] and FBVPA[b] and CAGEAN[c] models and the 95% confidence interval for the estimates from the CAGEAN model.

Year	Cohort analysis	FBVPA model	CAGEAN model	Confidence interval from CAGEAN model
1971	13.8	10.1	9.3	5.1 - 13.5
1972	13.5	9.7	9.7	5.5 - 13.9
1973	12.2	8.7	9.5	5.7 - 13.3
1974	10.6	7.4	7.1	3.5 - 10.7
1975	9.3	6.9	6.8	3.4 - 10.2
1976	8.5	6.5	7.2	4.4 - 10.0
1977	8.1	6.1	6.9	4.5 - 9.3
1978	7.6	5.8	6.6	4.4 - 8.8
1979	7.6	6.4	7.1	4.9 - 9.3
1980	9.0	8.5	8.7	6.3 - 11.1
1981	10.0	10.1	9.5	6.3 - 12.7
1982	10.1	10.1	8.9	5.7 - 12.1
1983	8.8	9.0	7.9	4.9 - 10.9

[a] Method of Pope (1972).

[b] Fishable biomass virtual population analysis (Kimura 1985a).

[c] Catch-age analysis (Deriso et al. 1985).

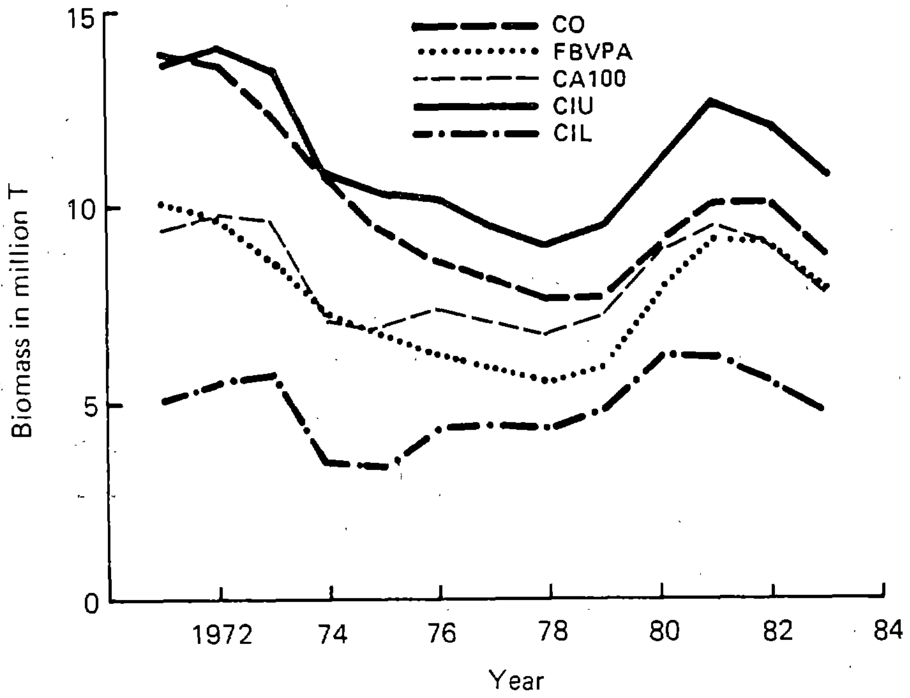

Figure 4. --Biomass estimates for walleye pollock based on age structured models: CO is cohort analysis, FBVPA is fishable biomass virtual population analysis, CA100 is CAGEAN or catch-age analysis and CIU and CIL are the upper and lower 95% confidence intervals for the biomass estimates from the CAGEAN model.

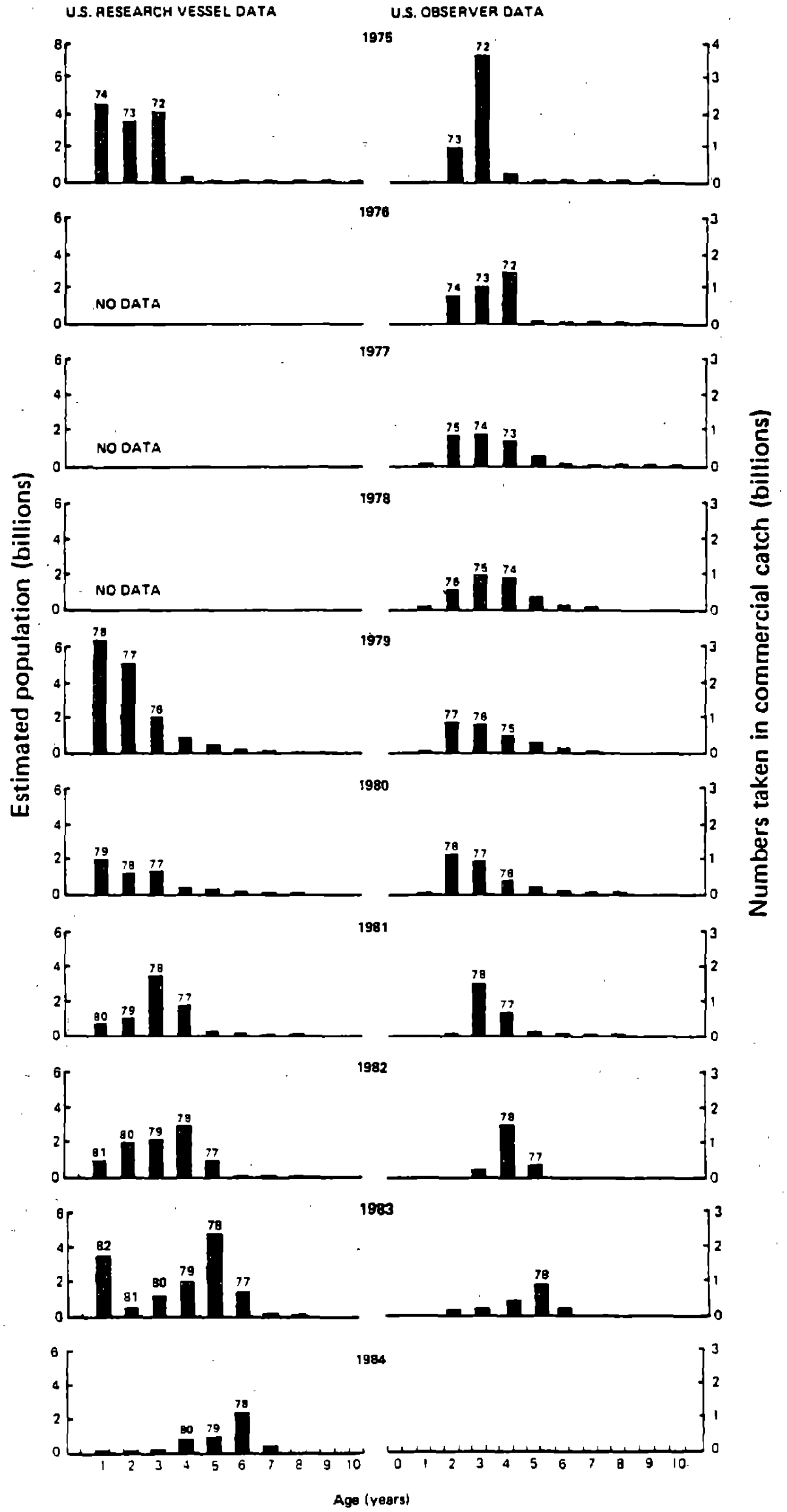

Figure 5.--Age composition of walleye pollock in the eastern Bering Sea as shown by data from Northwest and Alaska Fisheries Center research vessel surveys and by data collected in the commercial fishery by U.S. observers. Numbers above the bars indicate the principal year-classes.-

Length-frequency data from NWAFC bottom trawl surveys in 1979 and 1981-85 were used to further examine recruitment and abundance of age groups through 1985 (Fig. 6). These data show a continuation in the pattern observed since 1983 with the larger-older fish dominating the population and low numbers of 2 and 3 year old fish (represented by lengths from about 20-35 cm). Most of the larger fish in 1985 were between 40 and 50 cm, which would represent age 5 and older pollock.

The 1982 year-class, which appeared to be relatively strong as age 1 fish in 1983 (10-20 cm mode), appeared in only low numbers in the 1984 and 1985 survey length-frequency data as 2 and 3 year fish. The 1983 year-class at age 1 (10-20 cm fish) appeared weak in the 1984 survey length data and also appeared weak in the 1985 survey data. The 1984 year-class at age 1 (10-20 cm mode), however, appears to be of above average strength. Population estimates of age 1 pollock from bottom trawl surveys based on age analyses in 1979-84 (Fig. 5) and population numbers under 20 cm from the 1985 survey data (Fig. 6) were as follows:

Year	Year-Class	Population number estimates (billions)
1979	1978	8.7
1981	1980	1.0
1982	1981	0.9
1983	1982	3.6
1984	1983	0.4
1985	1984	4.5

Thus, the recruitment of age 1 pollock in 1985 appears to be better than in 1981-84.

Length-frequency data was also summarized from the 1985 hydroacoustic survey and is compared with length data from the 1979 and 1982 hydroacoustic surveys in Figure 7. The length data from the hydroacoustic survey could only be presented in terms of percent for this document and is thus not directly comparable to the bottom trawl length data in terms of population numbers (Fig. 6). The hydroacoustic data shows three modes in the length distribution rather than two as shown by the 1985 bottom trawl data. There were modes at 10-20 cm and 40-50 cm as in the bottom trawl data, but there was a third mode at 20-30 cm in the hydroacoustic survey data which was not present in the bottom trawl data. These 20-30 cm fish probably represent mainly age 3 year pollock of the 1982 year-class based on the aging of a small sample of fish in this size range. If this assumption is correct, then the 1982 year-class which was observed to be relatively strong as age 1 fish in the bottom trawl data, but appeared in only low numbers in bottom trawl data in 1984 and 1985, may have mainly occupied midwater in these latter 2 years.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) for eastern Bering Sea pollock has been estimated by, two methods: the general production model of Pella and Tomlinson (1969), and the method of Alverson and Pereyra (1969) --the latter for obtaining first approximation of yield per exploitable biomass. Estimates thus derived

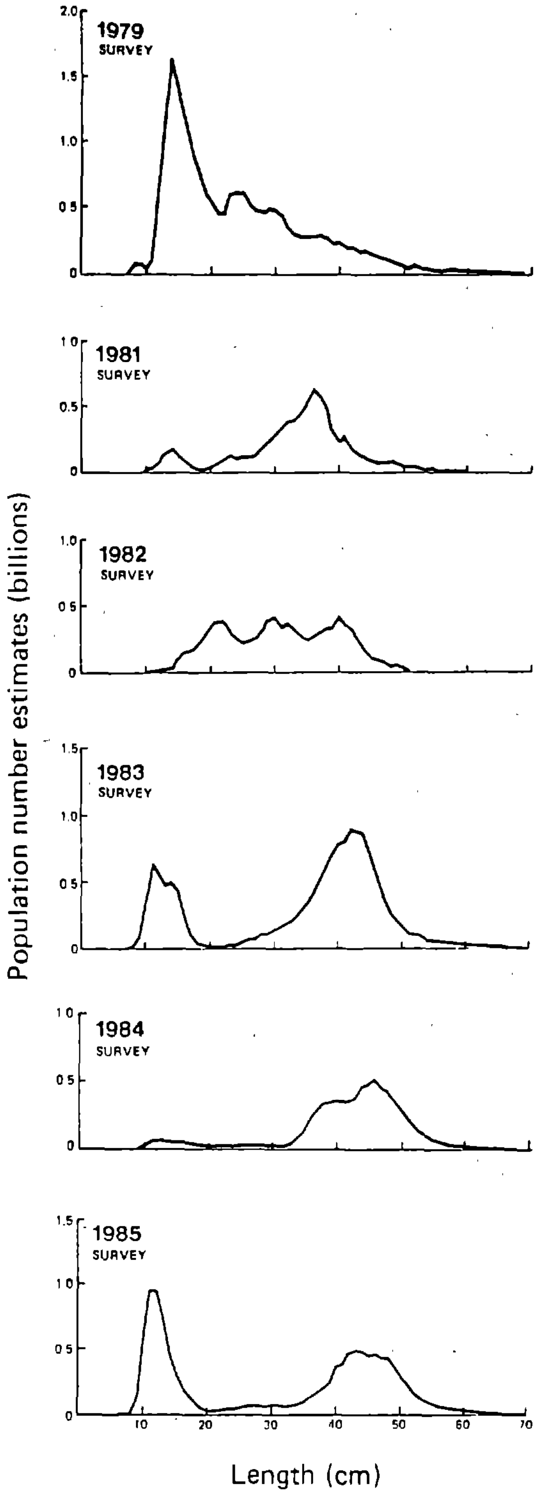

Figure 6.--Population estimates of walleye pollock by centimeter size interval, as shown by Northwest And Alaska Fisheries Center bottom trawl data from the continental shelf of the eastern Bering Sea in 1979-85.

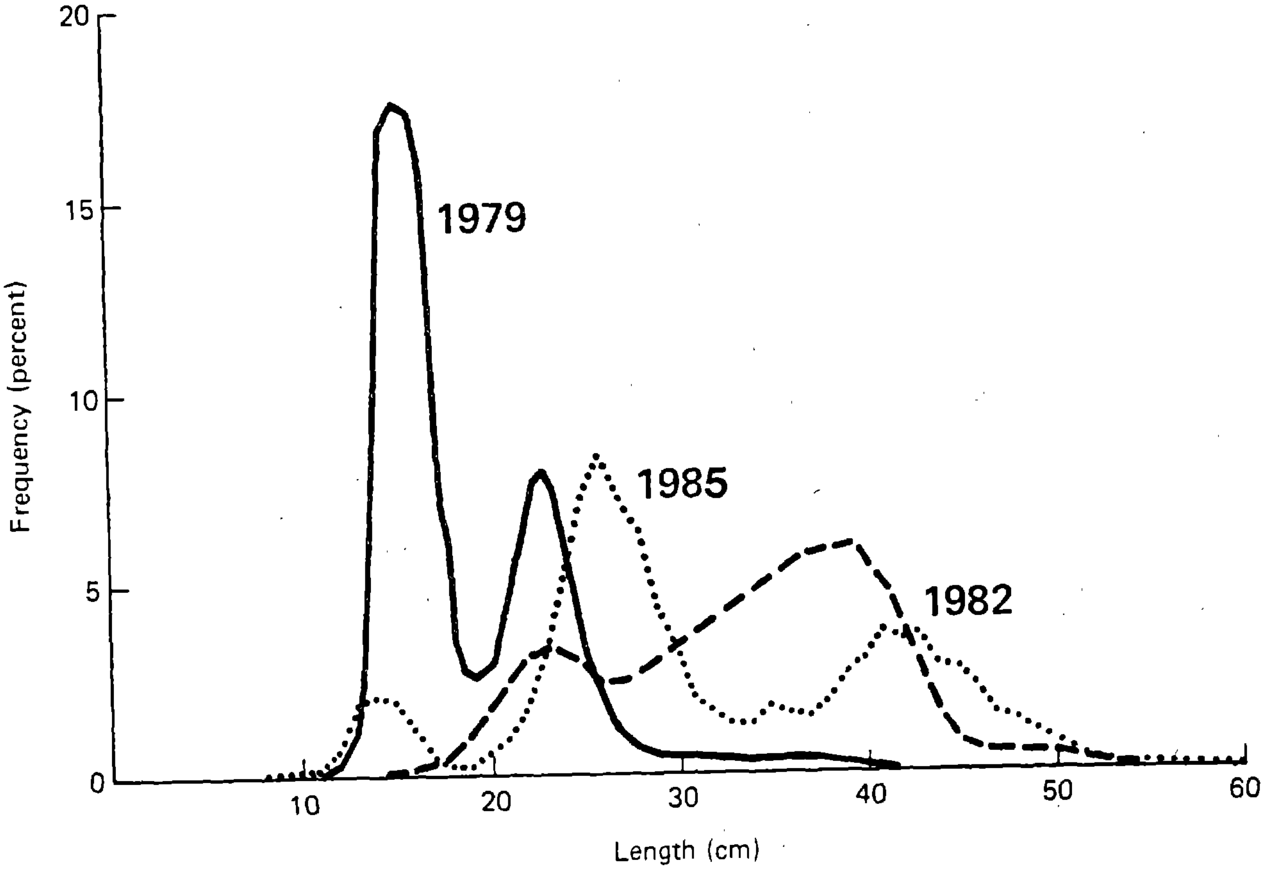

Figure 7.--Length-frequency distribution of walleye pollock taken in midwater over the continental shelf and slope of the eastern Bering Sea during Northwest and Alaska Fisheries Center hydroacoustic surveys in 1979, 1982 and 1985. The 1985 data are preliminary.

for the eastern Bering Sea from data available prior to 1974 ranged from 1.11 to 1.58 t (Low 1974). The incorporation of 1974-76. data, and the application of the procedure of Rivard and Bledsoe (1978), resulted in an estimated MSY of 1.5 million t (Low et al. 1978).

Based on the premise that the Aleutian Island region stock is independent of that in the eastern Bering Sea, a separate optimum yield has been established for this area by the North Pacific Fishery Management Council. Although MSY was not estimated because of lack of data for the Aleutian population, the optimum yield has been estimated at 100,000 t.

Biomass estimates for pollock in the Aleutian region are now available, based on the 1980 and 1983 U.S.-Japan demersal trawl survey in that region. The estimates were 280,200 t in 1980 and 539,400 t in 1983. Yet the biomass of pollock sampled by demersal trawls may only represent one-third to one-half of the total biomass of pollock in the Aleutians, as indicated by a comparison of the biomass estimates from demersal trawl surveys and those from cohort analysis and hydroacoustic surveys in the eastern Bering Sea. Assuming a vertical distribution of pollock in the Aleutians similar to that in the eastern Bering Sea, the overall biomass of pollock in the Aleutians may have approached or exceeded 1.0 million t in 1983.

EQUILIBRIUM YIELD

CPUE declined in the eastern Bering Sea during 1972-75 when catches ranged from 1.4 to 1.9 million t. CPUE stabilized in 1976-81 when catches ranged from 0.9 to 1.2 million t. This suggests that catches in the range of 0.9-1.2 million t were close to an equilibrium yield (EY) during this latter period.

Results from three age-structured models suggest that abundance increased from 1979 to a level of about 9 or 10 million t in 1982 (Table 11). These estimates are similar to the estimate of 8.8 million t derived from combined bottom trawl-hydroacoustic survey data in 1982 (Table 8). The age-structured models show a modest decline in biomass from 1982 to 1983 of about 1.0 million t with mean estimates ranging from 7.9 to 9.0 million t. Assessments of pollock in 1984 and 1985 based on bottom trawl survey results indicate a further decline between 1983 (133 kg/ha) and 1984 (99 kg/ha), but a leveling off in 1985 (97 kg/ha). Data from the fishery, however, did not show a decline in CPUE between 1983 and 1984. Thus, the trend in abundance of pollock between 1983 and 1985 is not clear but indications are that there has not been a substantial decline despite the apparent poor recruitment that has been observed in a number of recent year-classes. In addition, the 1984 year-class, which looks relatively strong and the 1982 year-class, which appeared to be abundant in midwater during summer 1985, should contribute to the exploitable stock in 1986.

Until there is clearer evidence of a decline in abundance of pollock as would be anticipated from the poor recruitment, there is no basis for altering EY. Thus, it is recommended that EY for the eastern Bering Sea be maintained at 1.1 million t.

Based on U.S.-Japan cooperative bottom trawl surveys in 1983, the biomass of pollock in the Aleutian region may be 1.0 million t or greater. However, because of the uncertainty about this estimate, EY for the Aleutian population is set at 10% of the estimate or 100,000 t.

Assuming that the biomass of pollock has not changed appreciably since 1983, the EY values of 1.1 million in the eastern Bering Sea and 100,000 t in the Aleutian region represent exploitation rates of about 12-14% and 10%, respectively. These rates appear biologically conservative based on yield per recruit theory [ICES 1984; Deriso (in press)]. For a healthy stock and using Von Bertalanffy growth and natural mortality parameters (M=0.20, L = 52.6 cm, K=0.30, t=-0.531, the theory suggests that the optimal exploitation rate is 22% ($F_{o.1}$=0.27, L_c=39.4).

PACIFIC COD

by

Richard G. Bakkala, Grant G. Thompson, and Allen M. Shimada

INTRODUCTION

Pacific cod, *Gadus macrocephalus*, are distributed widely over the Bering Sea continental shelf and slope and have a distributional range similar to that of walleye pollock, *Theragra chalcogramma*. During the early 1960s, a fairly large Japanese longline fishery harvested cod for the frozen fish market. Beginning in 1964, the Japanese North Pacific trawl fishery for pollock expanded, and cod became an important incidental catch in the pollock fishery and an occasional target species when high concentrations were detected during pollock operations. At present, cod is an incidental species for all foreign trawl fisheries, although it remains a target species of the Japanese longline fishery. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the eastern Bering Sea and Aleutian Islands areas. These two U.S. fisheries have dominated catches in the last two years, and in 1984 took 75,000 t, or 56% of the total catch.

Annual catches of Pacific cod by all nations in the eastern Bering Sea and Aleutians increased from 13,600 t in 1964 to 70,400 t in 1970, but then declined to range between 36,600 and 63,800 t in 1971-79 (Table 12). Catches in 1980-84 increased markedly from the level of the previous 3 years. because of increases in abundance of the resource (as will be discussed later) and catches by the new U.S. joint venture and domestic fisheries. All-nation catches of cod reached an historic high of 133,200 t in 1984, with most of this total (110,900 t) originating from the eastern Bering Sea.

CONDITION OF STOCKS

Relative Abundance

The abundance of Pacific cod in the eastern Bering Sea has increased substantially since the mid-1970s, mainly as a result of the recruitment of the strong 1977 and 1978 year-classes. The relative abundance of cod increased about seven-fold between 1976 and 1983 (Fig. 8), according to results from Northwest and Alaska Fisheries Center (NWAFC) surveys conducted in a comparative fishing area in the southeast Bering Sea (Fig. 9). Based on data from large-scale surveys that have sampled major portions of the eastern Bering Sea (see Fig. 9), the catch per unit of effort (CPUE) of cod increased approximately 9 times (from 2.7 to 24.8 kg/ha) between 1975 and 1983. In 1984 and 1985 the values declined moderately to 21.5 and 20.6 kg/ha, respectively. This decrease in CPUE indicates that overall population abundance may have peaked in 1983 and is now slowly declining.

Table 12 .--Commercial catches (t) of Pacific cod by area and nation, 1964-84[a].

	Eastern Bering Sea							Aleutian Islands			
Year	Japan	U.S.S.R.	R.O.K.[b]	Other nations[c]	Joint ventures[d]	U.S.[e]	Total	Japan	U.S.S.R.	R.O.K.	Other nations
1964	13,408	-					13,408	241	-	-	
1965	14,719	-					14,719	451	-		
1966	18,200	-					18,200	154	-		
1967	32,064	-	-				32,064	293	-		
1968	57,902	-	-				57,902	289	-	-	
1969	50,351	-	-				50,351	220	-	-	
1970	70,094	-	-				70,094	283	-	-	
1971	40,568	2,486	-				43,054	425	1,653	-	
1972	35,877	7,028	-				42,905	435	-	-	
1973	40,817	12,569	-				53,386	566	411	-	
1974	45,915	16,547	-	-			62,462	1,334	45	-	
1975	33,322	18,229	-	-			51,551	2,581	257	-	
1976	32,009	17,756	716	-			50,481	3,862	312	16	
1977	33,141	177	-	2		15	33,335	3,162	100	-	
1978	41,234	419	859	-		31	42,543	3,165	120	6	
1979	28,532	1,956	2,446	47		780	33,761	5,171	414	6	
1980	27,334	7	6,346	1,371	8,370	2,433	45,861	2,834	4	58	9
1981	27,570	0	6,147	2,481	7,410	8,388	51,996	2,426	0	476	12
1982	17,380	0	8,151	647	9,312	19,550	55,040	1,730	0	259	7
1983	29,411	0	9,792	32	9,662	34,315	83,212	1,845	0	392	34
1984	46,346	688	10,030	169	24,382	29,329	110,944	1,244	0	1	32

[a] Catch data for 1964-79 as reported by fishing nations and for 1980-83 from French et al. 1981, 1982; Nelson et al., 1983b, 1984; Berger et al., 1985a.

[b] Republic of Korea.

[c] Taiwan, Poland, and Federal Republic of Germany.

[d] Joint ventures between U.S. catcher boats and foreign processing vessels.

[e] U.S. vessels delivering catches to domestic processors.

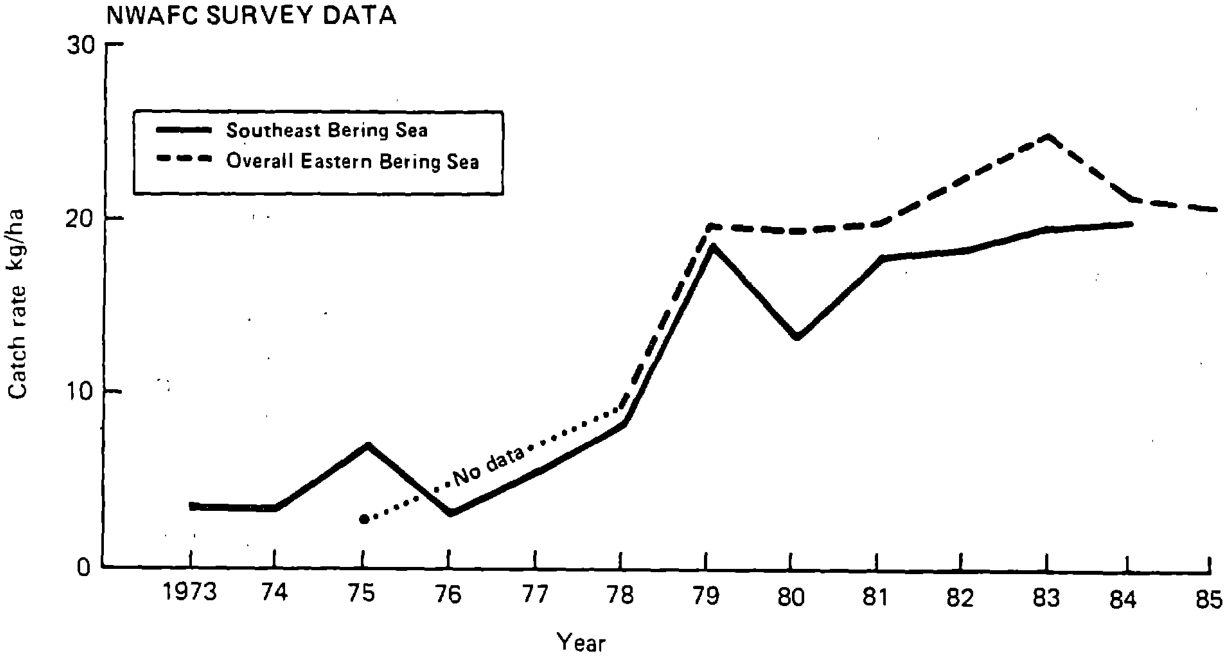

Figure 8.--Relative abundance of Pacific cod as shown by Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys.

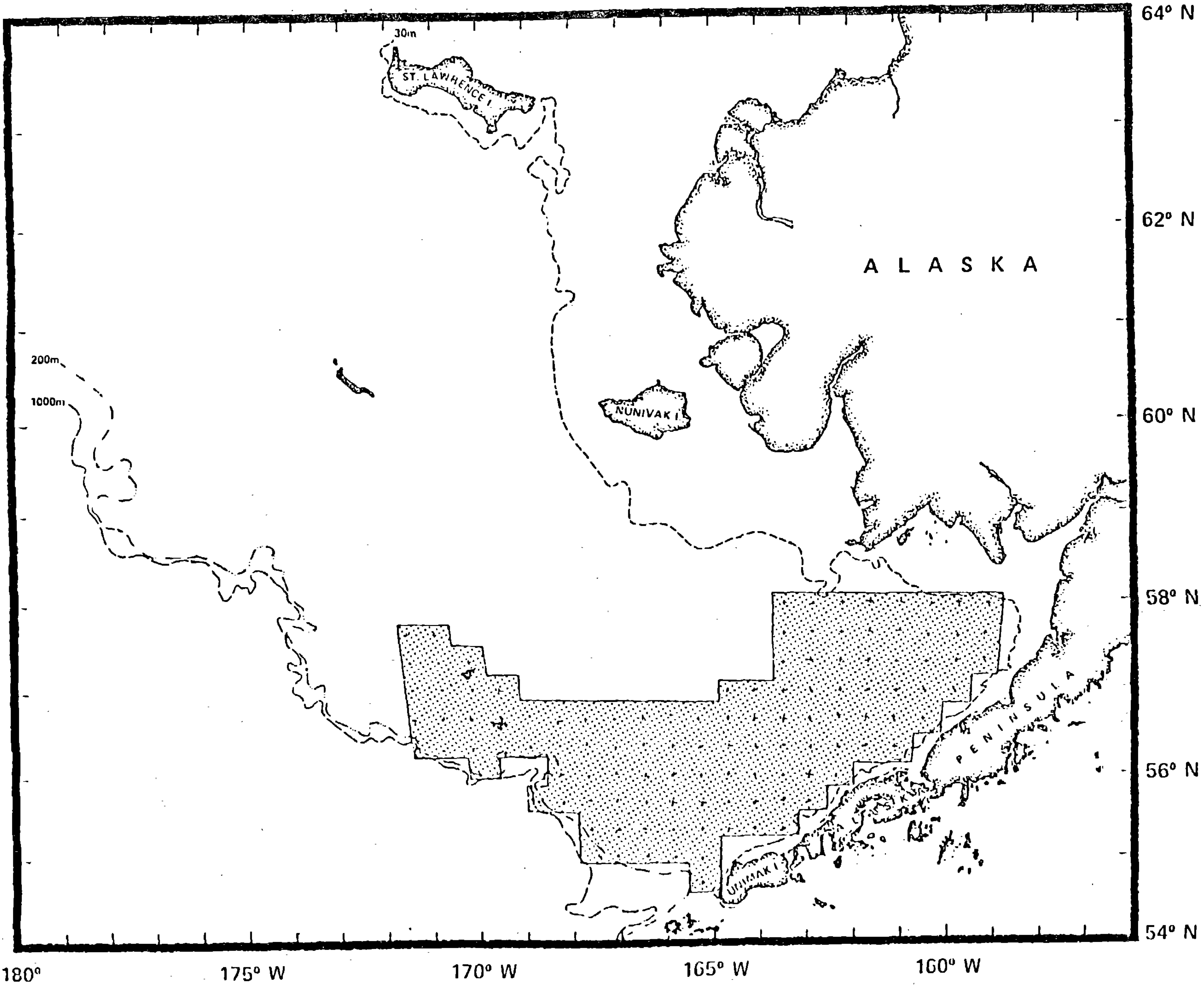

Figure 9.--Comparative fishing area sampled annually during Northwest and Alaska Fisheries Center demersal trawl surveys in 1973-84;

Biomass Estimates

Estimates of biomass from large-scale NWAFC demersal trawl surveys in the eastern Bering Sea since 1978 have been as follows:

	Biomass	
Year	Mean estimate (t)	95% confidence intervals (t)
1978	312,000	87,300 - 536,800
1979	792,300	603,200 - 981,400
1980	913,300	795,700 - 1,031,000
1981	840,100	691,700 - 988,400
1982	1,013,900	875,000 - 1,152,800
1983	1,126,400	904,000 - 1,348,800
1984	999,700	872,900 - 1,126,500
1985	957,600	855,500 - 1;059,800

Estimates continued to increase through 1983 before declining moderately in 1984 and 1985. These mean estimates indicate that population weight may have peaked in 1983, although the 95% confidence intervals overlap, suggesting that estimates have not been significantly different in recent years. Since the peak year of 1983, abundance has not declined as sharply as anticipated. The reasons for this will be discussed in the following section on size and age composition.

Three biomass estimates have been derived from surveys in the Aleutian Islands region: two based on summer cooperative U.S.-Japan surveys of the overall Aleutians in 1980 and 1983, and the other on a U.S. winter survey in the eastern Aleutians (Bakkala et al. 1983). These estimates (t) were as follows:

Year	Season	Aleutian Islands area (170°E - 170°W)	Aleutian Islands portion of INPFC Area I (170°W - 165°W)
1980	summer	78,800	66,100
1982	winter		283,300
1983	summer	136,900	45,600

The estimates from the summer surveys covering the entire Aleutian chain (170°E - 165°W) showed a moderate increase (26%) in the mean values between 1980 and 1983, similar to the 23% increase shown by estimates from the eastern Bering Sea in the same period. The 1982 winter survey estimate from the eastern Aleutians (170°W - 165°W) exceeds that from the 1980 and 1983 summer surveys for the entire Aleutian region, suggesting that cod may migrate from other areas in winter to spawn in the eastern Aleutian region.

Size and Age Composition

Previous analyses have attributed the increase in abundance of cod in the eastern Bering Sea mainly to the recruitment of the strong 1977 year-class to the population. In the absence of a reliable method of aging cod, the magnitude and progression of age groups in the population have been illustrated by length and weight frequency distributions (Fig. 10). This technique provided a method of following the progression of the 1977 and other year-classes through the population as well as a measure of recruitment of later year-classes as they enter the sampled population at age 1.

Recently, however,, an improved method of aging cod using dorsal fin rays has been developed at the NWAFC (Lai 1985). This method appears to produce reliable aging based on the observed modes in the length and weight frequency distributions and the longevity of the 1977 year-class. When used to age the 1984 sampled population of cod, the new method (Fig. 11) confirmed that the 1977 year-class at age 7, although reduced in numbers, still contributed a major share to the overall population biomass. The new aging technique also shows that the 1978 year-class is relatively strong and contributed about the same share to the overall biomass as the 1977 year-class in 1984. Assuming that the new aging technique is reliable, the previous failure to recognize the strength of the 1978 year-class apparently resulted from the extensive overlapping of length distributions of the 1977 and 1978 year-classes. The presence of two consecutive strong year-classes, rather than a single strong year-class as was previously thought, explains at least in part why there has not been a sharper decline in abundance of cod in recent years.

Also contributing to the continued high biomass of cod is the strength of the 1982 year-class, which is not as strong as the 1977 and 1978 year-classes, but still contributed about 200,000 t to the overall population biomass at age 3 in 1985. There also appears to be good recruitment from the 1984 year-class based on numbers of age 1 fish from the 1985 survey data (Fig. 10). The strength of the 1984 year-class may be greater than the 1982 year-class, but is not as great as the 1977 year-class.

PROJECTIONS OF ABUNDANCE

The abundance of Pacific cod has been projected through 1986 in previous reports (Bakkala and Wespestad 1985). The impetus for these forecasts has been the presence of the strong 1977 year-class and the need to estimate the response of the population to this strong recruitment and to develop exploitation strategies that would maximize yield during the period of high population abundance.

One of the problems encountered in forecasting abundance of cod had been the absence of reliable age data. Previous projections were based on estimates of numbers at age obtained by the method of MacDonald and Pitcher (1979), which utilizes an iterative procedure that fits a series of normal curves to length-frequency data. As described earlier, a satisfactory means of aging cod appears to have been developed by Lai (1985) using counts of annual rings from dorsal fin ray sections. Using this method, a sample of 326 cod from the 1984 eastern Bering Sea survey was aged. The age-length key from this sample was applied to random length-frequency samples from the NWAFC Bering Sea

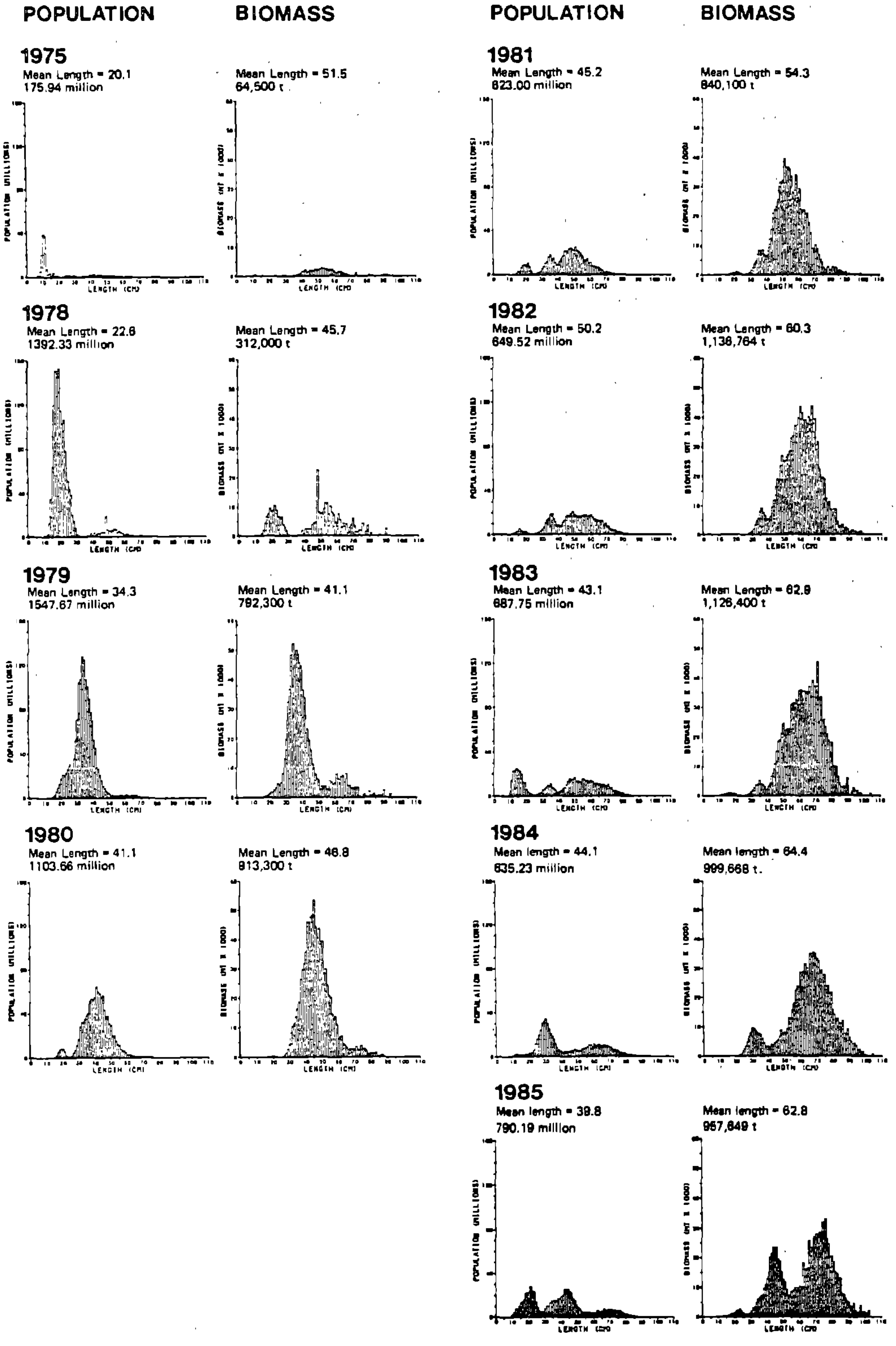

Figure 10.--Population and biomass estimates by centimeter length interval for Pacific cod as shown by Northwest and Alaska Fisheries Center bottom trawl surveys in 1975-85.

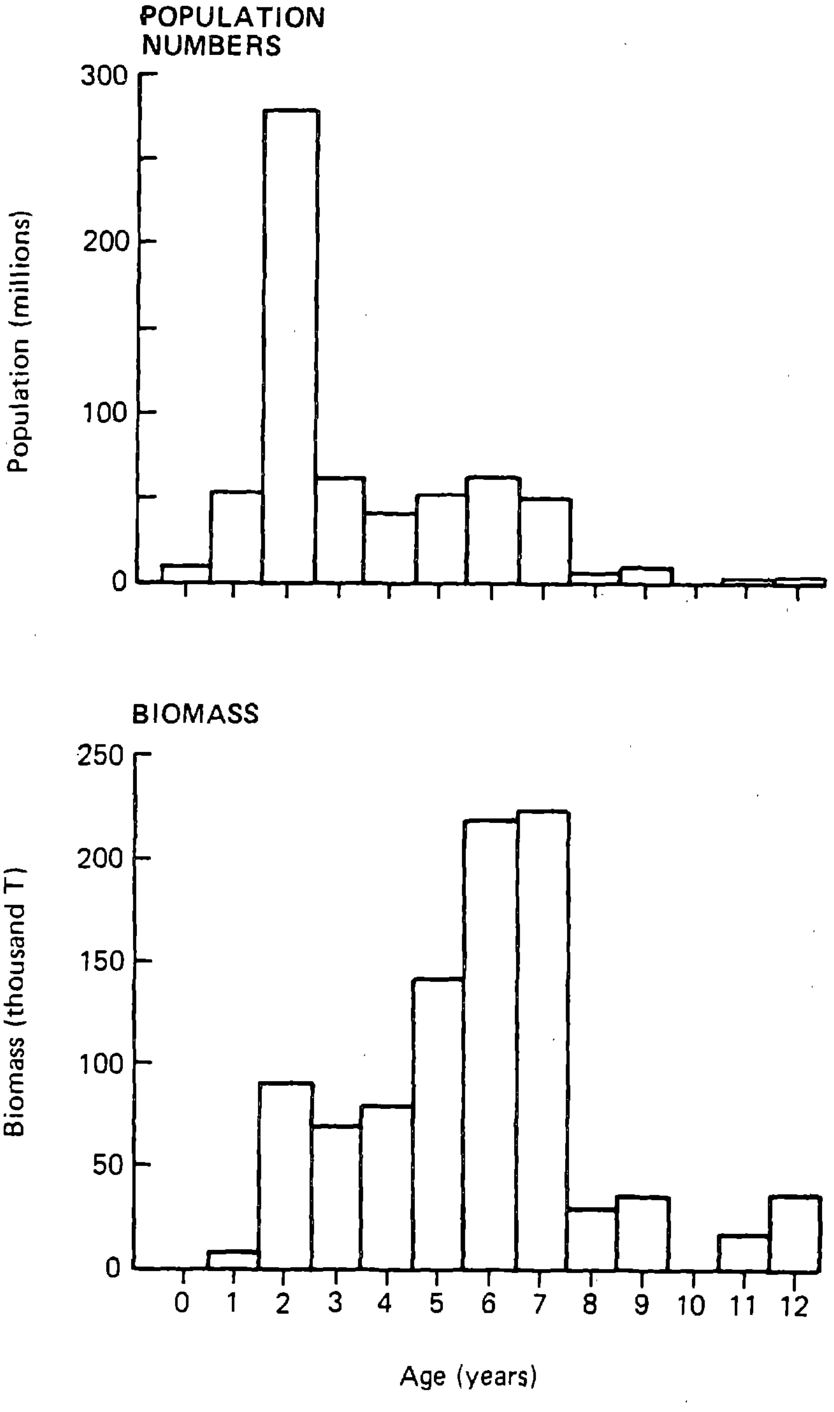

Figure 11 .--Age composition of Pacific cod in the eastern Bering Sea in 1984 in terms of population numbers and biomass. Aging was based on counts of annuli from dorsal fin rays.

surveys to produce a time series of annual numbers at age for the period 1978-85 (Table 13). This time series of numbers at age was then used to calibrate a new model designed to simulate the population dynamics of eastern Bering Sea cod.

It is important to note, however, that an age-length key obtained from a single year's sample cannot be applied to data from other years without some bias, unless the age distribution of the population is stable (Kimura 1977). Since the age distribution of the eastern Bering Sea cod population is not stable, the application of the 1984 age-length key to years 1978-1983 and 1985 should tend to bias the results in the direction of the 1984 age distribution. Because the 1984 age distribution is skewed more toward the older ages than would be expected under equilibrium conditions, the application of the 1984 age-length key to the earlier years in the time series should tend to bias the resulting age distributions toward the older ages.

Given numbers at age (Table 13), it was possible to estimate the age of full recruitment. This estimate was based on patterns observed in the instantaneous rate of total mortality (Z) by age (i) and year (j), computed according to the following equation:

$$Z(i,j) = -\ln[n(i+1,j+1)/n(i,j)], \qquad (1)$$

where $n(i,j)$ = number of fish at age i in year j in the survey population, i.e. the portion of the overall stock which is recruited to the survey gear.

The matrix of age- and year-specific Z's is shown in Table 14 for ages 0 through 4. It may be noted that the Z's for ages 0 and 1 are all negative, indicating that substantial recruitment is occuring during those ages. Three of the seven years show negative Z's at age 2, indicating that recruitment is continuing at that age, also. At age 3, however, Z is positive in each year and is actually higher than the corresponding Z at age 4 in every year except 1978, where it is slightly lower. This may be interpreted as evidence that the fish are fully recruited to the survey gear at age 3.

In addition to assuming that the fish are fully recruited to the survey population at age 3, it was also necessary to make an assumption regarding recruitment to the commercial fishery. Knife-edge recruitment at age 3 was assumed, following the findings of Fredin (1985). Similar assumptions were made both by Wespestad et al. (1982) in a study of Pacific cod and by Garrod (1973) in a study of Atlantic cod (*Gadus morhua*). It was further assumed that numbers of age 3 individuals in the fished population equaled numbers of age 3 individuals in the survey population.

Instantaneous rates of fishing mortality (F) and natural mortality (M) were derived from the catch data (Table 12), survey numbers at age estimates (Table 13), and survey biomass estimates. A problem arises in employing these figures, however, in that the surveys used to generate the biomass and numbers at age estimates occurred in the middle of their respective fishing seasons. As a simple means of bypassing this problem, it was assumed that fishing was undertaken at a uniform rate throughout the year, and that the catch statistics in Table 12 were based on a fishing season which began annually at the time of the survey. Although neither of these assumptions is strictly correct, each appears to be reasonable means of making full use of the available data.

Table 13.--Estimated numbers (millions) of Pacific cod at age in 1978-1985 based on a 1984 age-length key and annual length-frequency samples from NWAFC surveys in the eastern Bering Sea.

Age	1978	1979	1980	1981	1982	1983	1984	1985
0	31.9	0.6	0.5	1.4	3.8	18.2	3.3	15.3
1	1020.1	148.2	48.1	59.5	23.3	50.5	52.8	137.7
2	176.8	1140.2	453.1	135.6	132.8	85.0	278.7	189.1
3	56.1	180.5	461.0	220.0	167.3	133.7	61.0	191.9
4	22.1	26.5	92.6	91.7	87.7	75.3	39.9	36.5
5	12.7	10.4	22.6	53.4	80.7	68.1	51.8	24.3
6	11.1	10.4	14.8	37.2	75.3	77.5	63.8	40.1
7	6.0	6.9	8.7	18.9	49.1	57.6	52.7	47.1
8	0.8	0.5	0.6	0.9	4.7	5.4	7.7	5.8
9	0.8	1.9	1.2	3.8	13.4	11.6	9.3	5.9
10+	0.3	0.5	0.3	0.5	3.6	4.9	7.2	7.0

Table 14.--Instantaneous rates of total mortality (Z) for Pacific cod, age groups 0-4.

Age	1978	1979	1980	1981	1982	1983	1984
0	-1.5360	-4.3841	-4.7791	-2.8120	-2.5870	-1.0651	-3.7312
1	-0.1113	-1.1176	-1.0364	-0.8029	-1.2942	-1.7082	-1.2758
2	-0.0207	0.9056	0.7225	-0.2102	-0.0068	0.3318	0.3732
3	0.7500	0.6674	1.6149	0.9197	0.7983	1.2092	0.5136
4	0.7538	0.1592	0.5505	0.1278	0.2529	0.3741	0.4959

Given these assumptions, the first step in calculating F and M was to compute the instantaneous rate of total mortality (Z) for each year j:

$$Z(j) = -\ln(N(j+1)/N(j)), \tag{2}$$

where

$$N(j) = \sum_{i=3}^{10} n(i,j), \tag{3}$$

and

$$N(j+1) = \sum_{i=3}^{9} n(i+1,j+1). \tag{4}$$

Then, the estimated biomass at each age was computed by applying a length-age equation and a weight-length equation to numbers at age. The length-age equation used was the Von Bertalanffy growth equation, with parameters estimated from the 1984 pooled (male and female) sample using Fabens (1965) estimation technique. This procedure yielded the following equation of length (cm) as a function of age (years):

$$L(i) = 84.008(1.-\exp(-.203(i+.806))). \tag{5}$$

The weight-length equation was obtained by examination of over 3,000 specimens taken between 1975 and 1983, and gives weight (kg) as an exponential function of length (cm):

$$W(L) = .00000608\ L^{3.1635} \tag{6}$$

Application of equations (5) and (6) to the numbers at age shown in Table 13 gives the estimates of biomass at age shown in Table 15. Summing the estimated biomass at age over all ages gives anestimate of total biomass, shown in the next to the last row of Table 15. However, biomass estimates calculated in this manner should tend to underestimate actual biomass, as described by Pienaar and Ricker (1968). The amount of bias (last row, Table 15) can be derived by dividing each of the estimates of total biomass in Table 15 by the corresponding survey estimate of biomass.

The bias value for 1984 corresponds to the population sample used to generate the age-length key from which the matrix of numbers at age shown in Table 13 was generated. Because of the continued strength of the 1977 year class, the 1984 numbers at age distribution features a significant bulge at the older ages. Thus, as the 1984 age-length key is used to estimate annual numbers at age for increasingly early years, the sizes of the older (heavier per capita) age groups tend to be overestimated with increasing severity. This, in turn, increasingly compensates for the underestimate of actual biomass produced by use of the weight-length relationship. Thus, the bias values decline over time, as shown in the last row of Table 15.

The bias value for a particular column in Table 15 gives an estimate of the amount by which each estimate of biomass at age in that year is biased. Summing estimated biomass at age over ages zero through two and dividing by the bias in that year gives a corrected estimate of the biomass of those age

Table 15.--Estimated biomass (in thousands of metric tons) of Pacific cod by age group in 1978-85 based on numbers at age in Table 13, and estimated bias by year.

Age	1978	1979	1980	1981	1982	1983	1984	1985
0	0.6	0.0	0.0	0.0	0.1	0.3	0.1	0.3
1	180.9	26.3	8.5	10.5	4.1	9.0	9.4	24.4
2	94.0	606.0	240.8	72.1	70.6	45.2	148.1	100.5
3	58.8	189.1	483.1	230.5	175.3	140.1	63.9	201.1
4	36.8	44.1	154.2	152.7	146.0	125.4	66.4	60.8
5	29.5	24.2	52.5	124.1	187.6	158.3	120.4	56.5
6	33.1	31.0	44.1	110.8	224.3	230.9	190.1	119.5
7	21.6	24.8	31.3	68.0	176.7	207.3	189.7	169.5
8	3.3	2.1	2.5	3.8	19.6	22.5	32.1	24.2
9	3.7	8.9	5.6	17.8	62.6	54.2	43.5	27.6
10+	1.5	2.6	1.5	2.6	18.4	25.1	36.8	35.8
sum	463.8	959.1	1024.2	792.9	1085.4	1018.3	900.5	820.1
bias[a]	1.4866	1.2105	1.1214	0.9438	1.0705	0.9040	0.9007	0.8477

[a] Estimate of the amount by which each age group in a given year is biased.

Table 16.--Annual rates of exploitation (E), natural mortality (M) and fishing mortality (F) for Pacific cod in 1978-1984.

Year	E	M	F
1978	0.3022	0.1977	0.4571
1979	0.1211	0.3624	0.1608
1980	0.0834	0.9619	0.1082
1981	0.0625	0.2242	0.0801
1982	0.0573	0.3993	0.0731
1983	0.0810	0.5199	0.1049
1984	0.1316	0.3893	0.1760
Average	n/a	0.4364	n/a

groups in each year that are not fully recruited. Subtracting this number from the survey biomass estimate gives a figure for fishable biomass. Then, dividing total catch by fishable biomass gives exploitation rate (Table 16). Finally, F can be computed by the following equation:

$$F(j) = C(j)Z(j)/(N(j)-N(j+l)). \qquad (7)$$

The resulting estimates of F are shown in Table 16. Since F is the product of catchability and fishing effort, Table 16 represents a weighting of catchability by the annual fishing effort schedule for 1978-1984. For ease of comparison, fishing effort will be scaled to a value of 1.0 in 1984, thus setting catchability equal to 0.1760. It should be noted that catchability is defined here in a slightly different manner than that advocated by Ricker (1975), in which catchability is scaled from zero to one.

Subtracting F from Z in each year gives the estimates of M shown in Table 16. Averaging these values yields a figure of 0.4364 for overall M.

Recruitment to the survey population was assumed to follow the "platoon" pattern described by Ricker (1975), in which vulnerability of a year-class increases gradually over a period of several years. Fixing M at a level of .4364 and using the information on numbers at age displayed in Table 13, it was possible to compute average values for the rates involved in the gradual recruitment of an initial (i.e. pre-recruitment) number of age 0 fish to the survey population (Thompson et al. 1986).

Given the above set of life history parameters and a schedule of fishing effort, it is possible to project the entire history of a cohort, simply by knowing the initial number of individuals at age 0. To be able to simulate the entire population over time, then, it only remains to specify a mechanism that predicts the initial number of age 0 individuals from total numbers at age. The following four parameters are sufficient to define such a mechanism: 1) the sex ratio in the population (number of females divided by total numbers), 2) the schedule of maturity at age (number of mature individuals at age divided by total numbers at age), 3) the schedule of fecundity at age (number of eggs produced annually by a mature female individual at age), and 4) the ratio of total annual egg production to total number of age 0 individuals (recruited and non-recruited) at the time of the survey. For simplicity, this last quantity (4) will be termed the "egg survival rate," although the timing of the survey undoubtedly causes some additional mortality factors associated with very early life history stages to be incorporated in its calculation.

Umeda and Bakkala (1983) showed that females comprised 50.5% (by number) of the Pacific cod population in the eastern Bering Sea in 1980. Similar percentages of 51% and 48% were also observed in 1976 and 1979, respectively (Bakkala 1984). It thus appears that females account for about 50% (by number) of the total cod population in the eastern Bering Sea.

The only known maturity study of Pacific cod in the eastern Bering Sea was described by Teshima (1984). His preliminary results showed that 50% of male cod are mature by the time they reach 60 cm, and 50% of the females by 62 cm. Teshima's estimates of maturity at length for each sex were averaged to obtain an overall schedule of maturity at length (Table 17). These data were used to estimate the following relationship describing the proportion of mature individuals (m) as a function of length (L) in cm:

Table 17.--Length (cm) at which various proportions of male and female Pacific cod reach sexual maturity (Teshima 1984).

Proportion mature	Length males	Length females	Average length (sexes combined)
0.10	51	54	52.5
0.20	53	56	54.5
0.30	54	58	56.0
0.40	56	60	58.0
0.50	60	62	61.0
0.60	64	64	64.0
0.70	67	67	67.0
0.80	68	69	68.5
0.90	69	70	69.5
1.00	71	72	71.5

$$m(L) = 1/(1 + \exp(15.1642-(.2479L))). \tag{8}$$

No data are available on fecundity of Pacific cod in the eastern Bering Sea. However, Thompson (1962) examined fecundity of cod from Hecate Strait, British Columbia, and compared his data to those reported by Moiseev (1953) for samples taken in the area from Sakalin Island to Kamchatka. He concluded that the fecundity-length relationship was the same in each area.. Lacking data specific to the Bering Sea, it was assumed that the fecundity-length relationship derived by Thompson is applicable to the eastern Bering Sea population. The following equation, based on Thompson's data, gives fecundity (f) in number of eggs as a function of length in cm:

$$f(L) = 0.3949\,L^{3.6417} \tag{9}$$

Egg survival rate in year j may be computed as the ratio of age 0 fish in the overall population in year j (computed by using M and the estimated recruitment rates to back-calculate from numbers at age) to eggs produced in year j. Egg production may be estimated as follows: First, for each age i, maturity at age and fecundity at age are derived by converting age to length (L(i)) (equation (5)), and applying equations (8) and (9). Then, egg production at age i in year j is computed as n(i,j) multiplied by the product of the sex ratio (.50), m(L(i)), and f(L(i)). Finally, total egg production for year j is calculated by summing age-specific egg production over all ages. The resulting egg survival rates for the 1978-82 year-classes give an average value of .0257. This figure is within the range of egg survival rates observed by Grauman (1973) for Baltic cod (Gadus morhua) on three spawning grounds over the. years 1954-68.

By employing all of the above information, the model was able to simulate the population from ages 0 through 10 over any number of years desired, given a level of fishing effort for each year. This simulation capability was used to obtain an estimate of the optimum harvest level for 1986, given the following additional constraints: 1) the eastern Bering Sea portion of the catch was assumed to comprise 86.55% (the 1978-84 average) of the overall eastern Bering Sea/Aleutians catch, 2) the 1985 eastern Bering Sea/Aleutians catch was assumed to equal 150,000 t, and 3) optimum harvest was defined as the harvest which resulted in an age 0 recruitment value for 1987 equal to the average for 1978-85 (all the years for which data are available).

Since the 1985 survey results were still preliminary at this writing, the 1984 distribution of numbers at age was used to seed the simulation, giving the projection for 1986 shown in Table 18. These results suggest an optimal 1986 harvest of 215,800 t for the eastern Bering Sea component of the stock, for a total (eastern Bering Sea plus Aleutians) harvest of 249,300 t.

As with all fishery simulations, the results obtained from this simulation are dependent on the parameter values used as inputs; i.e., the simulation will inevitably be somewhat sensitive to variation in the input parameters. To obtain an example of how parameter variation can affect results, the simulation's sensitivity was examined with respect to a single parameter, namely the mean initial recruitment value used to constrain the optimum harvest calculation. The simulation was re-run for mean initial recruitment values 10% above and below the estimated value used in the original simulation. These runs resulted in suggested harvest levels 15.6% below and 15.4% above the original recommended level, respectively. Unfortunately, it is extremely difficult to obtain a comprehensive view of the simulation's sensitivity. A complete sensitivity test would require not only that results be checked for sensitivity to variation in each of the parameters individually, but the impact of simultaneous variation in all possible combinations of parameters would have to be checked as well. Thus, it is recommended that the results of this simulation be viewed with some caution.

Another reason for adopting a cautious view of these results stems from the projected age distribution of the suggested catch. The projection indicates that the majority of the catch in 1986 should come from age 3 and age 4 fish (the 1983 and 1982 year-classes). If this. projection should hold, it would constitute a significant change from the age distributions of recent harvests, which have been dominated by older ages. Since the projected size of the 1983 year class is based in part on assumptions regarding its continued recruitment as age 3 fish, it is probably more subject to error than size projections of fully-recruited year-classes.

Table 18.--Projected 1986 abundance and catch of eastern Bering Sea Pacific cod (does not include Aleutian component of stock).

		Projected 1986 abundance		Projected 1986 catch	
Age	Year class	Numbers (millions)	Biomass (1000 t)	Numbers (millions)	Biomass (1000 t)
0	1986	15.5	0.3	0.0	0.0
1	1985	226.4	44.6	0.0	0.0
2	1984	115.9	68.4	0.0	0.0
3	1983	128.3	149.2	42.5	49.5
4	1982	104.5	193.3	34.7	64.1
5	1981	16.9	43.7	5.6	14.5
6	1980	11.1	36.7	3.7	12.2
7	1979	14.4	57.5	4.8	19.1
8	1978	17.7	82.0	5.9	27.2
9	1977	14.6	76.0	4.9	25.2
10	1976	2.1	12.2	0.7	4.0
Total		667.5	763.7	102.7	215.8

MAXIMUM SUSTAINABLE YIELD

It is apparent that the eastern Bering Sea cod population is subject to wide fluctuations in abundance. Most data come from a period when the population was either undergoing a rapid increase in abundance or at a high level of abundance. Thus, observations of the population over a range of stable abundances are not available. Furthermore, neither the recruits-perspawner data nor the recruits-per-egg data seem to follow any simple density-dependent pattern. Therefore, a constant (density-independent) egg survival rate was assumed instead. When this assumption is employed, neither maximum sustainable yield nor equilibrium surplus production (as usually defined) can be calculated.

EQUILIBRIUM YIELD

Equilibrium yield (the annual yield which allows the stock to be maintained at approximately the same level of abundance in successive years) is not an appropriate management concept to apply to the cod resource at the present time. The current age distribution of the population is such that overall biomass is expected to decline over the next year regardless of the level of fishing effort.

As evidence of the decline among the older age groups, it may be noted that for ages 4 and older, the 1985 survey results show a decline of 27% from 1984 in terms of biomass (679,000 t to 493,900 t). However, this decline is being moderated by the recruitment of later year-classes with higher than average abundance, such as the 1982 and 1984 year-classes. For ages 3 and younger, the 1985 survey results show an increase in biomass of 47% over 1984 (221,500 t to 326,300 t).

Despite these moderating influences, it appears clear that yields cannot be adjusted to maintain the stock at its present level, but should instead be allowed to remain high to take advantage of the available surplus before it is lost to natural mortality. As an alternative to equilibrium yield, model simulations have estimated an optimal harvest level of 249,300 t designed to maximize catch while maintaining an adequate spawning stock. As mentioned earlier, it may be prudent to view this harvest level as an upper bound.

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YELLOWFIN SOLE

by

Richard G. Bakkala and Vidar G. Wespestad

INTRODUCTION

Yellowfin sole, Limanda aspera, is the second largest groundfish resource of the eastern Bering Sea after walleye pollock, Theragra chalcogramma. The abundance of yellowfin sole was substantially reduced by intense exploitation in the early 1960s. Cohort analyses (Wakabayashi et al. 1977; Bakkala et al. 1982) indicated that this intense exploitation in early years of the fishery and continued exploitation through the 1960s reduced the exploitable biomass to one third or less of pre-1960 levels. The resource began to recover in about 1972 and abundance in recent years is estimated to have been as high or higher than pre-1960 levels.

CONDITION OF STOCK

Catch Statistics

Following a period of intense exploitation in 1959-62, when catches averaged 404,000 metric tons (t) annually, catches declined, particularly in the 1972-77 period (ranging from 42,000 to 78,000 t). This decline was due primarily to the absence of a directed fishery for yellowfin sole by the U.S.S.R. (Table 19). The U.S.S.R. reentered the yellowfin sole fishery in 1978-79 and catches increased to range from 99,000 to 138,400 t. The U.S.S.R. was prohibited from fishing in the U.S. 200-mile fishery conservation zone in 1980-83, although they were allowed to process catches taken by U.S. fishermen in joint venture operations. In 1980-83, catches ranged around 100,000 t annually. Catch quotas established by the North Pacific Fisheries Management Council (NPFMC) during these latter years were 126,000 t in 1979 and 117,000 t in 1980-83 (see Table 4). For 1984, however, the quota was increased to 230,000 t and catches increased to about 160,000 t.

Relative Abundance

The two sources of information used to examine trends in relative abundance for yellowfin sole are pair trawl data from the Japanese commercial fishery and survey data from Northwest and Alaska Fisheries Center (NWAFC) resource assessment surveys. The pair trawl catch and effort data used are from 0.50 latitude by 1° longitude statistical blocks and months in which yellowfin sole made up 50% or more of the total catch. Effort data are adjusted for changes in horsepower.

Table 19.--Annual catches of yellowfin sole in the eastern Bering Sea (east of long. 180° and north of lat. 54°N) in metric tons[a].

Year	Japan	U.S.S.R.	R.O.K.[b]	Others	Joint venture	Total
1954	12,562					12,562
1955	14,690					14,690
1956	24,697					24,697
1957	24,145					24,145
1958	39,153	5,000				44,153
1959	123,121	62,200				185,321
1960	360,103	96,000				456,103
1961	399,542	154,200				553,742
1962	281,103	139,600				420,703
1963	20,504	65,306				85,810
1964	48,880	62,297				111,177
1965	26,039	27,771				53,810
1966	45,423	56,930				102,353
1967	60,429	101,799				162,228
1968	40,834	43,355	-			84,189
1969	81,449	85,685	-			167,134
1970	59,851	73,228	-			133,079
1971	82,179	78,220	-			160,399
1972	34,846	13,010	-			47,856
1973	75,724	2,516	-			78,240
1974	37,947	4,288	-			42,235
1975	59,715	4,975	-			64,690
1976	52,688	2,908	625			56,221
1977	58,090	283	-			58,373
1978	62,064	76,300	69			138,433
1979	56,824	40,271	1,919	3		99,017
1980	61,295	6	16,198	269	9,623	87,391
1981	63,961		17,179	115	16,046	97,301
1982	68,009		10,277	45	17,381	95,712
1983	64,824		21,050		22,511	108,385
1984	83,909	7,951	34,855	47	32,764	159,526

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[a] Sources of catch data: 1954-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to the United States by fishing nations; 1980-84, French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a.

[b] Republic of Korea.

From 1969 to 1976 the Japanese commercial fishery for yellowfin sole operated mainly in the months of October-March, but since then operations have shifted to summer and fall months. Catch per unit of effort (CPUE) values were originally calculated for the October-Marchperiod, but because of the seasonal changes in the fishery, they have recently been calculated for the September-December and July-October periods. The trends shown by the October-March and September-December data were similar (Table 20; Fig. 12).

The CPUE trend lines from the October-March and September-December pair trawl data have shown a substantial increase in the relative abundance of yellowfin sole between the 1972-73 and the 1977-78 fishing seasons (Fig. 12). Changes in fishing strategy between the 1973-74 and 1974-75 fishing seasons which increased the efficiency of the fleet (Bakkala et al. 1979) may have accounted for part of this increase. The CPUE values from the fishery peaked in 1979 or 1980 and have since declined. This decline in CPUE between 1979-80 and 1983 from the Japanese pair trawl data is not believed to be representative of the actual population abundance during this period in view of the increases in abundance shown by surveys and a cohort analysis that will be discussed later in this report.

To examine reasons for differences in estimates of relative abundance between the fishery and surveys, survey data were analyzed from the area where the majority, of yellowfin sole have been taken by Japanese pair trawlers. This area, bounded by 165-168° W longitude and 56°30°-58°30° N latitude, accounted for 70-93% of the annual catches of yellowfin sole by pair trawlers in 1977-83. The CPUE for yellowfin sole from survey data in this area was 128 kg/ha in 1979 and 113 kg/ha in 1984, showing a 12% decline. The CPUE from the overall survey area was 41 kg/ha in 1979 and 72 kg/ha in 1984, showing a 76% increase. The CPUE from the pair trawl fishery in the July - October period declined 37% between 1979 and 1984. Thus, the survey data taken from the main area of the fishery agrees more closely with the fishery data than does the overall survey data.

The NWAFC survey data also showed a major increase in abundance of yellowfin sole during the late 1970s (Fig. 12). CPUE values from these comprehensive surveys showed an approximate doubling of relative abundance (20-41 kg/ha) from 1975 to 1979. There was an apparent leveling off of abundance in 1980, but CPUE values showed further substantial increases through 1983.

The increase in CPUE between 1981 and 1982 was extremely large, increasing from 48 to 70.3 kg/ha. Abundance estimates from the 1982 survey were considerably higher than those from the 1981 survey for a number of flatfish. In addition to yellowfin sole, substantial increases were shown for Pacific halibut, _Hippoglossus stenolepis_; flathead sole, _Hippoglossoides elassodon_; rock sole, _Lepidopsetta bilineata_; and Alaska plaice, _Pleuronectes quadrituberculatus_. The reason for these major increases in abundance, which were so large for some species that they cannot be accounted for biologically, is believed to be a change in the standard trawls used during the surveys. The 400-mesh eastern trawl was the standard trawl used by most survey vessels until 1981, but due to the increasing size of survey vessels in recent years, it has been necessary to adopt a larger trawl. The new standard trawl with an 83-ft footrope and 112-ft headrope is a larger version of the 400-mesh eastern trawl. Prior to the beginning of the 1982 survey, test fishing operations were conducted in the Bering Sea to assure that the footrope of the new trawl was in contact with the bottom. As a consequence of these studies, the 83-112 trawl was rigged differently than in the past. Dandylines were changed from

Table 20.--Catch, effort, and catch per unit of effort (CPUE) for yellowfin sole by Japanese pair trawlers in 0.5° lat. by 1° long. statistical blocks and months in which yellowfin sole made up 50% or more of the total catch of groundfish.

Period	Fishing year	Catch (t)	Hours	Average hp	Thousands of hp hours	CPUE (t/thousand hp hours)
Oct.-March	1969-70	14,250	1,925	1,200	2,310	6.17
	1970-71	26,766	1,762	1,200	2,114	12.66
	1971-72	25,873	2,937	1,400	4,112	6.29
	1972-73	32,354	2,788	1,400	3,903	8.29
	1973-74	27,234	1,853	1,400	2,594	10.50
	1974-75	32,456	833	1,400	1,166	27.84
	1975-76	40,126	988	1,400	1,383	29.01
	1976-77	28,792	641	1,400	897	32.10
	1977-78	28,243	503	1,400	704	40.12
Sept.-Dec.	1969	7,009	1,051	1,200	1,261	5.56
	1970	11,768	1,052	1,200	1,262	9.32
	1971	23,447	2,546	1,400	3,564	6.58
	1972	15,978	1,666	1,400	2,332	6.85
	1973	19,291	1,059	1,400	1,483	13.01
	1974	20,911	563	1,400	788	26.54
	1975	25,825	566	1,400	792	32.61
	1976	22,243	517	1,400	724	30.72
	1977	26,407	476	1,400	666	39.65
	1978	21,692	458	1,400	641	33.84
	1979	16,088	238	1,400	333	48.31
	1980	13,231	174	1,400	244	54.23
	1981	19,658	440	1,400	616	31.91
	1982	21,993	648	1,400	907	24.25
	1983	17,390	868	1,400	1,215	14.31
	1984	13,926	1,112	1,400	1,557	8.94
July-Oct.	1978	22,373	631	1,400	883	25.34
	1979	30,619	826	1,400	1,156	26.49
	1980	30,330	950	1,400	1,330	22.80
	1981	29,717	1,155	1,400	1,617	18.38
	1982	27,855	1,411	1,400	1,975	14.10
	1983	28,936	1,594	1,400	2,232	12.96
	1984	28,202	2,054	1,400	2,876	9.81

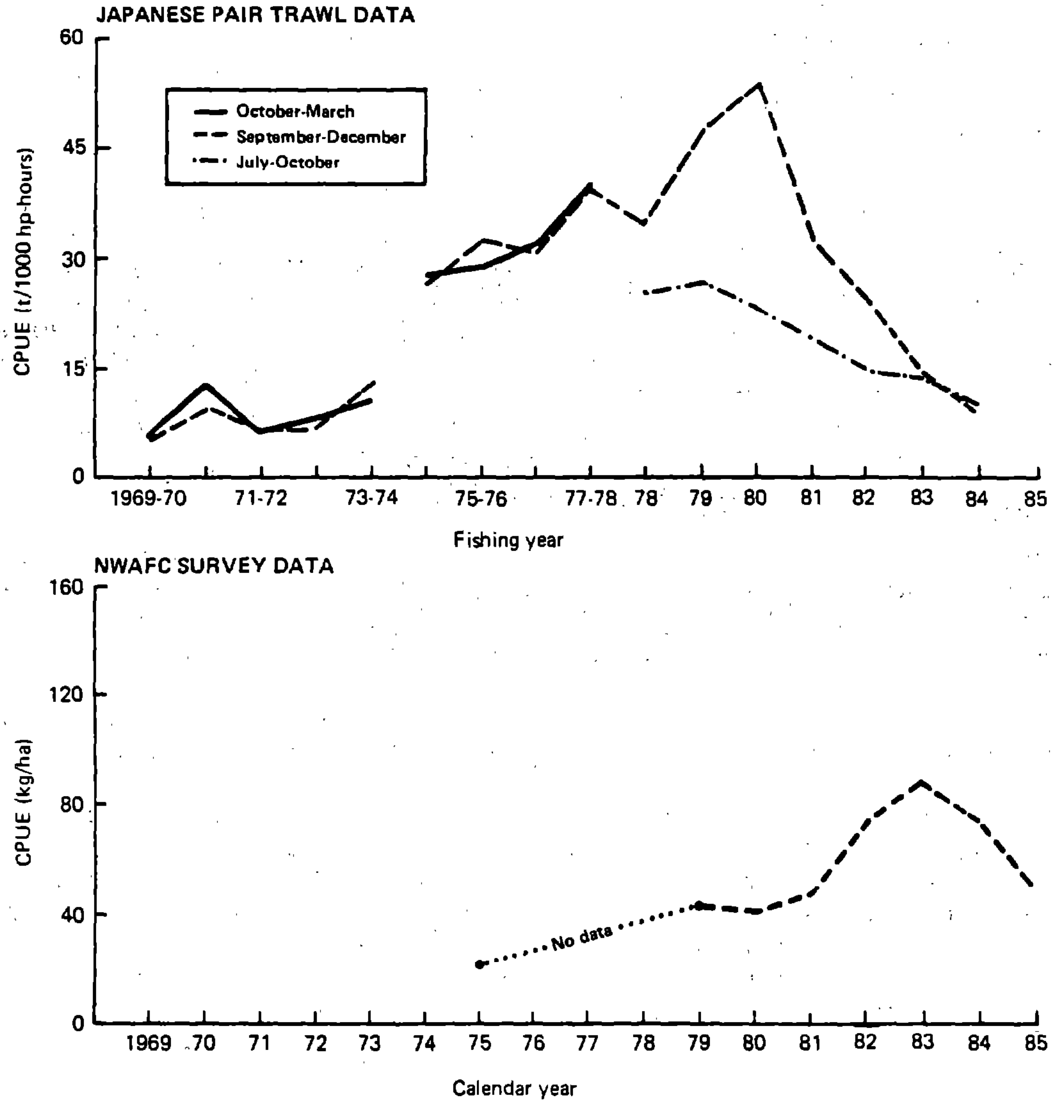

Figure 12.--Relative abundance (catch per unit of effort (CPUE)) of yellowfin sole in. the eastern Bering Sea as shown by Japanese pair trawl data and by data from Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys. Breaks in trend lines indicate changes in fishing gear or fishing techniques (see text).

a single 25-fathom (46 m) section branching into two 15-fathom (27 m) bridles for an overall length of 40-fathoms (73 m) to two 30-fathom (55 m) double dandylines. In addition, 24-in (61 cm) chain extensions were attached between each end of the footrope and the lower dandyline to improve bottom contact of the footrope. The new rigging was assumed to result in good contact with the bottom because substantial amounts of bottom debris were observed in catches.

The CPUE rose rather markedly again in 1983 to 86.5 kg/ha from 70.3 kg/ha in 1982 but declined to 72.4 kg/ha in 1984 and more sharply to 49.7 kg/ha in 1985. This sharp decline will be discussed further in the section on survey biomass estimates.

Age Composition

The primary reason for the increased abundance of yellowfin sole since the early 1970s has been the recruitment of abundant year-classes. Initial increases in abundance were from the strong 1966-70 year-classes which have predominated in research vessel and commercial fishery catches until the early 1980s (Fig. 13). These year-classes are now relatively old, ranging from 15 to 19 years in 1985. They may still contribute substantially to commercial catches, however; based on the 1983 survey data they contributed about one million t or 26% of the total sampled biomass of yellowfin sole.

A new series of strong year-classes (1973-77) have now entered the population and appear to be as strong or in some cases even stronger than the 1966-70 year-classes. It is mainly this new series of strong year-classes that is responsible for the more recent increases in abundance of the population in 1981-83.

The 1982 and 1983 age data show substantial increases in abundance for most year-classes from values derived in 1981 and earlier years (Fig. 13). These increases also reflect the higher efficiency of the trawls used in 1982 and 1983 compared to those used in earlier years as discussed previously. Another anomaly in the 1982 and 1983 data is the indication that the 1971 and 1972 year-classes are relatively strong; previous age data had consistently shown these year-classes to be weaker than adjacent year-classes. The reason for the relatively high abundance of the 1971 and 1972 year classes in more recent years is not apparent at this time but may reflect some error in aging. Nevertheless,, the age structure of the population appears to be well-balanced and should maintain the resource in a healthy state in the foreseeable future.

Biomass Estimates from Research Vessel Surveys

Biomass estimates from the large-scale NWAFC surveys and 95% confidence intervals around the mean estimates are as follows:

Year	Mean estimate(t)	95% Confidence interval(t)
1975	1,038,400	870,800 - 1,206,400
1976	1,192,600	661,700 - 1,723,600
1978	1,523,400	1,103,300 - 1,943,600
1979	1,932,600	1,669,000 - 2,196,100
1980	1,965,900	1,716,000 - 2,215,900
1981	2,039,900	1,791,000 - 2,288,800
1982	3,322,500	2,675,900 - 3,970,100
1983	3,951,500	3,459,200 - 4,443,900
1984	3,365,900	2,972,000 - 3,759,800
1985	2,308,300	2,026,900 - 2,589,700

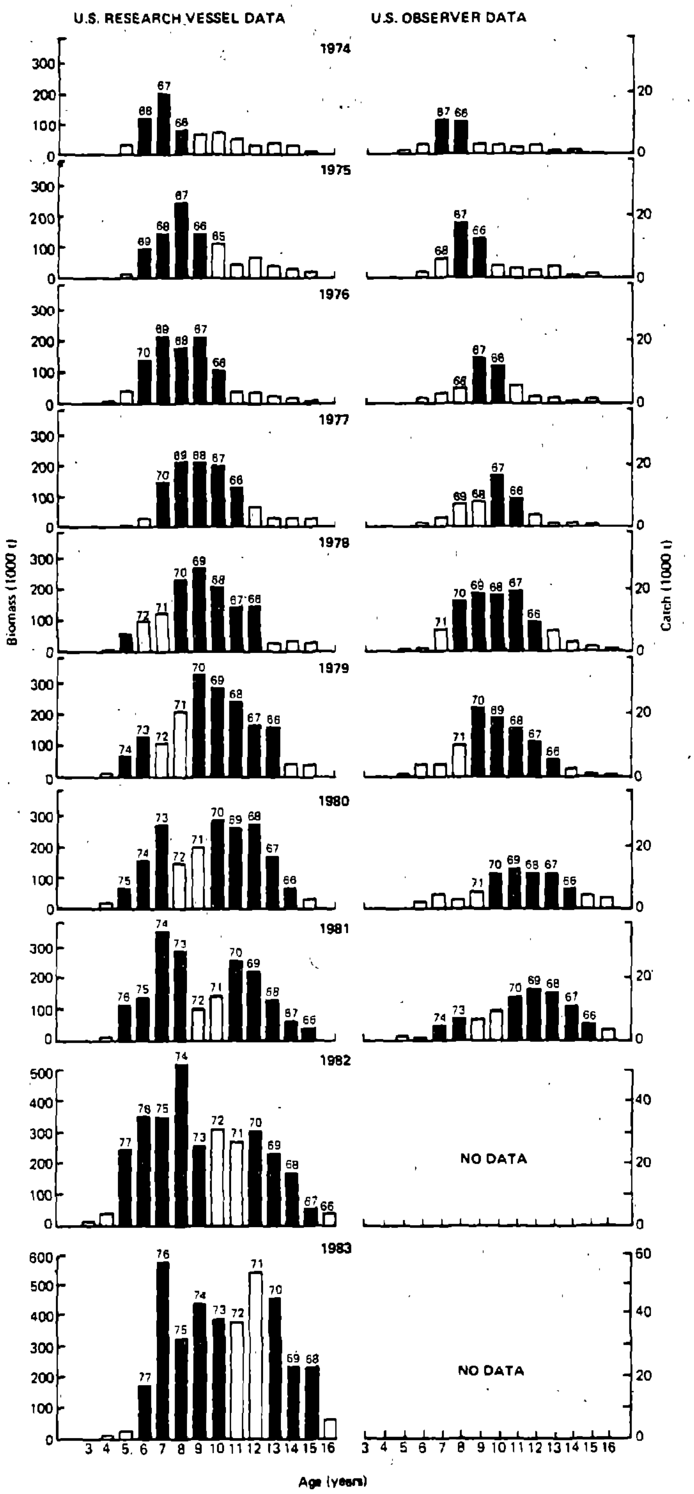

Figure 13.--Age composition of yellowfin sole of the eastern Bering Sea as shown by data from trawl surveys of the Northwest and Alaska Fisheries Center and by U.S. observer data from the commercial fishery. Year-classes for more abundant ages are shown with the appropriate bars, and darkened bars represent stronger than average year-classes.

Following the almost doubling of the biomass estimates between 1975 and 1979, there were only minor increases in 1980 and 1981. The 1982 estimate, however, was substantially higher (at 3.32 million t) than the l979-81 estimates, an increase that cannot reasonably be attributed entirely to increased growth, recruitment, and decreased mortality. A contributing factor (discussed earlier) was the improved efficiency of the trawl used in 1982 compared to trawls used during previous surveys for capturing bottom-tending species like yellowfin sole. Another factor accounting for the higher biomass estimate in 1982 compared to 1981 was that an area around Nunivak Island (see Figure 4) not surveyed in 1981 accounted for approximately 500,000 t of yellowfin sole in 1982. The 1983 estimate was again substantially higher at 3.95 million t, but the 1984 estimate was lower, and the 1985 estimate substantially lower at 2.3 million t. Population weight may have reached a maximum in 1983 and may now be declining following the complete recruitment of the strong 1973-77 year-classes to the survey area and as the abundance of the 1966-70 year-classes declines.

The approximately 1.0 million t decline in biomass between 1984 and 1985 represents a 31% decrease, which appears unreasonable considering the long life span of this species and the many age groups in the population. Similar declines in biomass between 1984 and 1985 were observed for Alaska plaice (24%) and rock sole (30%). The similarity in these declines among most of the small flatfish and the apparently unreasonable magnitude of the declines suggest that they may not be entirely real, but related to some other factor such as availability to or catchability of the trawls. The trawls and their rigging were the same in the 2 years, and therefore catchability would not be expected to change appreciably. Bottom water temperatures were colder on the inner shelf in 1985 than in 1984, which may have altered the distribution of these species to some extent, but it is difficult to believe that this would be a major factor considering the extensive coverage of shelf waters. Thus, the reason for the abnormally large decreases in abundance of these species is not now apparent.

Biomass Estimates from Cohort Analysis

Cohort analyses have previously been carried out for eastern Bering Sea yellowfin sole by Wakabayashi (1975), Wakabayashi et al. (1977), and Bakkala et al. (1981). The latter analysis was updated by Bakkala et al. (1982) and expanded to include the earlier years 1959-63. New estimates of biomass for the period of 1959-63 were calculated because of mounting evidence that natural mortality of yellowfin sole may be lower than the value of 0.25 used earlier by Wakabayashi (1975) and Wakabayashi et al. (1977). Results of the cohort analysis are given in Table 21 in terms of numbers and in Table 22 in terms of biomass.

These new biomass estimates for years prior to 1977 were lower than those obtained from earlier cohort analyses because of the lower value of natural mortality (M) used in this latter analysis. The biomass of age 7 and older yellowfin sole (ages fully recruited to research vessel catches) in the early years of high exploitation (1959-60) was approximately 1.1-1.2 million t. At the end of this period of high exploitation (1962), the biomass had fallen to about one-half that level; furthermore, the analysis showed that it remained at approximately this lower level through 1967 when there was a further decline to 273,000 t in 1972. Since then, the biomass has increased substantially, due mainly to the recruitment of the strong 1966-70 year-classes and the more recent series of strong year-classes spawned in 1973-77. In 1981, the abundance of age 7 and older yellowfin sole was estimated to be about 2.0 million t, based on the results of the new cohort analysis--the largest estimated biomass in the period 1959-81.

Table 21.--Estimated numbers of yellowfin sole (billions of fish) in the eastern Bering Sea, 1959-81, based on cohort analysis.

Age (yr)	1959	1960	1961	1962	1963	1964	1965	1966	1967
1	2.040	1.620	0.931	1.407	1.108	1.047	1.320	1.519	2.394
2	2.308	1.810	1.437	0.826	1.248	0.983	0.928	1.171	1.347
3	2.826	2.047	1.605	1.275	0.733	1.107	0.871	0.823	1.039
4	1.029	2.506	1.815	1.424	1.130	0.650	0.976	0.773	0.730
5	1.382	0.912	2.223	1.599	1.263	1.003	0.565	0.865	0.685
6	1.856	1.226	0.809	1.947	1.406	1.119	0.871	0.501	0.767
7	1.865	1.640	1.063	0.696	1.596	1.223	0.945	0.771	0.444
8	1.565	1.632	1.342	0.793	0.376	1.383	0.959	0.832	0.670
9	1.234	1.336	1.282	0.792	0.363	0.273	1.006	0.809	0.697
10	0.923	0.989	0.950	0.579	0.366	0.233	0.190	0.809	0.624
11	0.625	0.670	0.588	0.324	0.256	0.241	0.148	0.147	0.570
12	0.377	0.419	0.320	0.174	0.114	0.168	0.151	0.104	0.097
13	0.213	0.245	0.165	0.098	0.045	0.063	0.105	0.104	0.058
14	0.118	0.138	0.084	0.059	0.021	0.016	0.042	0.074	0.056
15	0.063	0.079	0.044	0.036	0.013	0.004	0.009	0.031	0.045
16	0.038	0.042	0.025	0.022	0.008	0.002	0.002	0.006	0.022
17	0.019	0.026	0.012	0.014	0.005	0.000	0.002	0.002	0.003
Total	18.482[a]	17.337	14.695	12.064	10.051	9.515	9.089	9.343	10.250

Age (yr)	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	2.779	3.693	5.662	6.117	3.542	2.390	5.964	6.791	5.461
2	2.123	2.465	3.275	5.022	5.425	3.141	2.120	5.289	6.023
3	1.195	1.883	2.186	2.905	4.454	4.812	2.786	1.880	4.691
4	0.921	1.060	1.670	1.939	2.576	3.950	4.268	2.471	1.668
5	0.648	0.817	0.940	1.481	1.719	2.285	3.504	3.785	2.192
6	0.608	0.574	0.724	0.833	1.313	1.521	2.024	3.107	3.356
7	0.668	0.538	0.501	0.629	0.715	1.134	1.336	1.787	2.753
8	0.358	0.565	0.471	0.380	0.402	0.572	0.921	1.157	1.562
9	0.501	0.289	0.410	0.323	0.240	0.336	0.425	0.751	0.986
10	0.480	0.379	0.166	0.254	0.190	0.177	0.242	0.332	0.560
11	0.401	0.353	0.172	0.116	0.127	0.145	0.120	0.195	0.215
12	0.308	0.283	0.160	0.101	0.077	0.092	0.091	0.086	0.141
13	0.059	0.210	0.111	0.071	0.044	0.056	0.046	0.069	0.064
14	0.028	0.034	0.113	0.055	0.021	0.029	0.022	0.030	0.046
15	0.021	0.014	0.006	0.050	0.002	0.012	0.013	0.012	0.016
16	0.021	0.009	0.004	0.002	0.007	0.002	0.004	0.006	0.006
17	0.012	0.012	0.000	0.000	0.000	0.006	0.001	0.002	0.002
Total	11.130	13.177	16.571	20.276	20.856	20.659	23.885	27.751	29.743

[a] Due to rounding, sums of columns may not equal totals.

Table 21 .--Continued.

Age (yr)	1977	1978	1979	1980	1981
1	7.389	2.674	0.000	0.000	0.000
2	4.843	6.554	2.372	0.000	0.000
3	5.342	4.196	5.813	2.104	0.000
4	4.161	4.738	3.810	5.155	1.866
5	1.479	3.690	4.201	3.379	4.572
6	1.940	1.308	3.261	3.720	2.993
7	2.963	1.711	1.147	2.870	3.283
8	2.418	2.610	1.455	0.998	2.514
9	1.358	2.105	2.191	1.244	0.867
10	0.799	1.171	1.759	1.859	1.064
11	0.444	0.642	0.946	1.482	1.588
12	0.167	0.349	0.472	0.782	1.258
13	0.118	0.133	0.273	0.376	0.648
14	0.049	0.100	0.098	0.220	0.293
15	0.039	0.041	0.077	0.080	0.174
16	0.010	0.033	0.032	0.064	0.064
17	0.004	0.008	0.027	0.027	0.048
Total	33.524	32.063	27.932	24.359	21.232

[a] Due to rounding, sums of columns may not equal totals.

Table 22.--Estimated biomass (in 1,000 t) of yellowfin sole in the eastern Bering Sea by age (with totals for all ages and ages 7 and above), 1959-81, based on cohort analysis.

Age (yr)	1959	1960	1961	1962	1963	1964	1965	1966	1967
1	10	8	5	7	6	5	7	8	12
2	21	16	13	7	11	9	8	11	12
3	51	37	29	23	13	20	16	15	19
4	34	83	60	47	37	21	32	26	24
5	77	51	124	90	71	56	32	48	38
6	163	108	71	171	124	98	77	44	68
7	209	184	119	78	179	137	106	86	50
8	211	220	181	107	51	187	129	112	90
9	196	212	204	126	58	43	160	129	111
10	171	183	176	107	68	43	35	150	115
11	131	141	124	68	54	51	31	31	120
12	88	97	74	40	26	39	35	24	23
13	56	65	43	26	12	17	28	28	15
14	33	39	24	16	6	5	12	21	16
15	19	23	13	11	4	1	3	9	13
16	13	15	9	8	3	1	1	2	8
17	7	10	4	5	2	0	1	1	1
	1,491[a]	1,492	1,273	938	723	733	711	744	735
7+	1,135	1,189	971	592	461	523	540	593	562

Age (yr)	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	14	18	28	31	18	12	30	34	27
2	19	22	29	45	49	28	19	48	54
3	22	34	39	52	80	87	50	34	84
4	30	35	55	64	85	130	141	82	55
5	36	46	53	83	96	128	196	212	123
6	53	51	64	73	116	134	178	273	295
7	75	60	56	70	80	127	150	200	308
8	48	76	64	51	54	77	124	156	211
9	80	46	65	51	38	53	68	119	157
10	89	70	31	47	35	33	45	61	104
11	84	74	36	24	27	30	25	41	45
12	71	66	37	24	18	21	21	20	33
13	16	55	29	19	12	15	12	18	17
14	8	9	32	15	6	8	6	8	13
15	6	4	2	15	1	3	4	4	5
16	8	3	1	1	3	1	1	2	2
17	4	5	0	0	0	2	0	1	1
	664	675	622	666	717	890	1,071	1,314	1,534
7+	489	469	353	317	273	371	456	631	895

[a] Due to rounding, sums of columns may not equal totals.

Table 22.--Continued.

Age (yr)	1977	1978	1979	1980	1981
1	37	13	0	0	0
2	44	59	21	0	0
3	96	77	105	38	0
4	137	156	126	170	62
5	83	207	235	189	256
6	171	115	287	327	263
7	332	192	128	321	368
8	326	352	196	135	339
9	216	335	348	198	138
10	148	217	326	344	197
11	93	135	199	311	334
12	39	81	109	181	292
13	31	35	72	99	171
14	14	28	27	62	82
15	12	12	23	24	51
16	4	12	11	23	23
17	2	3	10	10	17
	1,783[a]	2,029	2,224	2,432	2,593
7+	1,216	1,401	1,450	1,708	2,012

[a] Differences in totals due to rounding.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) for yellowfin sole was previously estimated to range between 169,000 and 260,000 t with a midpoint of 214,500 t (Bakkala et al. 1981) based on the yield equation of Alverson and Pereyra (1969), an M value of 0.25, and a range in virgin biomass of 1.3 million t (estimated by Alverson and Pereyra 1969) to 2.0 million t (estimated by Wakabayashi 1975). Bakkala et al. (1982) also considered estimates of MSY based on evidence that M may be as low as 0.12. Using this value in the yield equation of Alverson and Pereyra (1969) would produce an MSY range of 78,000-120,000 t.

Maximum sustainable yield likely falls somewhere in the midportion of the estimates which vary from 78,000 to 260,000 t. Long-term (1959-81) exploitation of the yellowfin sole population has averaged 150,000 t, which may represent a reasonable estimate of MSY. This figure is similar to the long-term sustainable yield (175,000 t) estimated from an ecosystem model (Low 1984). Thus MSY is probably near 150,000-175,000 t.

EQUILIBRIUM YIELD

Wakabayashi (1985) has estimated equilibrium yield for yellowfin sole from a yield per recruit analysis using age specific values of selectivity by the fishery and an optimum yield per recruit (which is the fishing mortality coefficient which will maintain spawners at half the numbers prior to the onset of fishing). The expected equilibrium yields (EY) for various values of natural mortality (M) from this analysis are as follows:

M	F_{Opt}[a]	OY/recruit (g)	Recruitment at age 3 (billions of fish)		EY (t)	
			LOW	High	Low	High
0.25	0.17	24.7	3.84	9.30	105,000	230,000
0.20	0.16	35.3	2.30	6.81	81,000	240,000
0.12	0.14	64.0	1.11	4.16	71,000	266,000

[a] F_{opt} = optimum fishing mortality coefficient.

Based on this analysis, Wakabayashi (1985) estimated equilibrium yield to be at least 230,000 t through the mid-1980s.

Biomass estimates from surveys, after increasing from 1.0 million t in 1975 to 2.0 million t in 1981, have since fluctuated widely. The biomass increased to as high as nearly 4.0 million t in 1983 and then declined to 2.3 million t in 1985, similar to the level in 1981. Fluctuations of this magnitude are unreasonable for a long-lived and slow-growing species like yellowfin sole. The fluctuations are therefore believed to be the result of factors other than natural causes and fishing mortality as previously. discussed.

Despite the variability in the survey biomass estimates, the 1985 estimate of 2.3 million t is still substantial and indicates that the abundance of yellowfin sole remains high and much above levels of the mid- and early-1970s. Based on the latest survey biomass estimate, an EY of 230,000 t (as estimated from the yield per recruit analysis) appears reasonable, representing a 10% exploitation rate.

GREENLAND TURBOT AND ARROWTOOTH FLOUNDER

by

Richard G. Bakkala, Miles S. Alton and Daniel K. Kimura

INTRODUCTION

The turbots--arrowtooth flounder, *Atheresthes stomias*, and Greenland turbot, *Reinhardtius hippoglossoides*--are large flatfishes that have similar bathymetric distributions in the eastern Bering Sea, with adults generally found in waters of the continental slope and juveniles restricted to waters of the shelf region. Greenland turbot are generally distributed throughout the eastern Bering Sea with the highest concentrations found along the continental slope at depths greater than 200 m. The distribution of arrowtooth flounder is primarily restricted to the southern portion of the eastern Bering Sea with highest abundance located in the 100-700 m depth zones. Catches of arrowtooth flounder may include Kamchatka flounder, A. *evermanni*, since taxonomic differences between the two forms are not readily apparent.

Both Greenland turbot and arrowtooth flounder range into the Aleutian Islands region where their abundance is lower than in the eastern Bering Sea. Because small juveniles of the two species have not been found in the Aleutians, the turbots here and in the eastern Bering Sea are assumed to represent single, stocks.

The Japanese fishery targeting on turbot is distinct from other flatfish fisheries since turbot stocks of commercial abundance are located on the continental slope and generally segregated from other flatfish species. The turbot complex is therefore managed as an independent unit. The Japanese mothership-North Pacific trawl fishery has often accounted for more than one-half of the catch of turbot (Table 23), presumably as an incidental part of the target fishery for walleye pollock, *Theragra chalcogramma,* and other species. A large part of these incidental catches of turbot are assumed to come from waters on the continental shelf and consist primarily of juvenile fish. The overall fishery, therefore; takes both juvenile and adult turbot.

Following a long period of relatively small catches in the eastern Bering Sea and Aleutian Islands region during the 1960s, catches of turbot increased, reaching an all-time high of approximately 103,000 t in 1974 (Table 23). Catches then declined but still ranged between 61,500 and 74,400 t in 1980-83. Catches, however, dropped to 32,600 t in 1984, in part due to catch restrictions placed on the fishery because of evidence of declining stock abundance.

Table 23.--All nation catches (t) of arrowtooth flounder and Greenland turbot, 1960-84[a].

	Eastern Bering Sea (east of long. 180°)							Aleutian Islands area							E. Bering Sea and Aleutians comb. total
	Japan							Japan							
Year	MS-LG-NPT[b]	LBD[c]	USSR	ROK[d]	Other nations[e]	Joint ventures[f]	Total	MS-LG-NPT	LBD	USSR	ROK	Other nations	Joint ventures	Total	
Arrowtooth Flounder and Greenland Turbot Combined															
1960	36,843	-	-				36,843	-	-	-				-	36,843
1961	57,348	-	-				57,348	-	-	-				-	57,348
1962	58,226	-	-				58,226	-	-	-				-	58,226
1963	31,565	-	-				31,565	-	7	-				7	31,572
1964	33,726	3	-				33,729	475	29	-				504	34,233
1965	7,648	299	1,800				9,747	299	1	-				300	10,047
1966	10,752	90	2,200				13,042	63	0	-	-			63	13,105
1967	20,574	656	2,639	-			23,869	167	227	-				394	24,263
1968	17,702	2,278	15,252	-			35,232	106	107	-	-			213	35,445
1969	13,525	5,706	16,798	-			36,029	51	177	-	-			228	36,257
1970	14,212	9,857	8,220	-			32,289	278	281	-	-			559	32,848
1971	29,313	12,483	17,460	-			59,256	1,329	1,002	-	-			2,331	61,587
1972	25,949	27,687	23,998	-			77,633	900	13,030	267	-			14,197	91,831
1973	31,082	17,201	16,214	-			64,497	1,478	10,531	362	-			12,371	76,868
1974	38,824	22,833	29,470	-	-		91,127	2,281	9,663	39	-	-		11,983	103,110
1975	32,382	21,484	31,785	-	-		85,651	926	2,685	143	-	-		3,754	89,405
1976	34,221	19,109	24,999	-	-		78,329	933	2,392	112	-	-		3,437	81,766
1977	16,375	15,454	5,333	-	-		37,162	640	3,824	24	-	-		4,488	41,650
1978	21,299	20,244	4,119	119	-		45,781	1,182	5,363	2	1	-		6,548	52,329
1979	24,492	14,885	1,574	1,948	20		42,919	1,227	11,620	0	0	-		12,847	55,766
1980	-	-	-	-	-		62,618	-	-	-	-	-	-	8,299	70,917
1981	-	-	-	-	-		66,394	-	-	-	-	-	-	8,040	74,434
1982	-	-	-	-	-		54,908	-	-	-	-	-	-	8,732	63,640
1983	-	-	-	-	-		53,659	-	-	-	-	-	-	7,869	61,528
1984	-	-	-	-	-		29,294	-	-	-	-	-	-	3,275	32,569

Table 23.--Continued.

	Eastern Bering Sea (east of long. 180°)							Aleutian Islands area						
	Japan							Japan						E. Bering Sea and Aleutians
Year	MS-LG-NPT[b]	LBD[c]	USSR	ROK[d]	Other nations[e]	Joint ventures[f]	Total	MS-LG-NPT	LBD	USSR	ROK	Joint ventures	Total	
Arrowtooth Flounder														
1970	9,047	307	3,244	-			12,598	274	0	-	-		274	12,872
1971	6,235	5,368	7,189	-			18,792	44	537	-	-		581	19,373
1972	1,261	2,562	9,300	-			13,123	194	1,023	106	-		1,323	14,446
1973	1,915	3,014	4,288	-			9,217	483	3,199	23	-		3,705	12,922
1974	1,221	1,602	18,650	-	-		21,473	1,378	1,817	0	-		3,195	24,668
1975	330	911	19,591	-	-		20,832	115	526	143	-		784	21,616
1976	139	1,535	16,132	-	-		17,806	96	1,274	-	-		1,370	19,176
1977	4,000	2,160	3,294	-	-		9,454	158	1,857	20	-		2,035	11,489
1978	4,598	1,093	2,576	91	-		8,358	524	1,256	2	0		1,782	10,140
1979	4,122	1,166	948	1,680	5		7,921	371	6,065	0	0		6,436	14,357
1980	-	-	-	-	-	-	13,762	-	-	-	-	-	4,603	18,365
1981	-	-	-	-	-	-	13,473	-	-	-	-	-	3,640	17,113
1982	-	-		-	-	-	9,103	-	-	-	-	-	2,415	11,518
1983	-	-	-	-	-	-	10,217	-	-	-	-	-	3,753	13,970
1984	-	-	-	-	-	-	7,977						1,472	9,449
Greenland Turbot														
1970	5,165	9,550	4,976	-			19,691	4	281	-	-		285	19,976
1971	23,078	7,115	10,271	-			40,464	1,285	465	-	-		1,750	42,214
1972	24,688	25,125	14,697	-			64,510	706	12,007	161	-		12,874	77,384
1973	29,167	14,187	11,926	-			55,280	995	7,332	339	-		8,666	63,946
1974	37,603	21,231	10,820	-	-		69,654	903	7,846	39	-		8,788	78,442
1975	32,052	20,573	12,194	-	-		64,819	811	2,159	0	-		2,970	67,789
1976	34,082	17,574	8,867	-	-		60,523	837	1,118	112	-		2,067	62,590
1977	12,375	13,294	2,039	-	-		27,708	482	1,967	4	-		2,453	30,161
1978	16,701	19,151	1,543	28	-		37,423	658	4,107	0	1		4,766	42,189
1979	20,370	13,719	626	268	15		34,998	856	5,555	0	0		6,411	41,409
1980	-	-	-	-	-	-	48,856	-	-	-	-	-	3,696	52,552
1981	-	-	-	-	-	-	52,921	-	-	-	-	-	4,400	57,321
1982	-	-	-	-	-	-	45,805	-	-	-	-	-	6,317	52,122
1983	-	-	-	-	-	-	43,442	-	-	-	-	-	4,116	47,558
1984	-	-	-	-	-	-	21,317	-	-	-	-	-	1,803	23,120

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[a] Sources of data: 1960-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to United States by fishing nations; 1980-84, French et al. 1981, 1982; Nelson et al. 1963a; 1984; Berger et al. 1985b.

[b] Mothership, North Pacific longline, and North Pacific trawl fisheries combined.

[c] Landbased dragnet trawl fishery.

[d] Republic of Korea. [e] Taivan, Poland, and Federal Republic of Germany.

[f] Joint ventures between U.S. fishing vessels and foreign processing vessels.

CONDITION OF STOCKS

Relative Abundance

Two sources of data have been used to examine trends in relative. abundance of Greenland turbot and arrowtooth flounder: catch and effort data reported by the Japanese from their landbased dragnet fishery, and data from Northwest and Alaska Fisheries Center (NWAFC) research vessel surveys. The Japanese landbased stern trawlers have targeted Greenland turbot, and these data may provide reasonably good indices of abundance for adults of this species. The data may not provide good indices of abundance for arrowtooth flounder because this species is apparently only taken as an incidental part of the catch.

The landbased dragnet fishery data come from west of 170°W because this fleet is not allowed to fish east of 170°W longitude by Japanese fishery regulations. For this report, catch and effort data were also examined from the entire eastern Bering Sea slope region (>184 m) by incorporating data from small trawlers of other Japanese fleets that fished in waters both east and west of 170°W longitude. Data collected by U.S. observers aboard the small trawlers during the months of May-August were selected because the fishery in 1984 was mainly restricted to these months. In this latter analysis, all catch and effort data were used regardless of the proportion of Greenland turbot in the catches.

The NWAFC research vessel surveys have been limited to continental shelf waters in most years and essentially sampled only the juvenile portion of the population. The 1979, 1981, and 1982 joint surveys with the Fisheries Agency of Japan, however, surveyed major portions of the eastern Bering Sea shelf and slope from depths of 20 to 1,000 m to provide assessments of both juvenile and adult turbot. A fourth cooperative U.S.-Japan survey of both shelf and slope waters was conducted in 1985, but results from only the shelf portion of the survey were available at the time this report was prepared.

Greenland turbot catch and effort data from the landbased fishery were analyzed by statistical blocks measuring 0.5° latitude and 1° longitude and by months in which Greenland turbot comprised 50% or more of the overall reported catch. This method is assumed to be a fairly accurate reflection of abundance trends of the exploitable population since it is based. on effort targeting on Greenland turbot. Figure 14 shows that following relatively high annual catch rates in 1972 and 1973 at approximately 48 t/l00 h trawled, CPUE declined to range from 27 to 33 t/100 h trawled in 1976-79. The CPUE values then increased to 41 t/100 h in 1980, but declined again sharply to 18 t/100 h in 1983. The 1984 value, however, increased to 32 t/100 h trawled.

The CPUE trend for all small trawlers fishing the eastern Bering Sea slope region was quite similar to that for the landbased trawlers (Fig. 14). These data also show a sharp decline in CPUE between 1981 and 1982-83 but a higher value in 1984.

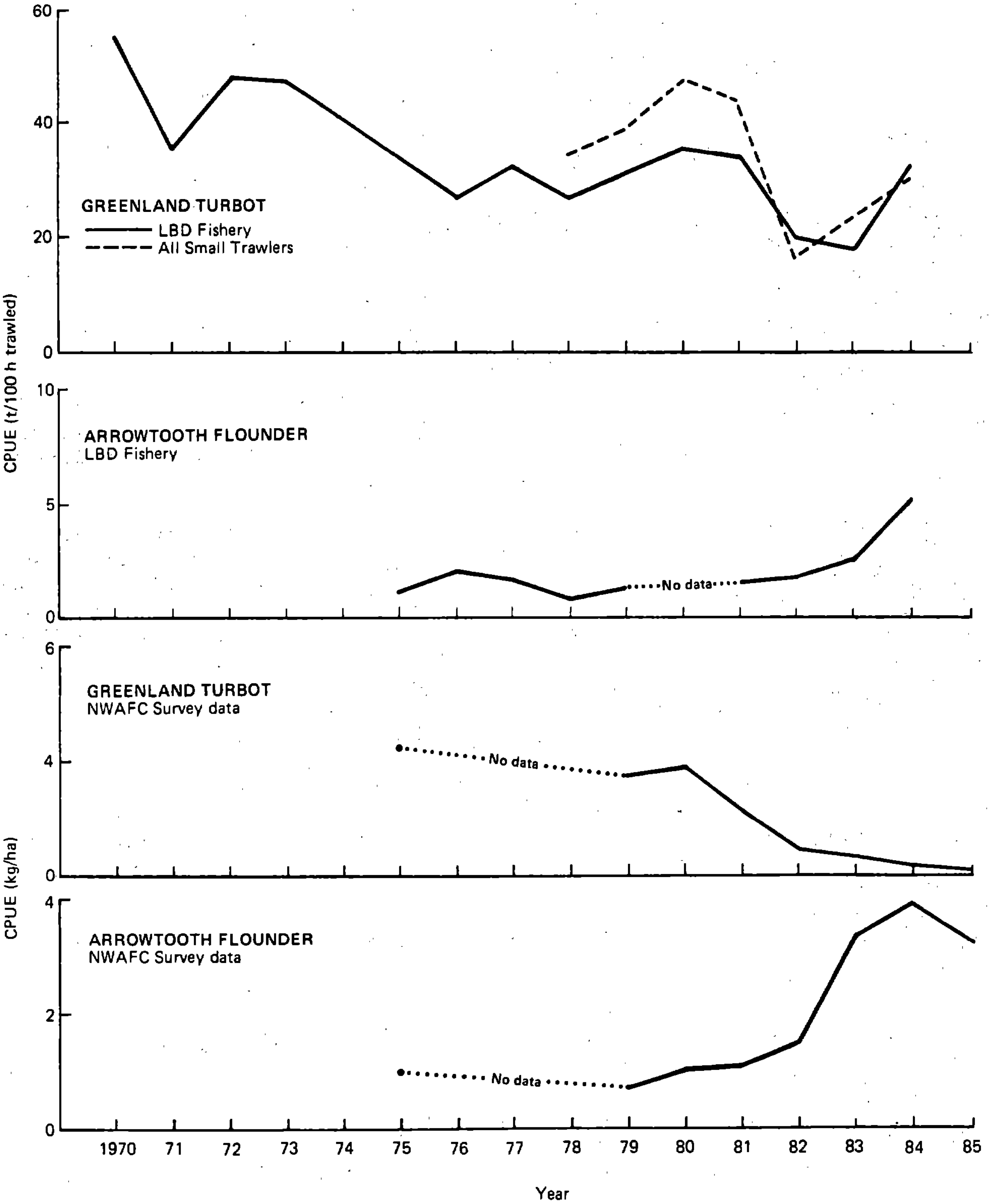

Figure 14.--Relative abundance (catch per unit of effort, CPUE) of Greenland turbot and arrowtooth flounder as shown by data from the Japanese fisheries and by large-scale surveys of the Northwest and Alaska Fisheries Center (NWAFC) that have sampled major portions of the eastern Bering Sea continental shelf.

Relative abundance values from large-scale NWAFC surveys in 1975 and 1979-84 (using data from comparable areas sampled on the continental shelf) reflected relative stability in the abundance of juvenile Greenland turbot between 1975 and 1980 and then a marked decline, with CPUE falling from 3.7 kg/ha in 1980 to 0.2 kg/ha in 1985. This low recruitment of juvenile fish was believed responsible for the decrease in abundance of the adult stock in 1982 and 1983. The increase in the fishery CPUE in 1984 was not expected because of the poor recruitment of juveniles that has been observed over the past several years. A contributing factor to the higher CPUE may have been the reduction in numbers of small Japanese trawlers in the eastern Bering Sea in 1984 to one-third of the numbers operating in earlier years, which might have increased the efficiency of the remaining fleet. The results of the 1985 slope survey should allow an evaluation of the 1984 fishery CPUE.

The trend in relative abundance of arrowtooth flounder, based on land-based fishery data from all statistical blocks in which the species was taken (Fig. 14), indicated a decline in CPUE between 1976 and 1978 and then moderate increases through 1983 and a sharper increase in 1984.

The CPUE values from the large-scale NWAFC surveys on the continental shelf indicated no change in abundance of juvenile arrowtooth flounder between 1975 and 1980, but continued annual increases from 1.0 kg/ha in 1980 to 3.9 kg/ha in 1984 before a moderate decline in 1985 (Fig. 14). The increase in abundance of the adult stock as shown by CPUE data from the landbased fishery in 1983 and 1984 may reflect the recruitment to the slope area of the relatively abundant juvenile fish that have been observed in shelf waters in recent years.

Biomass Estimates

Biomass estimates from large-scale NWAFC surveys on the eastern Bering Sea shelf, U.S.-Japan cooperative surveys on the eastern Bering Sea slope, and cooperative U.S. -Japan surveys in the Aleutian Islands region are shown in Table 24. The estimates from the NWAFC surveys on the shelf, which primarily represent the biomass of only the juvenile portion of the population, show an increase in biomass of juvenile Greenland turbot between 1975 (126,700 t) and 1979 (225,600 t) but a persistent decline since 1979. The estimate in 1985 was only 7,700 t. The extremely low estimates in recent years suggest a recruitment failure.

Biomass estimates for the adult stock of Greenland turbot on the continental slope are only available from cooperative U.S.-Japan surveys in 1979, 1981, and 1982. These estimates show a decline from 123,000 t in 1979 to 90,600 t in 1982 which is a more moderate decline than shown by CPUE data from the fishery. Based on the 45,880 t commercial catch in 1982 in this region, it is assumed that the biomass of the adult stock is underestimated by survey data. In the Aleutian region the biomass estimates increased from 48,700 t in 1980 to 63,000 t in 1983.

Biomass estimates for juvenile arrowtooth flounder based on NWAFC survey data on the eastern Bering Sea shelf show a consistent increase in estimates from 28,000 t in 1975 to 182,900 t in 1984 before a modest decline to 1,59,900 t in 1985 (Table 24). The estimates for the adult stock on the eastern Bering Sea slope decreased from 36,700 t in 1979 to 24,700 t in 1982. Based on the commercial catch of arrowtooth flounder in 1982 of 9,100 t, the biomass of the adult stock of this species may also be underestimated by survey data. There was only a minor change in biomass of arrowtooth flounder in the Aleutian Islands region between 1980 (40,400 t) and 1983 (45,100 t).

Table 24.--Biomass estimates (in metric tons, t) for Greenland turbot and arrowtooth flounder from U.S. and Japanese surveys in the eastern Bering Sea and Aleutian Islands region.

	Eastern Bering Sea			
Year	Shelf	Slope	Shelf and slope combined	Aleutians
Greenland turbot				
1975	126,700	---	---	---
1979	225,600	123,000	348,600	---
1980	172,200	---	---	48,700
1981	86,800	99,600	186,400	---
1982	48,600	90,600	139,200	---
1983	35,100	---	---	63,800
1984	17,900	---	---	---
1985	7,700	---	---	---
Arrowtooth flounder				
1975	28,000	---	---	---
1979	35,000	36,700	71,700	---
1980	47,800	---	---	40,400
1981	49,500	34,900	84,400	---
1982	67,400	24,700	92,100	---
1983	149,300	---	---	45,100
1984	182,900	---	---	---
1985	159,900	---	---	---

Size and Age Composition

Age samples for arrowtooth flounder and Greenland turbot have been collected during U.S. research vessel surveys and by U.S. observers from the commercial fishery. Samples from recent years have not been read as yet, but the age data from earlier years demonstrate the age composition of the shelf and slope populations and the age of recruitment to the slope population which is targetted by the fishery. Arrowtooth flounder taken during NWAFC surveys on the continental shelf are mainly 2- to 4-yr-olds (Fig. 15). Age data for arrowtooth flounder from Japanese large trawlers in 1977 and Japanese small trawlers (mainly landbased trawlers) in 1978 indicated that arrowtooth flounder become recruited to the commercial fishery at about age 4 and that catches consist mainly of ages 4-7.

Age data for Greenland turbot show that catches on the continental shelf are mainly age 1-3 yr fish (Fig. 16). Age data collected from catches by small Japanese trawlers in International North Pacific Fisheries Commission (INPFC) statistical areas I and II in 1978 and 1979 indicated that a wide range of age groups (3 or 4 to 19 yr) were represented in commercial catches with age groups 4 and 5 predominant in those years.

The recruitment of age 1 Greenland turbot in 1980-82 was low (Fig. 16), which accounts for the decline in abundance of juveniles starting in 1981. Size composition information from research vessel surveys shows continued poor recruitment of age 1 fish through 1985 and a major decline in population numbers of juveniles in continental shelf waters (Fig. 17). Population estimates decreased from approximately 289 million fish in 1981 to 11 million in 1985.

Length frequency data were also examined for the adult population on the continental slope sampled during cooperative U.S.-Japan surveys in 1979, 1981, and 1982 (Fig. 17). These data indicated that the adult, population decreased by approximately 50% from 53 million fish in 1979 to 27 million and 25 million in 1981 and 1982, respectively.

Numbers of juvenile arrowtooth flounder on the continental shelf increased from about 171 million in 1981 to 600 million in 1983, but declined to 553 million, in 1984 and 398 million in 1985 (Fig. 18). The increase during 1983 is largely attributed to 2-yr-olds of the apparently strong 1981 year-class which continued to dominate the length-frequency distribution in 1984 at age 3 and at age 4 in 1985.

Population numbers of adult arrowtooth flounder decreased on the continental slope from about 41 million in 1979 to 25 million by 1982.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) for Greenland turbot has been previously estimated at 67,000 t (Bakkala 1985b). Based on historic catch records (Table 23) and CPUE data (Fig. 14), the MSY estimate of 67,000 t appears to be too high. Survey and CPUE information appear to indicate the stock is at or below the level required to produce MSY. The average

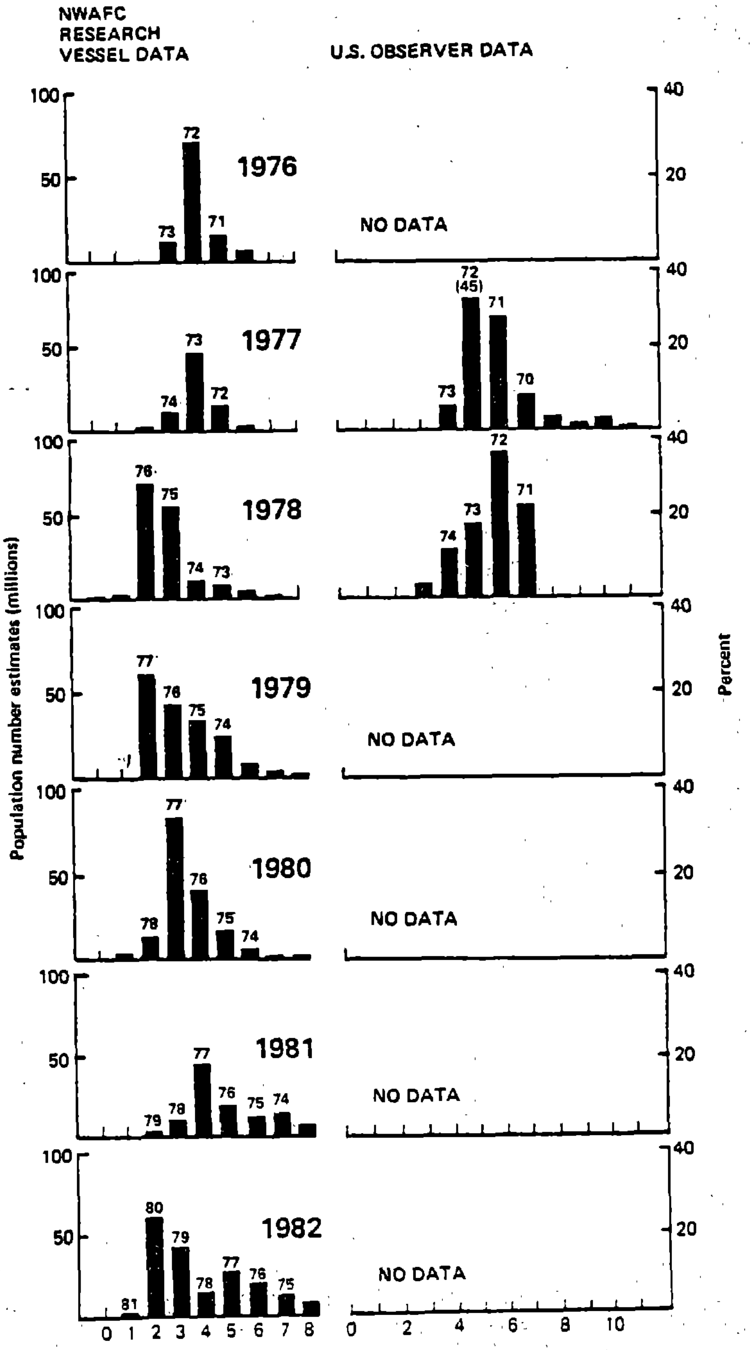

Figure 15.--Age composition of arrowtooth flounder as shown by data from Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by data collected in the commercial fishery by U.S. observers.

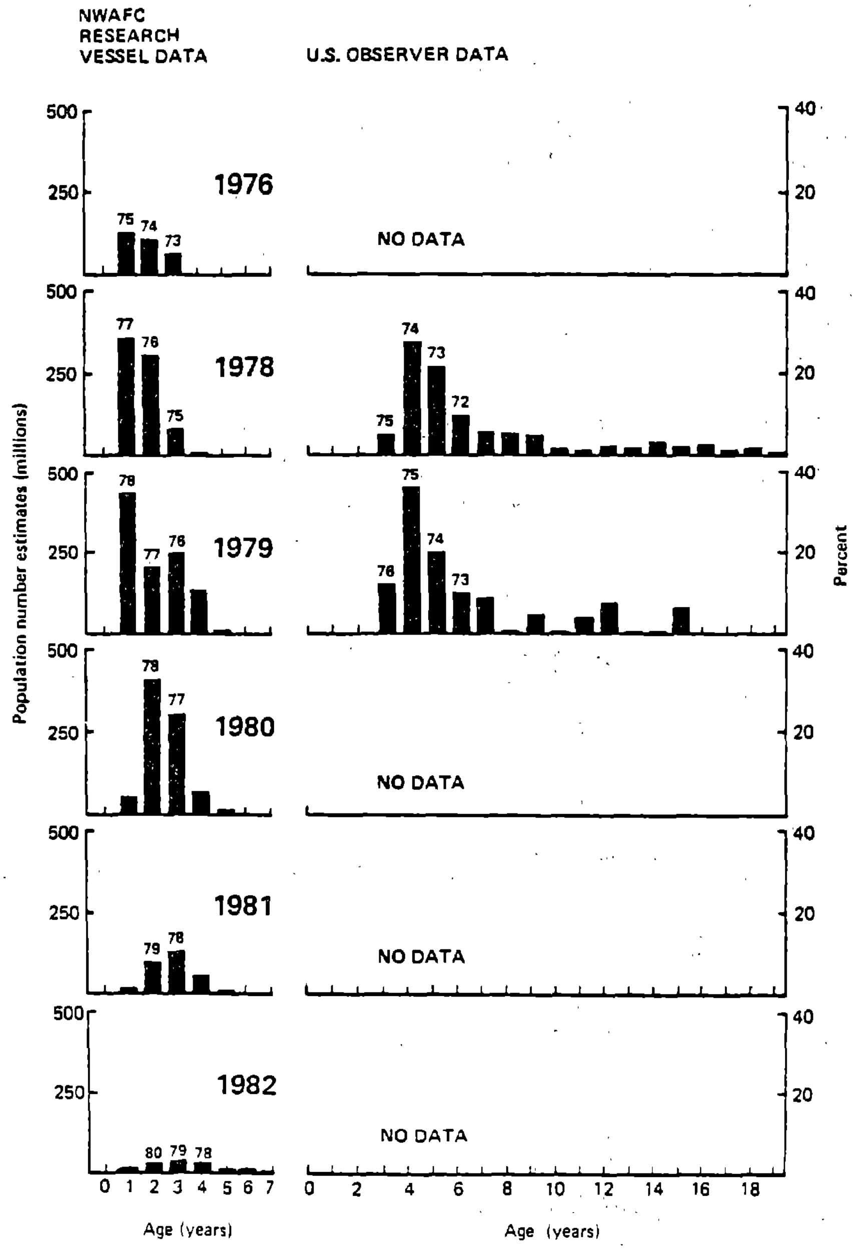

Figure 16.--Age composition of Greenland turbot as shown by data from Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by data collected in tie commercial fishery by U.S. observers.

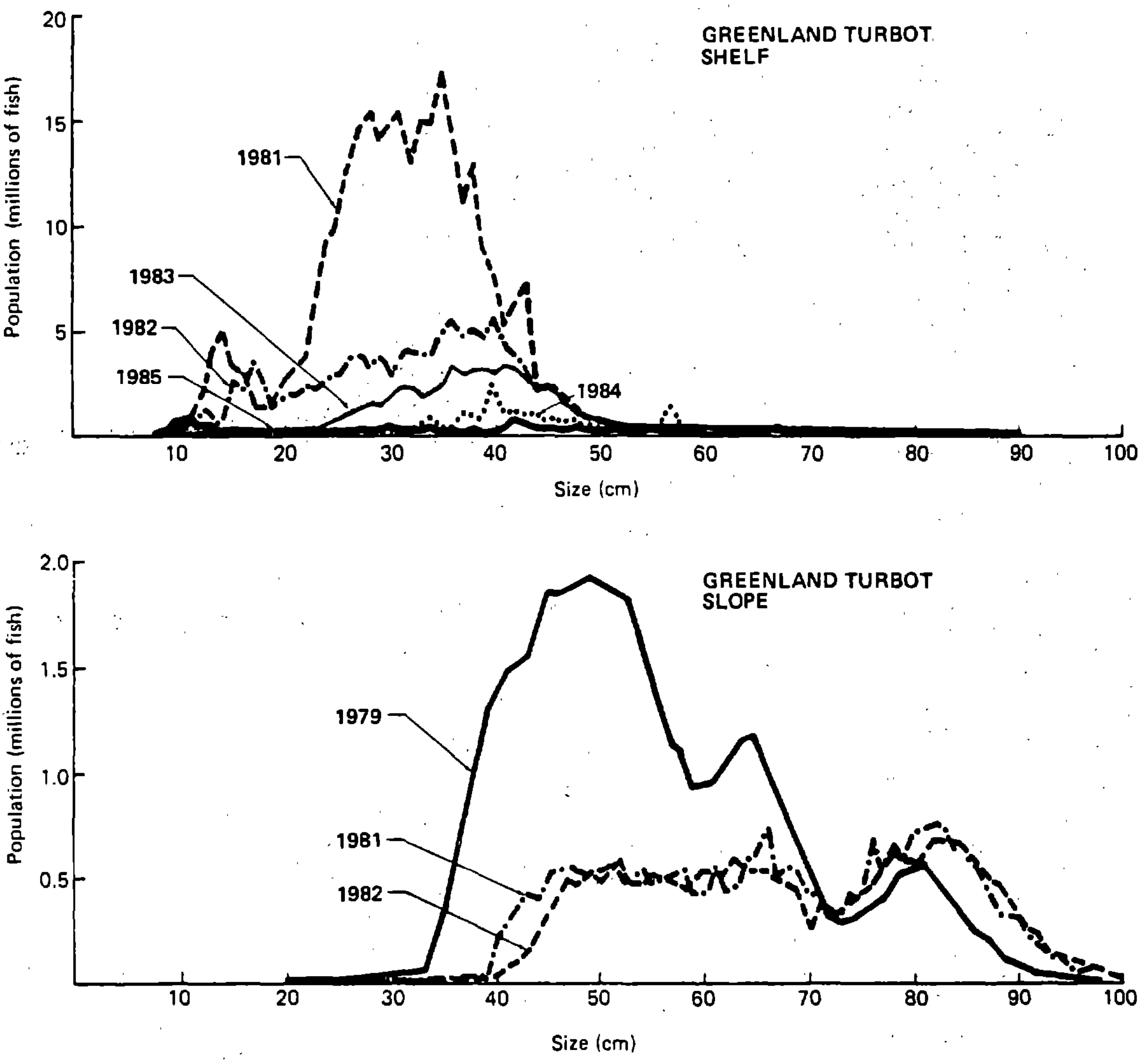

Figure 17.--Size composition of Greenland turbot on the eastern Bering Sea continental shelf and slope during research vessel surveys, 1979-85.

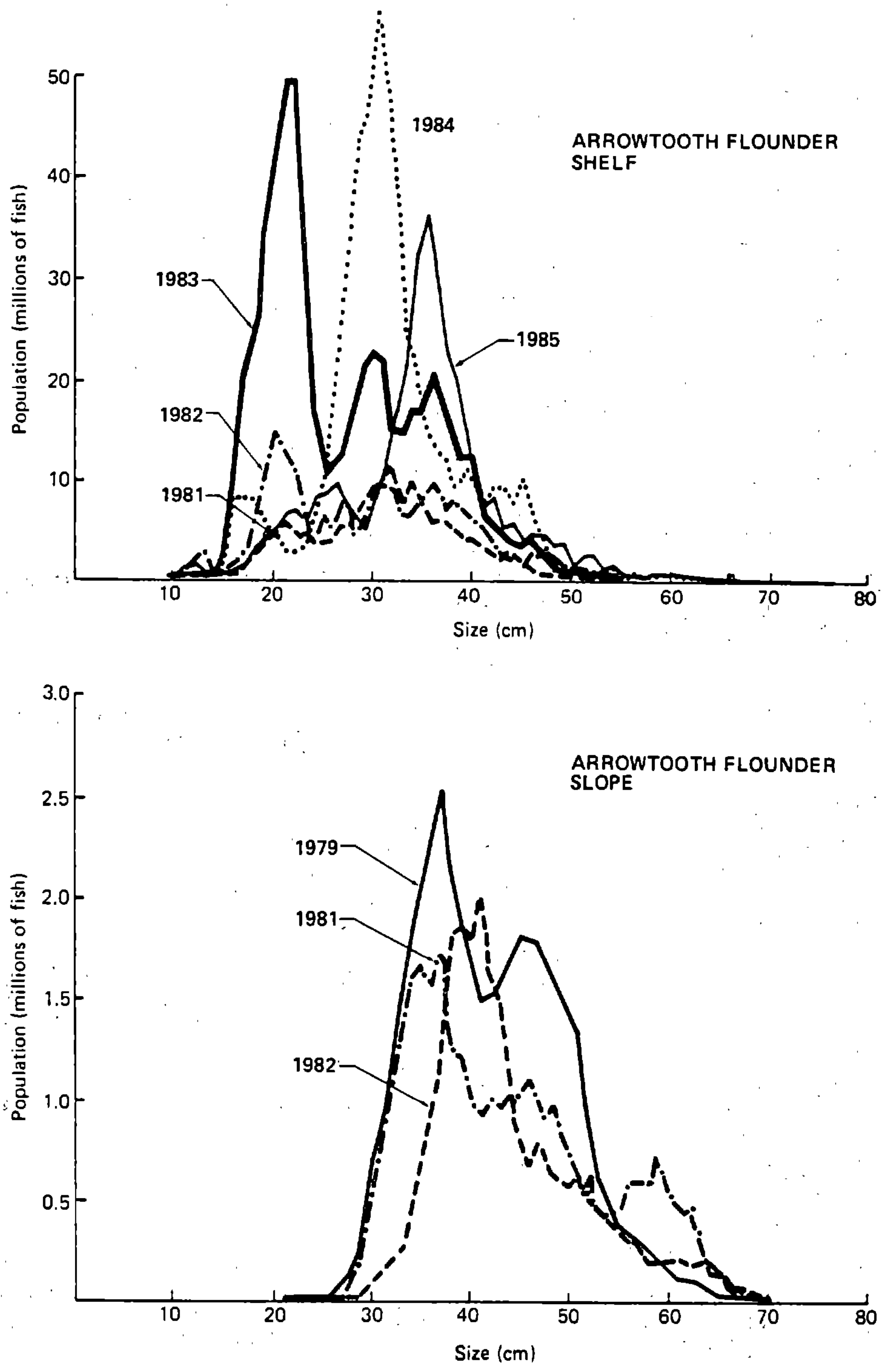

Figure 18.--Size composition of arrowtooth flounder on the eastern Bering Sea continental shelf and slope during research vessel surveys, 1979-85.

landings between 1970 and 1984 which reduced the stock to this level, were 50,585 t. Thus, a realistic upper bound to MSY might be 50,000 t. Stock Reduction Analysis (SPA) (Kimura et al. 1984; Kimura 1985b) was also used to estimate MSY. This method is described in some detail in the later section of this report on Pacific ocean perch. Given years of catch data, an estimate of natural mortality, and an estimate of change in abundance, such as are available from CPUE data, SPA provides estimates of initial population biomass (B_1), the change in biomass due to catch (P), and recruitment biomass consistent with the catch history and expected levels of recruitment. Although SPA does not require detailed age composition data, estimates of the age at recruitment, natural mortality, and Brody growth coefficients are required.

The age at recruitment for Greenland turbot was assumed to be 5 yr, natural mortality 0.18, the Brody weight coefficient 1.034 and $W_4/W_5 = 0.516$. Cushing recruitment coefficients were also used, the values being. $r = 0.0$ and 0.25. These coefficients represent the strength of the stock-recruitment relationship and the values used range from constant recruitment ($r = 0.0$) to a moderate relationship ($r = 0.25$). The analysis assumed that biomass had declined in 1984 to 50% of the 1970 biomass which equals the decline in CPUE during this period.

Estimates from SRA indicate that the virgin fishable biomass of Greenland turbot-in the eastern Bering Sea was between 810,000 and 920,000 t and that the current fishable biomass is between 305,000 and 356,000 t. Estimates of MSY ranged from 30,000 t ($r = 0.25$) to 38,600 t ($r = 0.0$).

The estimated MSY of 30,000 t appears to be too low based on evidence from CPUE data which indicate that catches in the 40,000 t range may be sustainable. In addition, the Aleutian Island portion of the population was not considered in the SRA which would increase the MSY. Thus the MSY is believed to fall somewhere between 38,600 and 50,000 t.

Stock reduction analysis was not used to estimate MSY for arrowtooth flounder because a sufficient time series of abundance estimates was not available. The estimate instead is based on the Alverson and Pereyra (1969) yield equation. Combined biomass estimates from the 1979 survey in the eastern Bering Sea and the 1980 survey in the Aleutians (98,500 t) were considered most representative of overall biomass of arrowtooth flounder during that period. Assuming that arrowtooth flounder had been fully exploited and that in 1979 the population had been reduced to a level that produces MSY (one-half the virgin population size), the virgin population was estimated at 197,000 t. Based on the yield equation and a natural mortality coefficient of 0.2 (Okada et al. 1980), MSY would be estimated as 0.5 x 0.2 x 197,000 t or 19,700 t.

The combined estimate of MSY for Greenland turbot and arrowtooth flounder for the overall management area is then believed to range between 58,300 and 69,700 t.

EQUILIBRIUM YIELD

Catch rates and biomass estimates for juvenile Greenland turbot, after being relatively stable from 1975 to 1980, declined sharply between 1981 and 1985. This decline has been the result of continued poor recruitment of age 1 fish since 1979. The impact of this poor recruitment on the adult stock was believed to have been reflected by the decline in CPUE from the fishery in 1982 and 1983. However, in 1984 the fishery CPUE increased. An increase in abundance appears illogical considering the poor recruitment of juveniles, and the higher CPUE may be the result of other factors such as greater efficiency of the fleet which was much reduced in 1984. With the uncertainties about the condition of the exploitable stock, and until results are available from the 1985 U.S.-Japan cooperative survey in continental slope waters, it is recommended that equilibrium yield (EY) be reduced to 35,000 t which is somewhat below the MSY range and represents an exploitation rate of approximately 10% based on the estimates of current biomass from SPA.

The CPUE and biomass estimates for juvenile arrowtooth flounder have increased in 1979-84 as a result of good recruitment of the 1979 and 1981. year-classes. Measures of abundance for the adult stock have been relatively stable. Based on the stability of the adult population and the good recruitment of juvenile fish; it is recommended that the equilibrium yield for arrowtooth flounder remain the same as MSY or 20,000 t.

For the combined turbot complex, the estimate of equilibrium yield for the eastern Bering Sea and Aleutians is 55,000 t.

OTHER FLATFISH

by

Richard G. Bakkala and Gary E. Walters

INTRODUCTION

The "other flatfish" species complex is made up of the following small flatfishes which have distributions that are mainly restricted to continental shelf waters of the eastern Bering Sea: flathead sole, *Hippoglossoides elassodon*; rock sole, *Lepidopsetta bilineata*; Alaska plaice, *Pleuronectes quadrituberculatus*; and small amounts of miscellaneous flatfishes including rex sole, *Glyptocephalus zachirus*; Dover sole, *Microstomus pacificus*; starry flounder, *Platichthys stellatus*; longhead dab, *Limanda proboscidea*; and butter sole, *Isopsetta isolepis*. Only small amounts of these species are taken in the Aleutian Islands region. All-nation catches of these species increased from around 30,000 metric tons (t) in the 1960s to a range of 65,000 to 92,000 t in 1970-72 (Table 25). At least part of this increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 25,000 t in 1975-82 but increased to 30,000 t in 1983 and 44,000 t in 1984. While catches of flathead sole have been relatively stable in recent years at around 5,000 t, those for rock sole since 1979 and for Alaska plaice since 1982 have increased and were each about 19,000 t in 1984. Most of the rock sole catch (64%) was taken by the joint venture fishery and most of the Alaska plaice catch (84%) by the foreign fishery.

CONDITION OF STOCKS

Relative Abundance

Because "other flatfishes" are taken incidentally in the target fisheries for other species, indices of abundance from commercial fisheries data do not accurately reflect trends in abundance for these species (Bakkala et al. 1979). It is therefore necessary to use research vessel survey data to assess the. condition of these stocks.

As described in the section on yellowfin sole, abundance estimates from the 1982 Northwest and Alaska Fisheries Center (NWAFC) survey were substantially higher than from the 1981 survey data for a number. of bottom-tending species such as the flatfishes. The increase in catch per unit of effort (CPUE) was particularly large, for rock sole (6.9 to 13.4 kg/ha) and Alaska plaice (10.6 to 14.5 kg/ha) while that for flathead sole was moderate (3.6 to 4.6 kg/ha). These higher 1982 estimates may have been due in part to better bottom contact or greater herding effects of the trawls used in 1982 compared to those used in 1981 and earlier years. The CPUE values were again high in 1983 and 1984, suggesting that the new rigging has increased the efficiency of the trawls for flatfish.

Table 25.--All-nation catches of other flatfishes in the eastern Bering Sea and Aleutian Islands region in metric tons (t) (1980-84 data includes catches from joint venture operations between U.S. fishing vessels and non-U.S. processing vessels).[a]

Year	Rock sole	Flathead sole	Alaska plaice	Miscellaneous flatfish[b]	Total
1963	5,029	29,639	975	-	35,643
1964	3,390	25,331	1,883	-	30,604
1965	3,825	6,841	1,020	-	11,686
1966	9,186	11,045	4,633	-	24,864
1967	4,787	23,469	3,853	-	32,109
1968	5,267	21,761	2,619	-	29,647
1969	9,242	18,565	6,942	-	34,749
1970	20,125	41,163	3,402	-	64,690
1971	40,420	51,040	992	-	92,452
1972	60,829	15,694	290	-	76,813
1973	23,837	18,165	1,917	-	43,919
1974	20,011	14,958	2,388	-	37,357
1975	12,014	5,888	2,491	-	20,393
1976	9,964	8,162	3,620	-	21,746
1977	2,914	7,909	2,589	981	14,393
1978	3,323	6,957	10,420	340	21,040
1979	1,468	4,351	13,672	233	19,724
1980	7,601	5,247	6,908	650	20,406
1981	9,021	5,218	8,653	536	23,428
1982	11,844	4,509	6,811	645	23,809
1983	13,618	5,240	10,766	830	30,454
1984	18,750	4,458	18,982	2,096	44,286

[a] Catches in 1977-83 differ from those shown by Bakkala (1985a). Previous estimates for these years were based on foreign reported and U.S. observer "best blend" catches which apparently included some turbot catches in the. miscellaneous flatfish category. Sources of the catch data are as follows:

1963-76, Wakabayashi and Bakkala 1978;
1977-84, Nelson et al. 1978, 1979, 1980, 1981b; 1982, 1983a; Berger et al. 1984, 1985b.

[b] Includes rex sole, Dover sole, starry flounder, longhead dab, and butter

The CPUE values from surveys that have sampled major portions of the eastern Bering Sea since 1975 are illustrated in Figure 19. These trends indicate that the abundance of rock sole and Alaska plaice may have increased moderately from 1975 to 1978-79 and increased more substantially in 1980-84. The abundance of flathead sole was relatively stable from 1975 to 1979 and then increased moderately each year in 1980-84. Values of CPUE for these species were lower in 1985, suggesting that abundance may have peaked and is now declining. However, the validity of this decline is questionable as will be discussed in the following section.

Biomass Estimates

Estimates from large-scale NWAFC surveys (Table 26) indicate that the biomass of Alaska plaice steadily increased from 127,100 t in 1975 to 745,400 t in 1983 before decreasing slightly in 1984 and declining further to 554,300 t in 1985. For rock sole, the estimates were relatively stable through 1979, but then increased substantially from 182,800 t in 1979 to 967,500 t in 1984 before declining to 678,200 t in 1985. The estimates for flathead sole increased from 101,800 t in 1979 to 340,900 t in 1984, and declined moderately to 293,600 t in 1985. The biomass of the miscellaneous species of flatfish increased through 1982, but have since declined.

The large increases in biomass between 1981 and 1982, representing a 104% increase for rock sole, a 26% increase for flathead sole, and a 33% increase for Alaska plaice, are believed due in part to the greater efficiency of the trawls used in 1982 and later years. Sampling in the vicinity of Nunivak Island in 1982 but not in 1981 also accounts for part of these increases for some species. The area not sampled in 1981 (see Fig. 3) accounted for about 20,400 t of biomass for rock sole, 98,000 t of Alaska plaice, and 24,200 t of miscellaneous flatfish species in 1982. None of the 1982 biomass estimate for flathead sole was accounted for in this area. Assuming the same distribution of biomass in 1981 and 1982, this area accounted for 20% of the 33% increase in biomass observed for Alaska plaice, but only 7% of the 104% increase for rock sole. Additional increases in the 1983 and 1984 biomasses compared to 1982 are believed to be the result of real increases in abundance of these species.

The declines in biomass for rock sole and Alaska plaice between 1984 and 1985 were relatively large and larger than might be expected from natural causes and fishing mortality. The decline was 30% for rock sole and 24% for Alaska plaice. A similar decline of 31% was observed in the biomass of yellowfin sole between 1984 and 1985. The similarity in these declines among most of the small flatfishes and the apparent unreasonable magnitude of the declines suggest that they may not be entirely real, but related to some other factor such as availability to the trawls or catchability of the trawls. As discussed in the section of this report on yellowfin sole, the reason for the abnormally large decreases in abundance of these species are not now apparent.

Although the actual changes in abundance of "other flatfish" in the eastern Bering Sea over the past several years is difficult to judge because of the changes in fishing gear, areas sampled, and other possible causes, abundance currently is obviously higher than in the late 1970s.

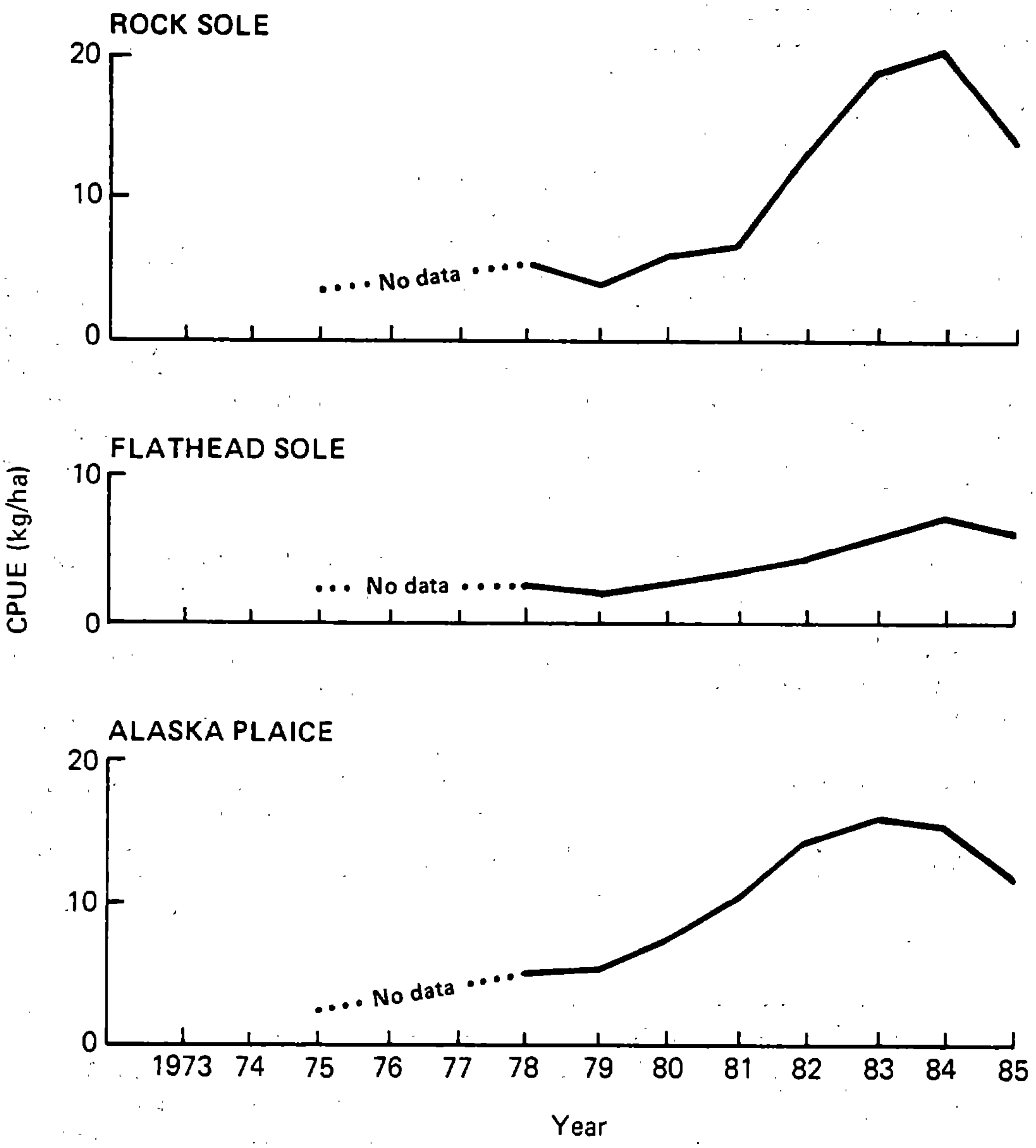

Figure 19.--Relative abundance (catch per unit of effort, CPUE) of rock sole, flathead sole, and Alaska plaice as obtained by large-scale bottom trawl surveys of the Northwest and Alaska Fisheries Center.

Table 26.--Estimated biomass (in metric tons) of species in the other flatfish complex in the eastern Bering Sea and Aleutian regions, based on research vessel survey data in 1975 and 1978-85,.

Year	Area	Species				Total all species excluding Alaska plaice	Total all species
		Rock sole	Flathead sole	Alaska plaice	Others		
1975	EBS[a]	170,300	113,000	127,100	11,000	294,300	421,400
1978	EBS	177,700	85,600	165,200	31,800	295,100	460,300
1979	EBS	182,800	101,800	283,000	50,500	335,100	618,100
1980	EBS	283,000	128,400	348,800	59,000	470,400	819,200
	Aleut.[b]	28,500	3,300	0	2,700	34,500	34,500
1981	EBS	298,900	168,300	500,500	71,700	538,900	1,039,400
1982	EBS	609,500	211,600	663,700	147,000	968,100	1,631,800
1983	EBS	869,700	279,200	745,400	69,700	1,218,600	1,964,000
	Aleut.	23,300	1,500	0	2,700	27,500	27,500
1984	EBS	967,500	340,900	726,800	52,000	1,360,400	2,087,200
1985	EBS	678,200	293,600	554,300	31,200	1,003,000	1,557,300

[a] Eastern Bering Sea.
[b] Aleutian Islands region.

Abundance of "other flatfish" is much lower in the Aleutian Islands region than in the eastern Bering Sea. The estimated biomasses derived from the 1980 and 1983 cooperative U.S.-Japan surveys in the Aleutians were 34,500 t and 27,500 t respectively, most of which was rock sole (Table 26).

Age Composition and Year-Class Strength

Age data for rock sole collected during NWAFC research vessel surveys since 1975 show that the 1965-70 year-classes formed the principal part of the sampled population through 1977, with the 1969 and 1970 year-classes being particularly strong (Fig. 20). These year-classesalso formed the major part of commercial catches of rock sole in 1975-79 (Fig. 20). The 1971-74 year-classes appear to be below average strength as evidenced by survey data, but the 1975-80 year-classes appear to be above average strength. This good recruitment is believed to account, at least in part, for the increases in estimates of relative and absolute abundance for rock sole that have been observed in the early 1980s.

Age data for flathead sole collected during research vessel surveys since 1976 and from the commercial fishery in 1977-79 (Fig. 21) show that the 1965-69 year-classes formed the bulk of the population sampled by research vessels in 1976 and were a major component, along with the 1970 year-class, of catches by the commercial fishery in 1977. In more recent years, there appears to be good recruitment from the 1974-80 year-classes, which may account for the higher abundance of flathead sole observed from survey data.

Recruitment of stronger than average year-classes may also be the primary reason for the increase in abundance of Alaska plaice in recent years. The 1967-71 year-classes have formed the major portion of the population since 1978 and continued to predominate in the population through 1982 at the relatively old ages of 11-15 yr (Fig. 22). Some later year-classes also appear to be abundant, particularly the 1974 and 1975 year-classes.

MAXIMUM SUSTAINABLE YIELD

Because of the absence of good population data for the "other flatfish" complex, maximum sustainable yield (MSY) for this group was approximated. The approximations were based on the assumption that this species group was fully utilized prior to 1975. With this assumption, one approximation of MSY was provided by the average catch from 1963 to 1974, which was 43,000 t. The second approximation was based on the Schaefer model (Schaefer 1954), which indicated that, with full utilization prior to 1975, the 1975 biomass would be about half its virgin size. A large-scale NWAFC research vessel survey that covered major portions of the eastern Bering Sea shelf in 1975 indicated that the standing stock of rock sole, flathead sole, and miscellaneous species of flatfish was 240,200-348,900 t, implying a virgin biomass of 480,400-697,800 t.

Assuming M is 0.23 for the rock sole-flathead sole-miscellaneous flatfish complex, the Alverson and Pereyra (1969) yield equation produces an MSY estimate of 55,200-80,200 t (0.5 x 0.23 x 480,400 to 697,800 t).

Estimates of MSY, therefore, range from 43,000 t to 80,200 t based on the two methods of approximation.

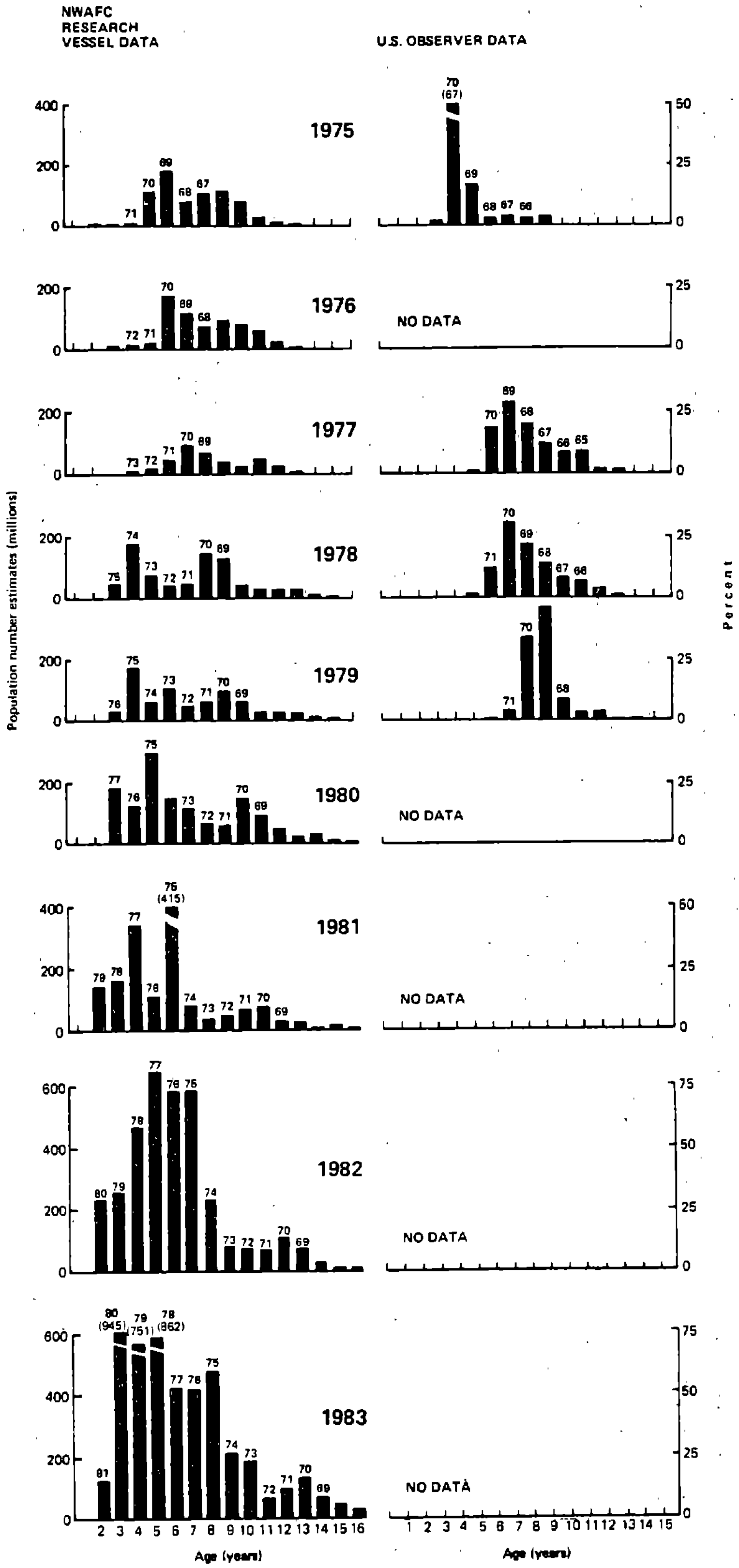

Figure 20.--Age composition of rock sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

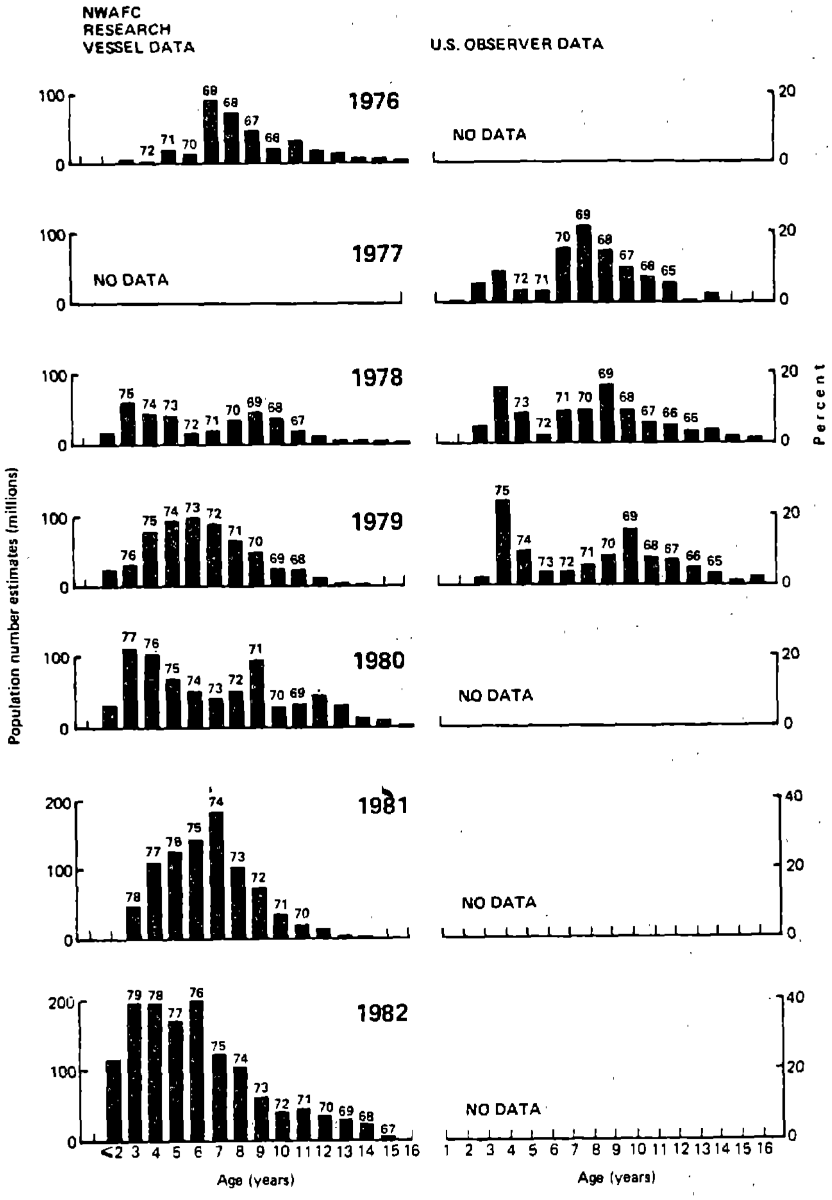

Figure 21.--Age composition of flathead sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

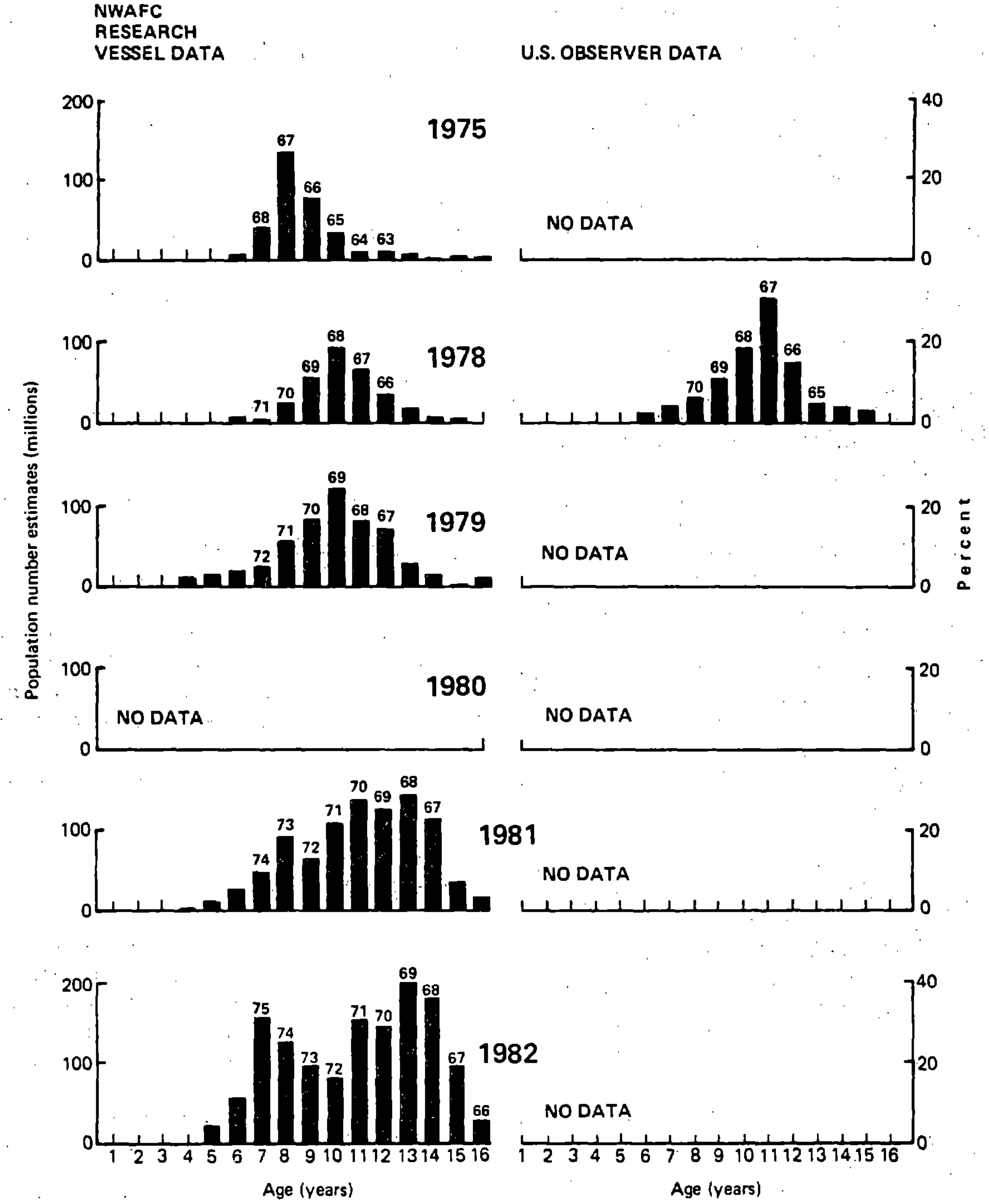

Figure 22. -Age composition of Alaska plaice as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

The mean estimated biomasses from the 1980 eastern Bering Sea and Aleutian surveys (504,900 t) and the 1981 eastern Bering Sea survey (538,900) fall within the estimated virgin population biomass derived from the 1975 data. Estimates since 1982 exceed the estimated range in virgin biomass and indicate that these species are in good condition and can sustain catches in the MSY range if not higher.

Alaska plaice have not been incorporated into estimates of MSY for the rock sole-flathead sole-miscellaneous flatfish complex because they have not been usually exploited at the same rate as rock sole and flathead sole. Alaska plaice have probably been less exploited because of their more inshore distribution, which is removed from the main fishing areas for pollock and yellowfin sole. Inclusion of Alaska plaice would increase MSY and subsequent estimates of equilibrium yield (EY). This higher EY might be used primarily for rock sole and flathead sole rather than being distributed among the three species, which could possibly lead to overexploitation of rock sole and flathead sole.

Separate estimates of MSY and EY have therefore been derived for Alaska plaice. Biomass estimates for Alaska plaice based on data from large-scale surveys since 1975 have been increasing and continued to increase through 1983. From an estimate of 127,100 t in 1975, they show an apparent increase to 745,400 t in 1983 and then a decline to 554,300 t in 1985. The MSY for Alaska plaice was estimated based on the 95% confidence interval around the 1981 mean estimate; because this species has only been lightly exploited throughout the history of the fishery and because the biomass more than doubled between 1975 and 1981, the 1981 biomass may have approximated the abundance of the virgin population. Based on these assumptions, and using the yield equation and an M value of 0.23, MSY was estimated to be (0.5 x 0.23 x 392,000 to 609,000 t) or 45,100-70,000 t.

EQUILIBRIUM YIELD

Abundances of rock sole, flathead sole, and Alaska plaice as shown by NWAFC survey data have fluctuated abnormally in some years due to changes in sampling trawls and possibly other factors, making it difficult to judge the actual magnitude of changes. Nevertheless, good recruitment has resulted in increases in abundance of these species and abundance is currently high.

The biomass of rock sole, flathead sole, and miscellaneous species of flatfish was estimated to be 1.0 million t in 1985. Based on this estimate, these species are capable of producing catches at the upper end of the MSY range or 80,000 t which represents an exploitation rate of 8% based on the latest biomass estimates.

The biomass of Alaska plaice was estimated to be 554,300 t in 1985. The population should be capable of producing catches at the midpoint of the MSY range or 57,500 t which represents an exploitation rate of 10%.

SABLEFISH[1]

by

Sandra A. McDevitt

INTRODUCTION

The distribution of sablefish, Anoplopoma fimbria, ranges from off northern Mexico along the Pacific west coast through the Gulf of Alaska and along the Aleutian Island Chain and edge of the continental slope in the eastern Bering Sea. Their range continues off the Siberian and Kamchatkan coasts of the U.S.S.R. to the northeast coast of Japan. The sablefish resource is managed by discrete regions to distribute exploitation throughout its wide geographical range. There are two management areas in the Bering Sea: the eastern Bering Sea, and the Aleutian Islands region.

Longline and trawl vessels fish for sablefish in relatively deep waters of 400-900 m. Japanese longliners began operations in the eastern Bering Sea in 1958. The fishery rapidly expanded and catches increased to a peak of 25,990 t in 1962 (Table 27). As fishing grounds used by longliners became preempted by expanding trawl fisheries, the longline fleet expanded to the Aleutian region and the Gulf of Alaska. Catches peaked in the Aleutian region at 3,530 t in 1972 (Table 28).

Catches declined in the eastern Bering sea and the Aleutian region after 1972 largely due to declining stock abundance. Catches since 1977 have remained at relatively stable and reduced levels because of continued low stock abundance and catch restrictions placed on the fishery. In 1984 the all-nation catch of sablefish was 2,790 t in the eastern Bering Sea, and 1,040 t in the Aleutian region. The Japanese were responsible for 36% of the catch in the eastern Bering Sea and 69% in the Aleutians, while the United States caught 54% and 4.5% of the respective regional catches.

CONDITION OF STOCKS

Relative Abundance Estimates from the Fishery

The interpretation of catch per unit of effort (CPUE) data is complicated by variation in gear types, differing assumptions made in data selection, fishing power increases, and management regulations which have influenced fishing patterns. With these limitations, CPUE data from commercial fisheries may only provide general indications of abundance trends.

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[1] This is a revised update of the following report: Narita, R. E. 1985. Sablefish. In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 97-112. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

Table 27.--Annual sablefish catches in metric tons from the eastern Bering Sea by nation, 1956-84[a].

Year	Japan	U.S.S.R.	R.O.K.	Taiwan	U.S.	Other[b] nations	Joint Venture	Total[c]
1956	--	--	--	--	--	--	--	--
1957	--	--	--	--	--	--	--	--
1958	6	--	--	--	--	--	--	6
1959	289	--	--	--	--	--	--	289
1960	1,861	--	--	--	--	--	--	1,861
1961	15,627	--	--	--	--	--	--	15,627
1962	25,989	--	--	--	--	--	--	25,989
1963	13,706	--	--	--	--	--	--	13,706
1964	3,545	--	--	--	--	--	--	3,545
1965	4,838	--	--	--	--	--	--	4,838
1966	9,505	--	--	--	--	--	--	9,505
1967	10,462	1,236	--	--	--	--	--	11,698
1968	10,118	4,256	--	--	--	--	--	14,374
1969	14,430	1,579	--	--	--	--	--	16,009
1970	8,863	2,874	--	--	--	--	--	11,737
1971	12,276	2,830	--	--	--	--	--	15,106
1972	10,621	2,137	--	--	--	--	--	12,758
1973	4,765	1,192	--	--	--	--	--	5,957
1974	4,181	77	--	--	--	--	--	4,258
1975	2,728	38	--	--	--	--	--	2,766
1976	2,798	29	96	--	--	--	--	2,923
1977	2,661	--	2	53	2	--	--	2,718
1978	1,006	--	182	5	--	--	--	1,192
1979	1,058	49	261	6	--	2	--	1,376
1980	1,648	--	324	30	2	168	35	2,206
1981	2,091	--	339	102	2	46	24	2,604
1982	2,315	--	506	208	148	1	6	3,184
1983	2,231	--	372	--	47	1	44	2,695
1984	1,006	--	179	--	1,518	13	76	2,793

[a] Japanese catch data for 1958-70 from Forrester et al. 1978, for 1971-76 from Forrester et al. 1983; U.S.S.R. data for 1967-76 provided through U.S.-U.S.S.R. bilateral agreements; R.O.K. 1976 data provided through U.S.-R.O.K. bilateral agreements; U.S. data 1977-84 provided by U.S. state fishery agencies; 1977-84 data for all other nations from U.S. foreign fisheries observer program. The catches provided in this table may differ from previous tables as they no longer include catches from the western Bering Sea (INPFC areas 3 and 4).

[b] Poland, Federal Republic of Germany, and Portugal.

[c] Discrepancies between actual sums of component figures and totals are due to rounding.

Table 28.--Annual sablefish catches in metric tons from the Aleutian Islands, by nation, 1963-84[a].

Year	Japan	U.S.S.R.	R.O.K.	U.S.	Other[b] nations	Joint Venture	Total[c]
1963	664	--	--	--	--	--	664
1964	1,541	--	--	--	--	--	1,541
1965	1,249	--	--	--	--	--	1,249
1966	1,341	--	--	--	--	--	1,341
1967	1,652	--	--	--	--	--	1,652
1968	1,673	--	--	--	--	--	1,673
1969	1,673	--	--	--	--	--	1,673
1970	1,248	--	--	--	--	--	1,248
1971	2,766	170	--	--	--	--	2,936
1972	3,262	269	--	--	--	--	3,531
1973	2,740	162	--	--	--	--	2,902
1974	2,463	14	--	--	--	--	2,477
1975	1,630	79	38	--	--	--	1,747
1976	1,558	61	40	--	--	--	1,659
1977	1,810	--	87	--	--	--	1,897
1978	798	--	23	--	--	--	821
1979	617	--	165	--	--	--	782
1980	233	--	26	3	8	4	274
1981	320	--	56	--	1	156	533
1982	715	--	92	28	1	118	955
1983	527	--	45	29	3	70	673
1984	717	--	7	47	1	272	1,043

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[a] Japanese catch data for 1963-70 from Forrester et al. 1978, for 1971-76 from Forrester et al. 1983; U.S.S.R. data for 1971-76 provided through U.S.-U.S.S.R. bilateral agreements; R.O.K. 1975-76 data provided through U.S.-R.O.K. bilateral agreements; U.S. data 1980-84 provided by U.S. state fishery agencies; 1977-84 data for all other nations from U.S. foreign fisheries observer program.

[b] Federal Republic of Germany and Taiwan.

[c] Discrepancies between actual sums of component figures and totals are due to rounding.

Prior to 1977, Japan harvested the greatest portion of sablefish catches in U.S. waters. Japanese longline and stern trawl vessel CPUE data have been used to provide estimates of sablefish abundance trends prior to the availability of survey data (Table 29). Japanese stern trawlers generally target on other species, with only a few targeting specifically on sablefish. Estimates of relative abundance from stern trawl vessels may therefore not be representative of actual abundance trends for sablefish (Sasaki 1985b).

Data from longline vessels whose effort has been directed toward sablefish may depict stock abundance trends. Japanese longline data indicates a considerable decline in CPUE for both the eastern Bering Sea and the Aleutian region (Table 29). To better illustrate the trend in abundance of sablefish as shown by Japanese longline data, the Japanese CPUE estimates in units of kg/l0 hachi, from Table 29, are standardized below by setting the 1970 values to 100 units:

	Eastern Bering Sea		Aleutian Region	
Year	All nation catch (t)	Normalized CPUE	All-nation catch (t)	Normalized CPUE
1970	11,700	100	1,200	100
1971	15,100	77	2,900	83
1972	12,800	49	3,500	86
1973	6,000	61	2,900	85
1974	4,300	68	2,500	86
1975	2,800	54	1,700	70
1976	2,900	61	1,700	47
1977	2,700	56	1,900	45
1978	1,200	22	800	17
1979	1,400	20	800	16
1980	2,200	27	300	27
1981	2,600	31	500	40
1982	3,200	41	1,000	57
1983	2,700	45	700	63
1984	2,800	Not Available	1,000	Not Available

The data shows a general decline through 1977. In 1977 the CPUE value in the eastern Bering Sea was 56% of the 1970 level, while the value for the Aleutian region was 45% of the 1970 level. The CPUE values for 1978-83 may not be consistent with data from previous years due to changes in fishing patterns brought about by fishing regulations following enactment of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977. Even though catches after 1978 remained relatively stable at a low level, CPUE values continued to drop, reaching lows of 20 and 16% of the 1970 values in 1979 for the eastern Bering Sea and Aleutian region respectively. The CPUE data shows an upward trend beginning in 1980, which is a reflection of the recruitment to the fishery of the strong 1977 year-class. In 1983, rates increased to 45% of 1970 values in the eastern Bering Sea and to 63% in the Aleutians, still below values of 1975 and earlier years.

Table 29.--Sablefish catch per unit effort trends in the eastern Bering Sea and Aleutian region based on data from Japanese longline and trawl fisheries, 1964-83.

	Eastern Bering Sea				Aleutian Region				
	Japan estimates		U. S. estimates		Japan estimates		U. S. estimates		
	longline		longline	trawl	longline		longline		trawl
	kg/10 hachi[a]	T/vessel day[b]	kg/10 hachi[c]	kg/h[c]	kg/10 hachi[a]	T/vessel day[b]	kg/10 hachi[c]	T/vessel day[c]	kg/h[c]
1964	93	2.4	61		141	3.1	139		
1965	105	3.0	54		183	4.1	110		
1966	166	4.5	139		233	6.3	229		
1967	216	6.2	210	151	275	7.1	277		154
1968	140	5.1	143	134	161	5.9	165		259
1969	187	6.9	189	142	183	7.1	184		318
1970	241	8.7	231	50	241	9.4	189		112
1971	185	5.6	120	76	202	9.4	165	4.5	222
1972	117	3.3	50	62	208	11.6	203	11.8	123
1973	148	6.0	47	41	204	7.7	192	4.6	115
1974	164	7.4	141	24	208	7.8	187	4.4	44
1975	130	4.9	68	13	168	6.0	98	1.8	30
1976	147	5.6	69	6	114	4.5	71		7
1977	135	5.4	73	5	108	4.0	70	1.1	3
1978	52		16	1	40		24		2
1979	48		24	1	39		26		1
1980	64		31	2	66		24		2
1981	75		35	0	96		40		<1
1982	99		47	2	138		76		<1
1983	109		49		152				

[a] Sasaki (1985c). Hachi is a unit of longline gear 100 m long.
[b] Sasaki (1978).
[c] Method of Low et al. (1977).

Yearly changes in catch and effort data used to compute the CPUE values of Table 29 are shown in Figure 23. Catches and effort showed corresponding fluctuations through 1977 in both the eastern Bering Sea and Aleutians. In 1977-78 there was a large drop in catches despite a minor increase in fishing effort. Effort continued to increase through 1979 with catches remaining at a low level, which provides further evidence that the stocks were in poor condition during those years.

Data collected by U.S. observers from Japanese longline vessels fishing at depths greater than 500 m provide another source for evaluating the condition of sablefish stocks (Table 30). Sablefish were not the dominant species in the sampled catches until 1984 in the eastern Bering Sea, but have been the dominant species in the Aleutian region since 1980. Thus, the Aleutian data may be a better indication of sablefish abundance than eastern Bering Sea data. Nevertheless, both sets of data show the same trends.

Catch per unit effort values show a general increase starting in 1981 or 1982 and continuing through 1984. The increases were 288% in the eastern Bering Sea between 1981 and 1984, and 477% in the Aleutian Islands between 1979 and 1984. Whether these data accurately reflect changes in sablefish abundance is difficult to evaluate because observer coverage increased during this time period (Table 31) and time periods fished varied between years. In addition, the average depth fished in 1984 in the eastern Bering Sea was 370 m greater than the previous year. Nevertheless, although the magnitude of the increases may be questioned, the increasing trend in abundance parallels that shown by the foreign-reported CPUE data.

Abundance Estimates from Surveys

There are two series of U.S.-Japan cooperative surveys that provide biomass estimates for the exploitable population: trawl surveys and longline surveys. The trawl surveys have been conducted in the eastern Bering Sea slope region of International North Pacific Fisheries Commission (INPFC) statistical areas 1 and 2 in 1979, 1981, and 1982. A fourth slope survey was conducted in 1985 but data from this latter survey is not yet available. Trawl surveys are conducted triennially in the Aleutian region and biomass estimates from these surveys are available for 1980 and 1983. The Aleutian surveys also cover the Aleutian portion of INPFC Area 1 (north Aleutians east of 170°W) which is not included in the eastern Bering Sea slope surveys. The biomass estimates from the Aleutian Island portion of area 1 are added to the estimate's from the eastern Bering Sea slope surveys to provide total biomass estimates for areas 1 and 2 combined.

Japan and the U.S. have conducted annual cooperative longline surveys in the Gulf of Alaska since 1978. This survey has included the Aleutian region since 1980 and the eastern Bering Sea since 1982. The longline survey catch data is stratified by 100 m depth intervals. Catch per unit of effort in units of fish per hachi are multiplied by the respective areas of each depth strata to obtain an index of relative population number (RPN). Relative population numbers by length group are calculated and then weighted by the mean body weight of fish by length catagory to produce indices of relative population weight (RPW). These surveys provided relative population weight indices for 1982-84 in the eastern Bering Sea and 1980-84 in the Aleutian region. The survey was again conducted in 1985 but results are not yet available. The results from the 1979-84 trawl and longline surveys are presented in Table 32.

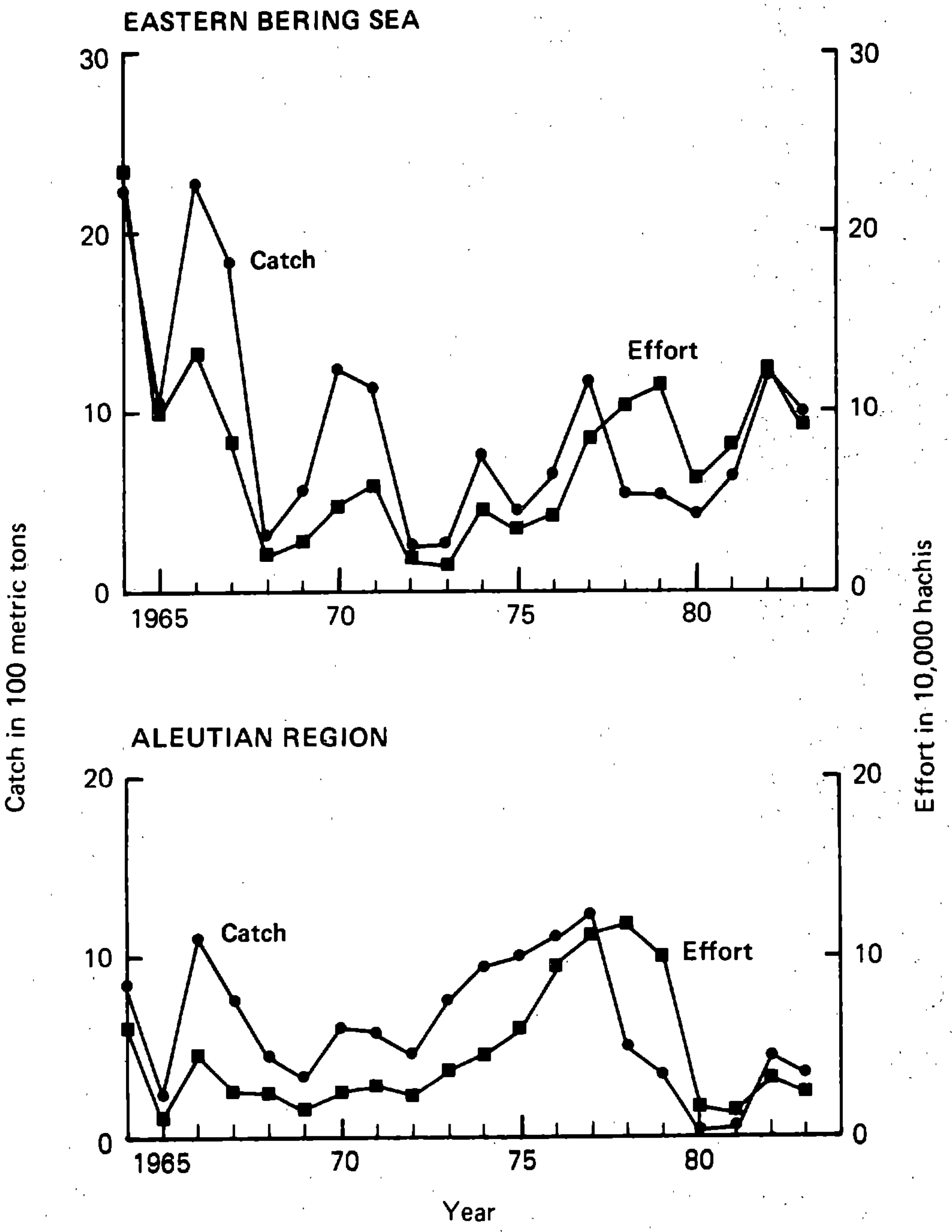


Figure 23.--Catch and effort trends of Japanese longline vessels targeting on sablefish in the eastern Bering Sea and the Aleutian region, 1964-83.

Table 30.--Japanese longline CPUE data for sablefish from hauls sampled by U.S. observers at depths greater than 500 m, 1977-84[a].

Year	Area	Average Depth (m)	Sablefish[b] catch (t)	Percent sablefish in sampled catch	Rank[c]	CPUE t/1000 hooks
1978	EBS	633	12.0	14	2	.037
1979	EBS	693	95.3	11	3	.052
1980	EBS	666	100.3	7	4	.038
1981	EBS	660	180.7	16	2	.096
1982	EBS	662	648.3	22	2	.117
1983	EBS	623	641.6	24	2	.129
1984	EBS	997	229.6	39	1	.372
1977	Aleutians	636	9.6	29	2	.082
1978	Aleutians	641	42.3	35	1	.136
1979	Aleutians	670	119.4	21	3	.082
1982	Aleutians	650	164.6	51	1	.269
1983	Aleutians	634	239.1	57	1	.404
1984	Aleutians	668	348.0	62	1	.473

[a] There was no observer coverage in the eastern Bering Sea for 1977, or in the Aleutians for 1980-81.

[b] This is estimated sablefish catch for vessels and days on which observers sampled the catch, and should not be taken as total sablefish catch.

[c] Rank of sablefish in the catch by weight.

Table 31.--Percentage of Japanese longline catch sampled by U.S. observers in the eastern Bering Sea and the Aleutian Islands, 1977-84.

Year	Eastern Bering Sea	Aleutian Islands
1977	0	1.7
1978	9.6	8.2
1979	28.2	22.2
1980	19.2	0
1981	16.2	0
1982	59.8	28.8
1983	67.1	49.4
1984	76.3	60.5

Table 32.--Estimated biomass and relative population weight indices of sablefish from U.S.-Japan cooperative trawl and longline surveys (Doc. 2910 and 2946).

Area	1979	1980	1981	1982	1983	1984
<u>Trawl Surveys (Biomass in t)</u>						
Eastern Bering Sea (Areas 1 & 2)	12,600	--	39,400	42,900	--	--
(95% Confidence intervals)	(0-56,900)		(23,800-55,100)	(35,800-50,100)		
Eastern Bering Sea (Area 1, N. Aleutians)	--	8,500	--	--	9,900	--
(95% Confidence intervals)		(0-17,500)			(400-19,300)	
Aleutian Region (Area 5)	--	20,300	--	--	68,500	--
(95% Confidence intervals)		(8,100-32,400)			(0-143,200)	
<u>Longline Survey (Relative Population Weight, RPW)</u>						
Eastern Bering Sea (Areas 1 & 2)	--	--	--	33,538	26,029	38,513
Aleutian Region (Area 5)	--	28,241	27,500	30,984	35,888	44,282

Eastern Bering Sea

Increases in commercial catches and abundance estimates from the fishery and research vessels all indicate that sablefish abundance has generally increased between 1980 and 1984. This increase reflects the recruitment of the unusually strong 1977 year-class into the exploitable stock. This year-class was first observed as age 1 juveniles in 1978 during the annual U.S. trawl survey of the eastern Bering Sea shelf (Fig. 24). Sablefish have rarely been observed on the shelf since the survey was initiated in 1971, but appeared in abundance in 1978. Subsequent surveys indicated that the 1977 year-class persisted in continental shelf waters of the eastern Bering Sea through 1980. In 1981 the abundance on the shelf sharply declined, and there was a corresponding increase in abundance on the continental slope (Fig. 25). This was presumably due to the movement of these 4-yr-old fish from the shelf to slope waters. Population estimates by length intervals (Fig. 25) from the 1979, 1981, and 1982 U.S.-Japan slope surveys show that population numbers on the slope quadrupled between 1979 (5.3 million fish) and 1982 (22.7 million fish).

The U.S.-Japan trawl surveys also show a general increase in biomass between 1979 and 1982 in areas 1 and 2 of the eastern Bering Sea, and in the north Aleutian portion of eastern Bering Sea area 1 (Table 32). However, the 95% confidence intervals for the two estimates overlap extensively, indicating that they may not be significantly different. In 1982 the total eastern Bering Sea biomass was 52,800 t (summed mean estimates from 1982 eastern Bering Sea areas 1 and 2 and 1983 north Aleutian area 1, Table 32). This is a 150% increase over the 1979 total biomass estimate for areas 1 and 2 of 21,100 t (summed mean estimates from 1979 eastern Bering Sea areas 1 and 2 and 1980 north Aleutian area 1). The numbers probably reflect increases due to the recruitment of the 1977 year-class; however, the extent of the increases should be viewed with caution as the numbers are associated with wide variances and overlapping 95% confidence intervals. Relative population weight indices from the U.S.-Japan longline survey in the eastern Bering Sea show a 22% decrease in relative biomass from 1982 to 1983, and an overall increase of 15% from 1982 to 1984 (Sasaki 1985c, Table 32).

Aleutian Region

Joint U.S.-Japan trawl surveys of the Aleutian Islands region were conducted in 1980 and 1983. These surveys were the first comprehensive assessment of Aleutian groundfish resources in which the United States has participated that encompassed areas north and south of the Aleutian Chain between Attu Island and Unimak Pass. Estimates, of sablefish biomass from these surveys are given in Table 32.

The trawl survey data indicated a 237% increase of sablefish biomass between 1980 and 1983. Most of the increase occurred in the central Aleutians, particularly north of the chain where biomass estimates increased nearly five times from 10,100 t in 1980 to 47,100 t in 1983 (Fig. 26). The Aleutian trawl survey biomass estimates are also characterized by overlapping 95% confidence intervals (Table 32). These increases are also believed to reflect the recruitment of the 1977 year-class, but the extent of the increases is not clear. The U.S.-Japan longline surveys also showed increases in relative biomass, but to a lesser extent. Relative biomass increased 57% between 1980 and 1984.

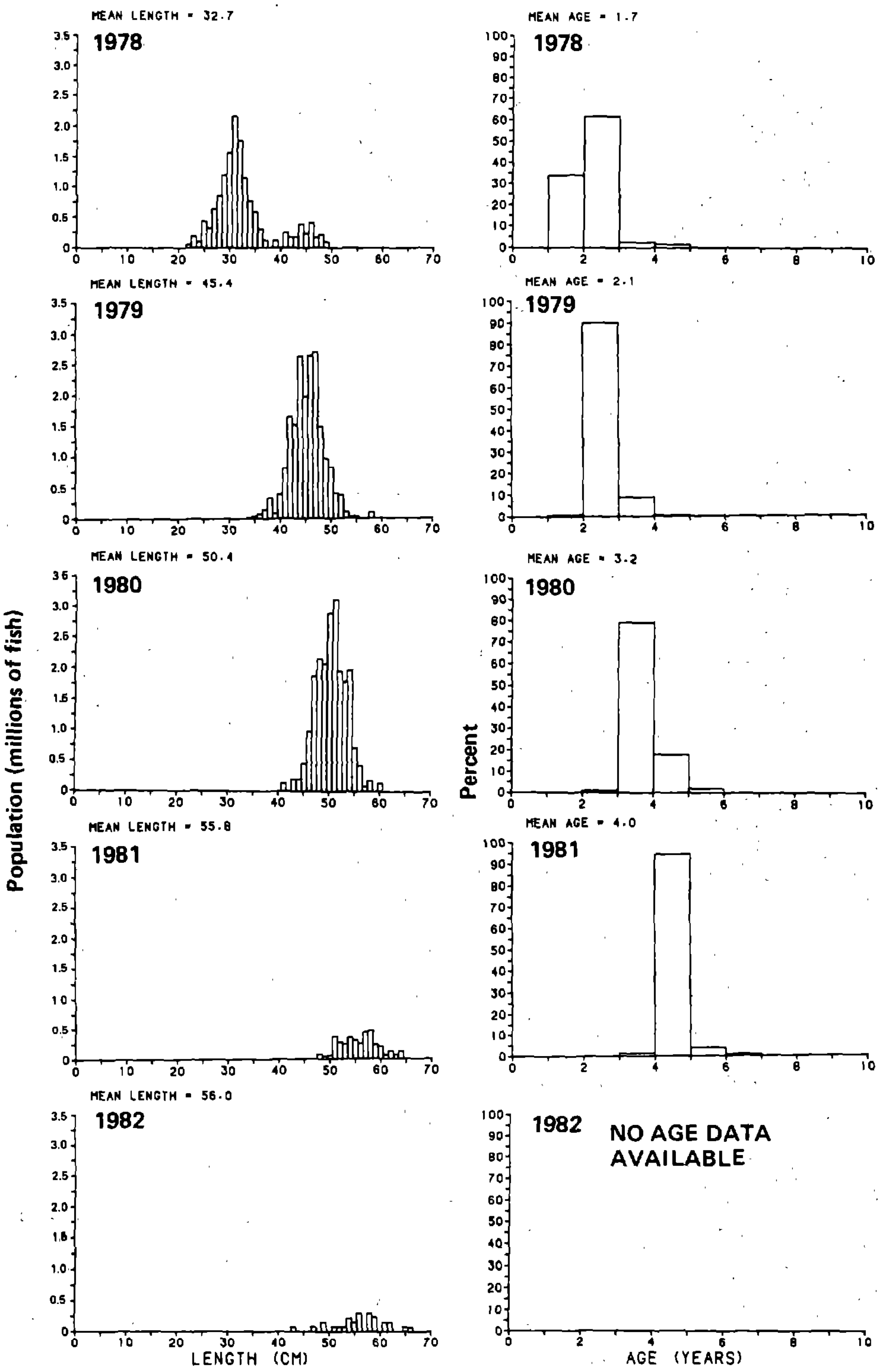


Figure 24.--Size and age composition of sablefish from the continental shelf area surveyed by U.S. research vessels, 1978-82. Age determinations for 1978 may be inaccurate due to differences in aging structures; scales were used in 1978, and otoliths were used in subsequent years (Umeda et al. 1983).

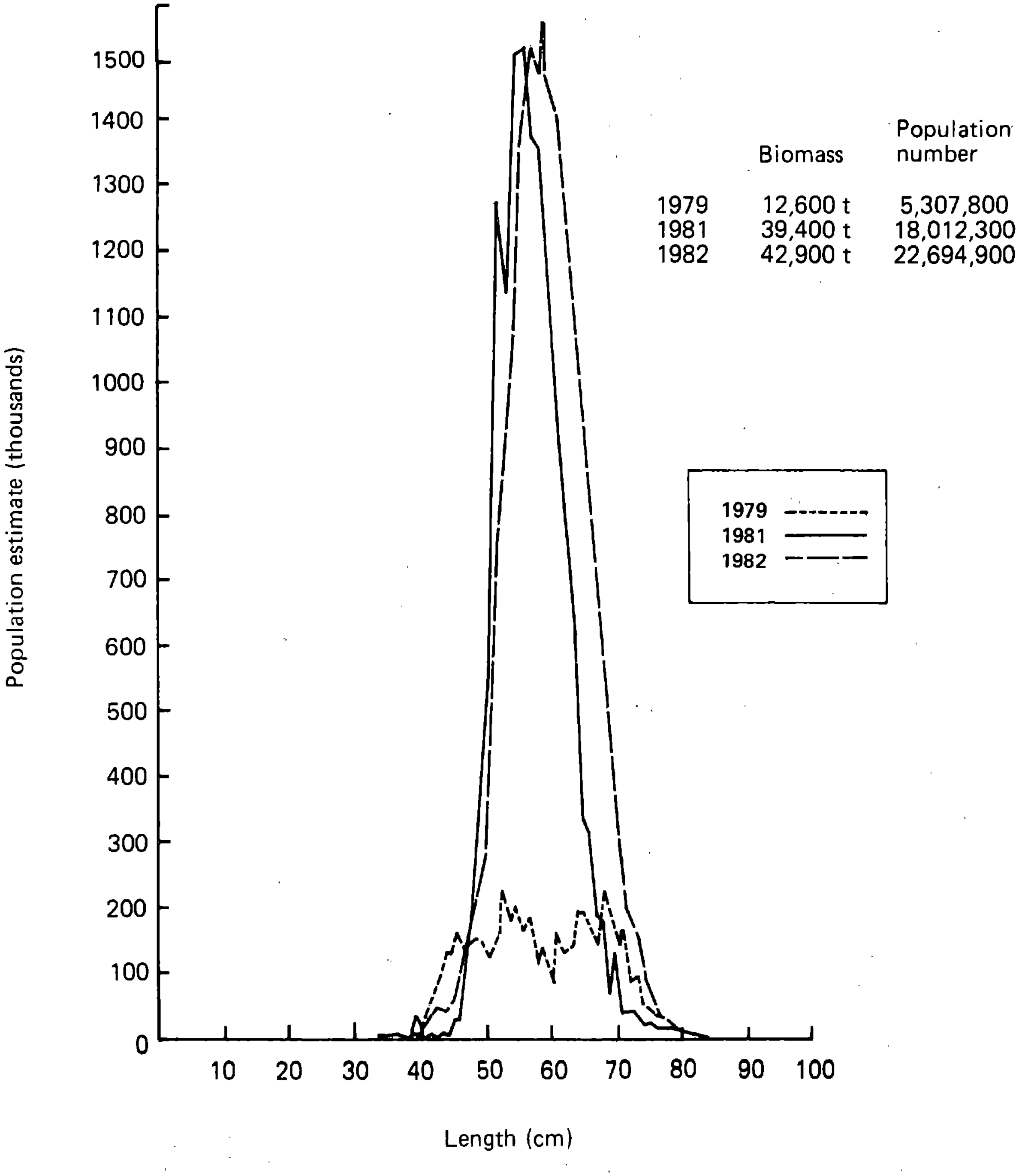


Figure 25.--Population estimates of sablefish by centimeter size interval on the continental slope of the eastern Bering Sea as shown by data from cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, 1982. Total estimated biomass and population number for the slope areas surveyed are also given.

Western Aleutians
173° E-180°
North of chain

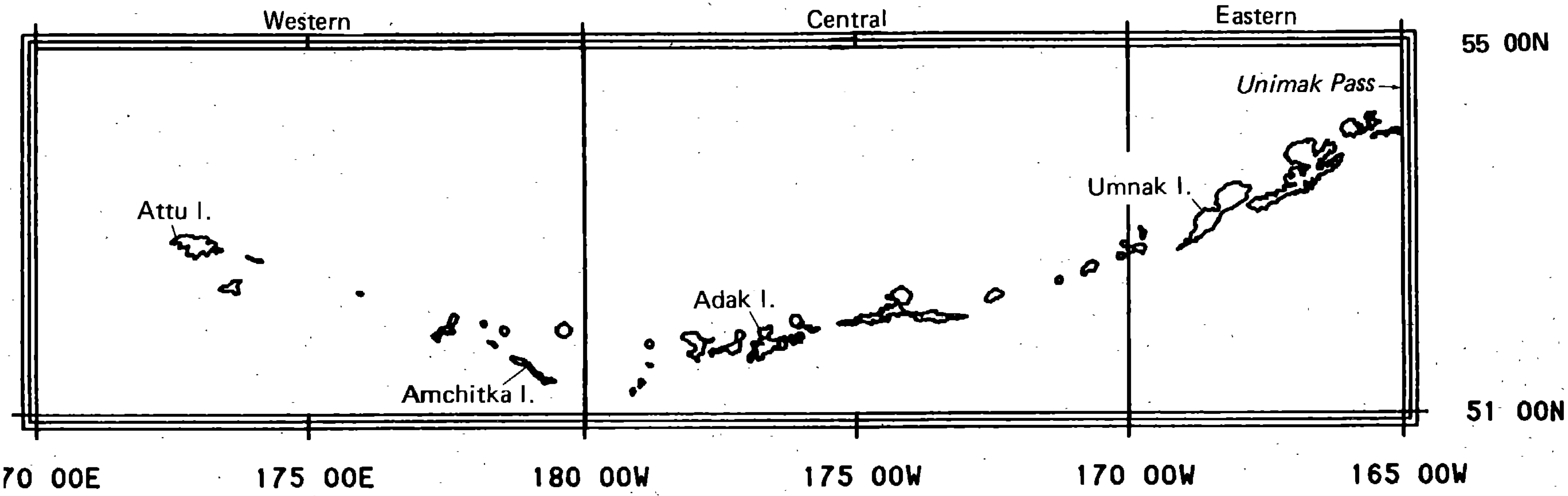
1980----- 2,100
1983----- 3,500

Central Aleutians
170° W-180°
North of chain

1980----- 10,100
1983----- 47,100

Eastern Aleutians
165° W-170° W
North of chain
(Bering Sea Area I)

1980----- 8,500
1983----- 9,900



Western Aleutians
173° E-180°
South of chain

1980----- 2,100
1983----- 3,600

Central Aleutians
170° W-180°
South of chain

1980------ 5,800
1983----- 14,300

Figure 26.--Biomass estimates of sablefish in metric tons (t) in the Aleutian Islands region, by area, as shown by 1980 and 1983 U.S.-Japan cooperative trawl survey data.

Historically the catches and trawl survey biomass estimates from the Aleutian region have been much lower than in the eastern Bering Sea (Tables 27, 28 and 32), indicating a lower biomass in the Aleutians. The recent trawl and longline surveys, along with fishery CPUE data, indicate a higher biomass in the Aleutian region as compared to the eastern Bering Sea.

MAXIMUM SUSTAINABLE YIELD

The long-term productivity of sablefish in each management region is believed to be related to the overall condition of the resource throughout its range from the Bering Sea to California. Based on this premise, U.S. scientists have estimated maximum sustainable yield (MSY) at 50,300 t for the Bering Sea to California region. This estimate is derived from a general production model. The MSY estimate has been apportioned to regions according to historical catches: Bering Sea, 25%; Aleutian region, 4%; Gulf of Alaska, 47%; and the British Columbia-Washington region, 25% (Low and Wespestad 1979). Therefore, MSY was estimated at 13,000 t in the Bering Sea and 2,100 t in the Aleutian region. Current CPUE and biomass trends indicate that MSY is probably overestimated in the Bering Sea and underestimated in the Aleutian region. The 13,000 t estimate for the Bering Sea includes areas 3 and 4 of the western Bering Sea. Therefore MSY for the eastern Bering Sea alone was less than 13,000 t.

Japanese scientists had estimated MSY for the overall North Pacific as 69,600 t based on the same general production model used by U.S. scientists, but using a different weighting of data among the regions (Sasaki 1978). Sasaki (1985b) recently reevaluated MSY for the waters from California to the eastern Bering Sea using a regression of CPUE on effort determined to be directed toward sablefish. He estimates MSY to be 81,878 t. Historical catches from California to the eastern Bering Sea have never exceeded 65,000 t and yet the stock has undergone declines. Sustained exploitation at the levels of 69,600 t or 81,878 t would therefore not seem possible.

EQUILIBRIUM YIELD

Estimated equilibrium yields (EY) in 1981 were 2,000 t for the eastern Bering Sea and 900 t for the Aleutian region. These values were estimated largely from trends in CPUE and catch. Since then, trawl survey data have become available for estimating the biomass of sablefish. Biomass was estimated to be 52,800 t in the eastern Bering Sea in 1982 and 68,500 t in the Aleutian region in 1983. Based on these biomass estimates, the exploitation rates at the 1981 EY levels would be 3.8 and 1.3% respectively.

Low exploitation rates and the recruitment of the strong 1977 year-class have improved stock conditions in both regions during 1981-83 from the low levels of abundance during 1977-80. Exploitation rates of 3.8 and 1.3% appear very conservative for sablefish. Sasaki (1985c) has suggested a sustainable exploitation rate of 5% to calculate EY which also seems conservative and should allow for continued rebuilding of the stocks. Applying this rate to the latest biomass estimates for the eastern Bering Sea in 1982 and for the Aleutian region in 1983, the EY for sablefish would be 2,600 t in the eastern Bering Sea and 3,400 t in the Aleutian region.

PACIFIC OCEAN PERCH

by

Daniel H. Ito

INTRODUCTION

Pacific ocean perch, *Sebastes alutus*, are found in commercial concentrations along the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Two main stocks have been identified in the Bering Sea by Chikuni (1975)--an eastern Bering Sea slope stock and an Aleutian Islands stock (Fig. 27). Delineation of these stocks was based on areal differences in growth rate and length-weight, age-length, and length-fecundity relationships of the adult populations. More recent information from biochemical genetic analyses, however, suggest that Pacific ocean perch do not form abrupt or discrete stock groups (Wishard and Gunderson 1981). Nevertheless, the two stocks described by Chikuni have been maintained by the North Pacific Fishery Management Council (NPFMC) as management units.

Pacific ocean perch were highly sought after by Japanese and Soviet fisheries and supported a major trawl fishery throughout the 1960s. This fishery began in the eastern Bering Sea slope region in about 1960 and by 1962 had expanded into the Aleutian region. Catches of Pacific ocean perch peaked in the eastern Bering Sea in 1961 at 47,000 t and in the Aleutian region in 1965 at 109,000 t (Table 33). Catches since then have declined substantially. In 1984, harvests were but a small fraction of peak levels: 290 t from the eastern Bering Sea slope region and 629 t from the Aleutian Islands region.

Reported catches of Pacific ocean perch probably included some catches of northern rockfish (S. *polyspinis*), rougheye rockfish (S. *aleutianus*), shortraker rockfish (S. *borealis*), and sharpchin rockfish (S. *zacentrus*). These four species are similar in color and physical characteristics to S. *alutus* and may have been misidentified as Pacific ocean perch in commercial catches. Beginning in 1979, the NPFMC permitted catches of these four species to be combined with S. *alutus* and reported as Pacific ocean perch. Of the five species which make up the Pacific ocean perch complex, S. *alutus* has been the most widely studied with respect to its distribution and biology. Because relatively little is known about the distribution and biology of the others, the analyses presented in this report deals almost exclusively with S. *alutus*.

CONDITION OF STOCKS

Eastern Bering Sea Region

Relative Abundance

Catch per unit effort (CPUE) data from Japanese trawl fisheries indicate that stock abundance has declined to very low levels in the eastern Bering sea (Tables 34, 35). However, CPUE data from these fisheries may not be a good

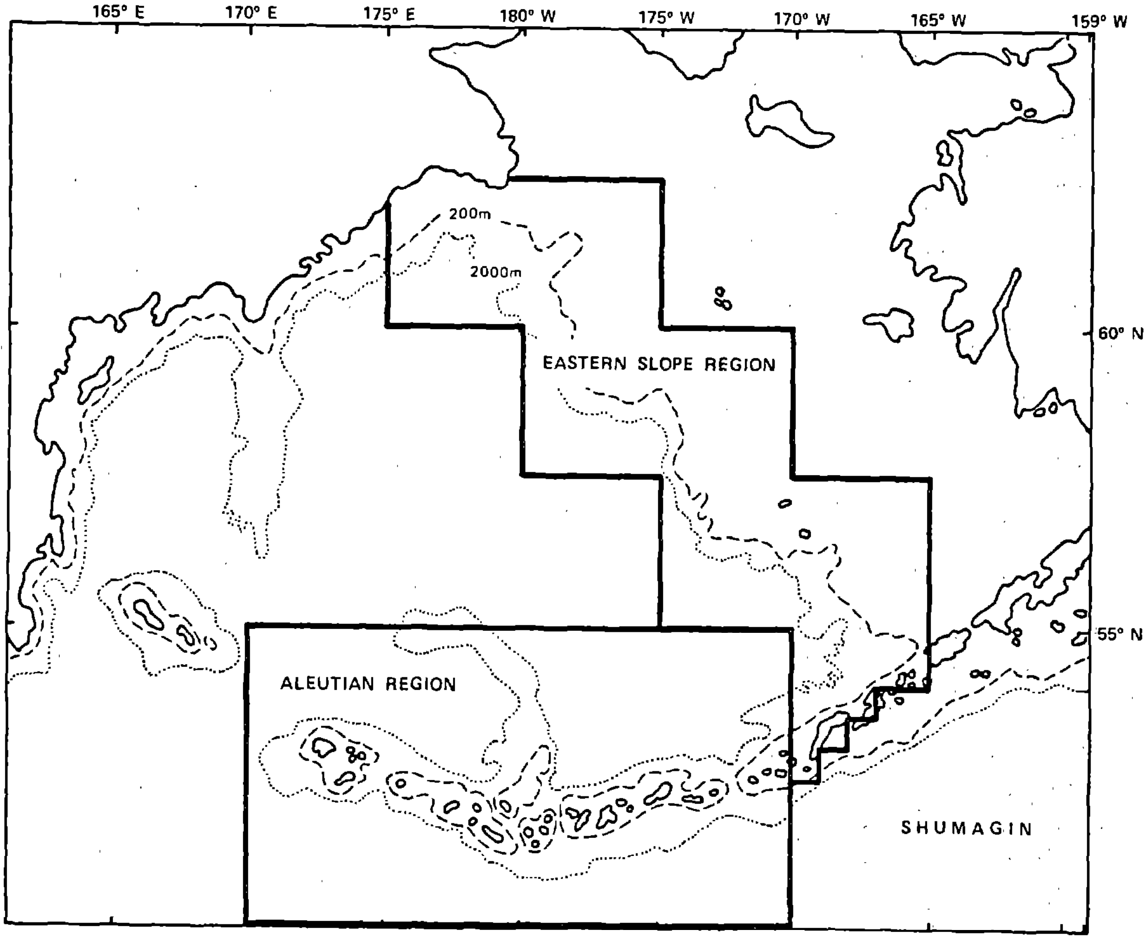


Figure 27. --The Bering Sea with the two proposed stock areas (regions) for Pacific ocean perch delineated.

Table 33.--Annual catch of Pacific ocean perch (Sebastes alutus) from the eastern Bering Sea and Aleutian Islands regions (thousands of metric tons).[a]

	Eastern Bering Sea				Aleutian Islands				Regions Combined			
Year	Japan[b]	USSR[c]	Other nations[d]	Total	Japan	USSR	Other nations	Total	Japan	USSR	Other nations	Total
1960	1.1	5.0	---	6.1	---	---	---	---	1.1	5.0	---	6.1
1961	13.0	34.0	---	47.0	---	---	---	---	13.0	34.0	---	47.0
1962	12.9	7.0	---	19.9	0.2	---	---	0.2	13.1	7.0	---	20.1
1963	17.5	7.0	---	24.5	0.8	20.0	---	20.8	18.3	27.0	---	45.3
1964	14.4	11.5	---	25.9	29.3	61.0	---	90.3	43.7	72.5	---	116.2
1965	7.8	9.0	---	16.8	38.1	71.0	---	109.1	45.9	80.0	---	125.9
1966	17.5	2.7	---	20.2	28.2	57.7	---	85.9	45.7	60.4	---	106.1
1967	19.6	---	---	19.6	9.3	46.6	---	55.9	28.9	46.6	---	75.5
1968	28.4	3.1	---	31.5	18.3	26.6	---	44.9	46.7	29.7	---	76.4
1969	14.5	0.0	---	14.5	15.6	23.2	---	38.8	30.1	23.2	---	53.3
1970	9.9	0.0	---	9.9	13.6	53.3	---	66.9	23.5	53.3	---	76.8
1971	9.8	0.0	---	9.8	14.6	7.2	---	21.8	24.4	7.2	---	31.6
1972	5.5	0.2	---	5.7	8.6	24.6	---	33.2	14.4	24.8	---	39.2
1973	2.7	1.0	---	3.7	9.3	2.5	---	11.8	12.0	3.5	---	15.5
1974	6.6	7.4	---	14.0	21.7	0.8	---	22.4	28.3	8.2	---	36.5
1975	3.2	5.4	---	8.6	8.5	8.1	---	16.6	11.7	13.5	---	25.2
1976	2.8	12.1	---	14.9	10.3	3.7	---	14.0	13.1	15.8	---	28.9
1977	2.7	3.5	0.4	6.6	5.7	0.1	0.1	5.9	8.4	3.6	0.5	12.5
1978	1.9	0.1	0.2	2.2	4.8	0.2	0.3	5.3	6.7	0.3	0.5	7.5
1979	1.6	Tr[e]	0.1	1.7	5.3	Tr[e]	0.2	5.5	6.9	Tr[e]	0.3	7.2
1980	--	--	--	1.1	--	--	--	4.7	--	--	--	5.8
1981	--	--	--	1.2	--	--	--	3.6	--	--	--	4.8
1982	--	--	--	0.2	--	--	--	1.0	--	--	--	1.2
1983	--	--	--	0.2	--	--	--	0.3	--	--	--	0.5
1984	--	--	--	0.3	--	--	--	0.6	--	--	--	0.9

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[a] Source: Bakkala et al. (1980) for catches through 1977; catches for 1978-84 are from U.S. observer program best-blend estimates (Nelson et al. 1979, 1980, 1981b, 1982, 1983a; Berger et al. 1984, 1985b).

[b] Catches from mothership-longline, North Pacific trawl, and landbased dragnet fisheries.

[c] May include some amounts of rockfishes, Sebastes spp., other than S. alutus.

[d] Republic of Korea, Taiwan, Poland, Federal Republic of Germany, and joint venture operations.

[e] Tr: Trace less than 58 t.

Table 34.--Pacific ocean perch (POP) catch and effort data from vessel class-4 stern trawlers of the Japanese mothership-longline North Pacific trawl fishery in the eastern Bering Sea Slope region, 1968-84[a]. Vessel class-4 stern trawlers have consistently taken Pacific ocean perch over the years.

Year	Catch of POP (t)	Catch of all species (t)	POP in total catch (%)	Total effort (h)	CPUE[b] of POP (kg/h)
1968	3,847	51,942	7.41	31,619	121.7
1969	3,709	68,341	5.43	29,590	125.4
1970	215	74,929	0.29	30,130	7.1
1971	1,558	96,829	1.61	41,257	37.8
1972	997	67,825	1.47	30,618	32.6
1973	422	82,438	0.51	27,995	15.1
1974	640	86,984	0.74	29,485	21.7
1975	578	99,330	0.58	42,115	13.7
1976	323	96,571	0.33	50,461	6.4
1977	385	71,221	0.54	48,424	7.9
1978	531	77,203	0.69	64,553	8.2
1979	731	66,713	1.10	56,179	13.0
1980	186	91,771	0.20	64,620	2.9
1981	289	97,869	0.30	64,165	4.5
1982	109	65,827	0.17	61,066	1.8
1983	118	74,522	0.16	64,635	1.8
1984	24	99,098	0.02	44,054	0.5

[a] 1973-84 vessel class-4 data converted to pre-1973 gross tonnage classification of 301-500 gross registered tons.

[b] CPUE = Catch per unit of effort.

Table 35.--Pacific ocean perch (POP) catch and effort data from stern trawlers of the Japanese land-based dragnet fishery in the eastern Bering Sea region, 1969-84.

Year	Catch of POP (t)	Catch of all species (t)	POP in total catch (%)	Total effort (h)	CPUE[a] of POP (kg/h)
1969	3,427	39,639	8.7	63,433	54.0
1970	3,643	48,205	7.6	85,325	42.7
1971	4,664	62,428	7.5	101,996	45.7
1972	1,587	71,853	2.2	121,241	13.1
1973	1,349	48,410	2.8	78,605	17.2
1974	3,045	65,410	4.7	110,240	27.6
1975	1,666	61,019	2.7	120,981	13.8
1976	1,115	56,841	2.0	131,869	8.5
1977	1,052	68,532	1.5	142,479	7.4
1978	414	82,106	0.5	133,838	3.1
1979	492	57,363	0.9	99,431	5.0
1980	178	61,325	0.3	116,839	1.5
1981	234	63,409	0.4	115,822	2.0
1982	148	54,696	0.3	126,419	1.2
1983	25	43,162	0.1	117,847	0.2
1984	219	45,733	0.5	56,483	3.9

[a] CPUE = catch per unit of effort.

index of stock abundance in recent years, because most of the fishing effort in the eastern Bering Sea is now directed to species other than pacific ocean perch. Nevertheless, overall fishing effort remains high in areas where Pacific ocean perch are commonly found, and the low incidental catches of this species support the evidence from the CPUE data that stock abundance is at a low level.

To examine catch and CPUE trends in greater detail, the eastern Bering Sea was subdivided into two areas; P and Z (Fig. 28). Subarea P generally accounted for most of the Pacific ocean perch harvest; catches peaked in both areas in 1968 but declined rapidly thereafter (Table 36). Currently, this species comprises only a minor fraction of the total groundfish catch relative to its importance in earlier years.

In subareas P and Z, CPUE has declined precipitously since the early 1960s (Table 36). Recent values, however, may not be satisfactory indices of stock abundance because Pacific ocean perch is no longer a major target species in either subarea. Within the past 13 yr, this species never comprised more than 0.63% of the total groundfish catch. As mentioned previously, total trawl effort remains high and incidental catches of Pacific ocean perch remain extremely low, suggesting a depressed stock condition.

Estimates of Absolute Abundance

Trawl Surveys--Data from the 1979, 1981, and 1982 cooperative trawl surveys by the Northwest and Alaska Fisheries Center (NWAFC) and the Fisheries Agency of Japan provide biomass estimates for Pacific ocean perch in the eastern Bering Sea. These surveys were conducted both on the continental shelf and the continental slope, but almost all catches of Pacific ocean perch were taken by Japanese research trawlers fishing on the slope at depths greater than 200 m. For this reason, only data collected by Japanese vessels were employed to calculate Pacific ocean perch abundance estimates.

Shelf waters only were sampled by the NWAFC in 1983 and 1984, and these survey data were not useful for assessing population changes of Pacific ocean perch. Both the continental shelf and slope of the eastern Bering Sea were again sampled during the 1985 U.S.-Japan cooperative trawl survey. However, these data were not yet available for analysis at the time of this writing.

Survey results from the eastern Bering Sea slope region indicate that biomass increased from 4,459 t in 1979 to 9,821 t in 1981 and then decreased to 5,505 t in 1982 (Table 37); population numbers parallel this trend. These estimates, however, were characterized by relatively wide variances. The 95% confidence intervals overlapped extensively, indicating that the point estimates may not be significantly different;

The surveys conducted in 1979, 1981, and 1982 did not sample the Aleutian Islands (long. 165° W to 170° W) portion of the eastern Bering Sea management area. This area, however, was sampled during the 1980 and 1983 U.S.-Japan trawl surveys of the Aleutian Islands which provided biomass estimates of about 7,000 t and 95,000 t, respectively. Because of the wide variances of these latter estimates, a conservative approach was taken in estimating biomass for the entire eastern Bering Sea region (13,600 t) by using the 1980 point estimate from the Aleutian Islands segment and the average of the 1979-82 estimates from the eastern Bering Sea slope.

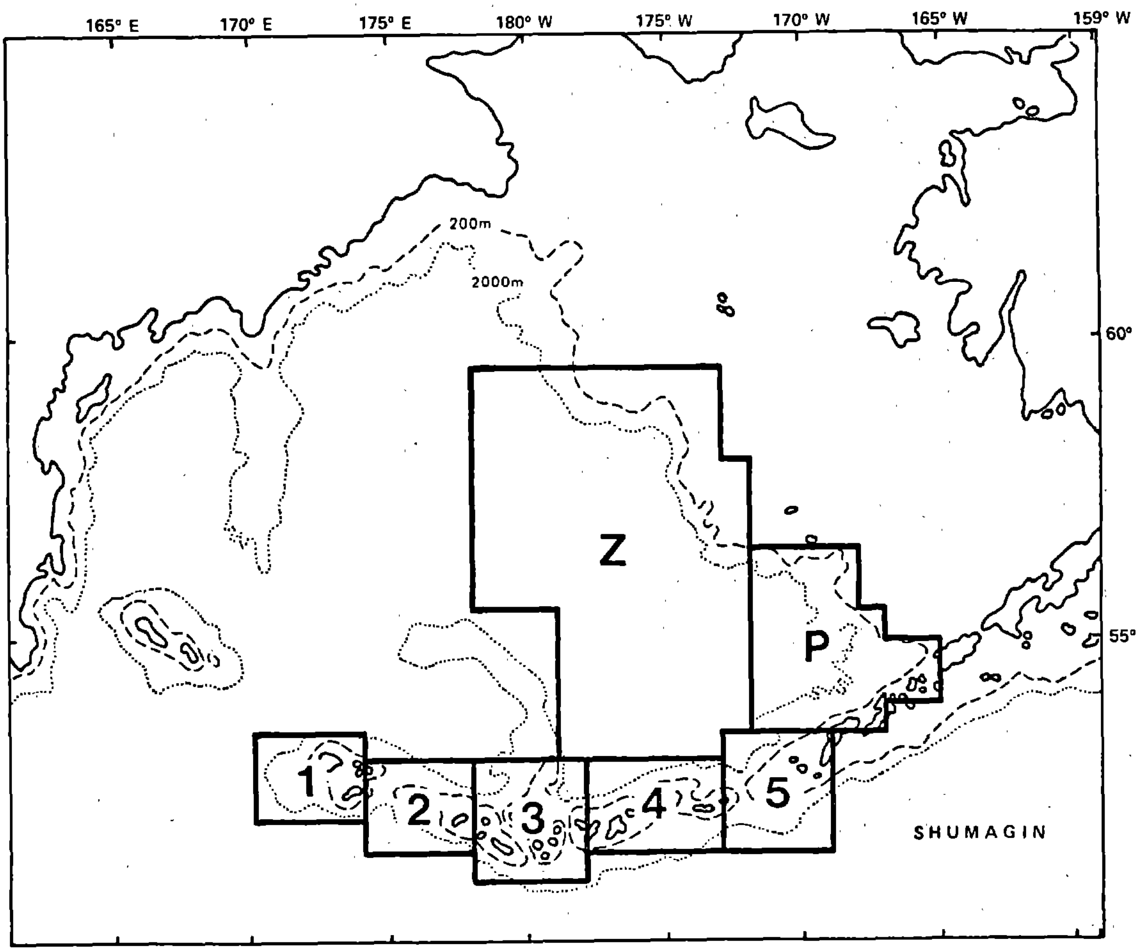

Figure 28.--Subdivisions of the eastern Bering Sea and Aleutian Islands region used to examine trends of catch and catch per unit of effort (CPUE) for Pacific ocean perch.

Table 36.--Annual catch of Pacific ocean perch (POP), total catch of all species combined, percentage of POP in the total groundfish catch, total trawl effort, and catch per unit of effort (CPUE) from the Japanese mothership-longline North Pacific trawl fishery for the eastern Bering Sea subareas (stern trawls only) 1963-84.

	Subarea P					Subarea Z				
Year	POP catch (t)	Total catch (t)	% POP	Total effort (h)	POP CPUE (kg/h)	POP catch (t)	Total catch (t)	% POP	Total effort (h)	POP CPUE (kg/h)
1963	559	1,350	41.41	324	1,725.3	381	943	40.40	189	2,015.9
1964	517	965	53.58	250	2,068.0	51	593	8.60	126	404.8
1965	2,133	7,127	29.93	1,135	1,879.3	49	205	23.90	73	671.2
1966	1,962	22,954	8.55	2,850	688.4	586	2,262	25.91	771	760.0
1967	4,889	116,233	4.21	14,785	330.7	3,492	14,852	23.51	3,366	1,037.4
1968	12,603	161,562	7.80	23,626	533.4	5,781	75,042	7.70	23,443	246.6
1969	6,144	306,786	2.00	35,483	173.2	3,867	55,194	7.01	18,367	210.5
1970	3,693	285,093	1.30	31,505	117.2	1,532	153,145	1.00	26,911	56.9
1971	2,505	466,882	0.54	48,541	51.6	1,538	221,665	0.69	42,579	36.1
1972	1,879	351,855	0.53	47,018	40.0	846	193,680	0.44	27,938	30.3
1973	509	155,881	0.33	24,006	21.2	363	407,696	0.09	43,196	8.4
1974	1,132	324,262	0.35	52,604	21.5	659	225,177	0.29	32,988	20.0
1975	414	326,588	0.13	51,719	8.0	916	224,139	0.41	46,155	19.8
1976	582	268,044	0.22	52,457	11.1	438	155,983	0.28	32,831	13.3
1977	831	132,526	0.63	33,890	24.5	314	149,915	0.21	30,511	10.3
1978	725	128,833	0.56	43,884	16.5	423	139,216	0.30	25,557	16.6
1979	855	169,595	0.50	46,386	18.4	120	103,846	0.12	21,403	5.6
1980	190	180,879	0.10	47,694	4.0	12	111,290	0.01	23,202	0.5
1981	191	186,887	0.10	52,144	3.7	14	88,918	0.02	17,026	0.8
1982	126	130,059	0.10	48,502	2.6	2	75,369	0.00	15,827	0.1
1983	41	108,145	0.04	43,747	0.9	5	136,823	0.00	22,426	0.2
1984	30	62,178	0.05	25,673	1.2	3	132,549	0.00	15,007	0.2

Table 37.--Estimated catch per unit effort (CPUE), population numbers, and biomass of Pacific ocean perch in the eastern Bering Sea region as shown by data from cooperative U.S.-Japan trawl surveys in 1979-82 and a trawl survey conducted by Japan in 1969.

		Mean Estimates[a]			
Depth strata	Year	CPUE (kg/ha)[b]	Population numbers (millions)	Biomass (t)	95% confidence intervals for biomass estimates (t)
100-1000 m	1979	1.20	6.322	4,459	0 - 9,217
	1981	2.63	14.317	9,821	5,567 - 14,074
	1982	1.48	7.781	5,505	3,074 - 7,937
189-366 m	1969	22.64	--	31,329	12,732 - 49,926
	1979	3.15	6.273	4,363	--
	1981	5.41	10.814	7,486	4,065 - 10,908
	1982	3.80	7.490	5,254	2,834 - 7,673

[a] These estimates do not represent the entire eastern Bering Sea region. The Aleutian Islands portion (165° W to 170° W long.) of this region was not covered by the 1979-82 U.S.-Japan cooperative trawl surveys.

[b] ha = hectare.

A Japanese groundfish survey conducted in 1969 along the eastern Bering Sea slope provided sufficient information to estimate Pacific ocean perch biomass within the 189-366 m (100-200 fathom) depth strata. Biomass estimates were also calculated for this depth strata from the 1979-82 survey. data. Although the sampling design and trawl gear differed between the 1969 and 1979-82 surveys, the data should still provide an approximation of changes in abundance between the two periods. The data indicate that Pacific ocean perch biomass fell approximately 86% during the 10-yr period from 1969 to 1979 (Table 37). This decline approximates that shown by CPUE data from the fishery.

Survey data probably underestimate the true population size of Pacific ocean perch. As pointed out by Bakkala et al. (1982), this species is known to occupy the water column above that sampled by bottom trawls and also is known to inhabit areas of rough bottom which were avoided during the surveys to prevent damage to the trawls.

Cohort Analysis--Commercial CPUE data have become increasingly difficult to interpret. Standardizing and partitioning total groundfish effort into effort directed solely toward Pacific ocean perch is extremely difficult, particularly with effort data from the eastern Bering Sea. Increased quota restrictions, shifts in effort to different target species, and rapid improvements in fishing technology have confounded the estimation of effective fishing effort. These factors must be considered if CPUE is to accurately reflect changes in stock abundance.

An alternative to fishery CPUE and trawl survey stock assessments is cohort analysis. Cohort analysis techniques have been developed to circumvent the need for reliable effort statistics. These techniques estimate past population numbers and biomass at age and age-specific rates of instantaneous fishing mortality. Historical catch-at-age data, an estimate of natural mortality (M), and an estimate of terminal fishing mortality (F(t)) for each year-class are required for the analysis.

Ito (1982) applied cohort analysis to catch-at-age data from the eastern Bering Sea fishery based on the equations of Pope (1972). Catch and age data (1963-79) were derived from Chikuni (1975), foreign reported catches, and U.S. observer data bases. Natural and terminal fishing mortalities were estimated from the literature. Assuming M = 0.15 and F(t) = 0.35 represented reasonable estimates, mean stock biomass in the eastern Bering Sea was estimated to have declined from 201,461 t in 1963 to 30,970 t in 1976, a reduction of about 85%.

Because of the uncertainty regarding the true values of the input parameters (M and F(t)), Ito (1982) examined the effect of other values of M and F(t) on results of the cohort analysis. Natural mortality (M) values used were 0.05, 0.10, 0.15, 0.20, and 0.30. The values of F(t) employed were 0.175, 0.350, 0.525, 0.700, and 1.050. Based on the literature, these values encompassed the conceivable range for the model parameters. Twenty-five computer runs were necessary to accommodate all possible combinations of these trial values.

The paired values of M= 0.05, F(t) = 1.050 and M = 0.30, F(t) = 0.175 yielded the lowest and highest estimates respectively of stock abundance for any given year. Abundance estimates based on these two sets of parameter values established a "range" about the most likely (M = 0.15, F(t) = 0.350) population estimate. The trend in mean biomass, regardless of the parameter set employed, was downward (Fig. 29). When M = 0.30 and F(t) = 0.175 were used, the decline in biomass was much steeper than when the other two parameter sets were employed. Overall, the abundance estimates were highly sensitive to changes in M, more so than to changes in F(t).

Virtual Population Analysis (VPA)--The data from Ito's (1982) cohort analysis was reexamined using Gulland's (1965) virtual population analysis (VPA). In Ito's analysis, a terminal fishing mortality (F(t)) value was required for every cohort being analyzed. The VPA technique used in this study, however, requires only one estimate of fishing mortality to begin the computations. This is accomplished by applying a given F-value to an age group in a single cohort and then linking the other cohorts by assuming different ages were fished at the same rate in the same year. The method of linking cohorts is described in greater detail by Tagart (1982).

For all VPA runs, natural mortality was assumed to equal 0.15. This figure seems reasonable assuming that Pacific ocean perch do not live greater than 25-38 yr. A range of F-values was used to initiate the VPA computations because precise estimates of F were not known. The values employed for the eastern Bering Sea stock ranged from 0.05 to 1.00. Although these values were chosen somewhat arbitrarily, they were believed to encompass the range of conceivable F-values for this stock. The linking of the cohorts was structured so as to fully utilize the convergence properties of VPA.

The VPA results, like those from cohort analysis, indicated a long-term decreasing trend in biomass for the eastern Bering Sea stock (Fig. 30). Depending on the initial F-value chosen, this stock declined 60.4-98.8% during the 16-yr period from 1963 to 1979. Regardless of the F-value used, however, the resulting biomass trends converged back toward a level of about 188,000 t. This convergence point is probably a good estimate of virgin biomass assuming, of course, that M = 0.15 and the catch-at-age data are accurate.

Given an estimate of the virgin stock biomass, maximum sustainable yield (MSY) can be estimated as:

$$MSY = 0.5\ M\ B_o,$$

where M = natural mortality rate and B_o = the virgin (unexploited) biomass of the exploitable stock. The B_o estimate was calculated by assuming knife-edge recruitment at 9 yr and summing the age-specific biomass estimates from ages 9 to 20 yr from the VPA results for the earliest year in the data series. Because the VPA analysis was executed with a range of F-values, the above summing procedure was done to obtain the corresponding range of exploitable virgin biomasses. The B_o value used in the MSY calculation was taken as the midpoint of this range, 134,000 t in 1963. Assuming M = 0.15, MSY was estimated at about 10,050 t for the eastern Bering Sea stock.

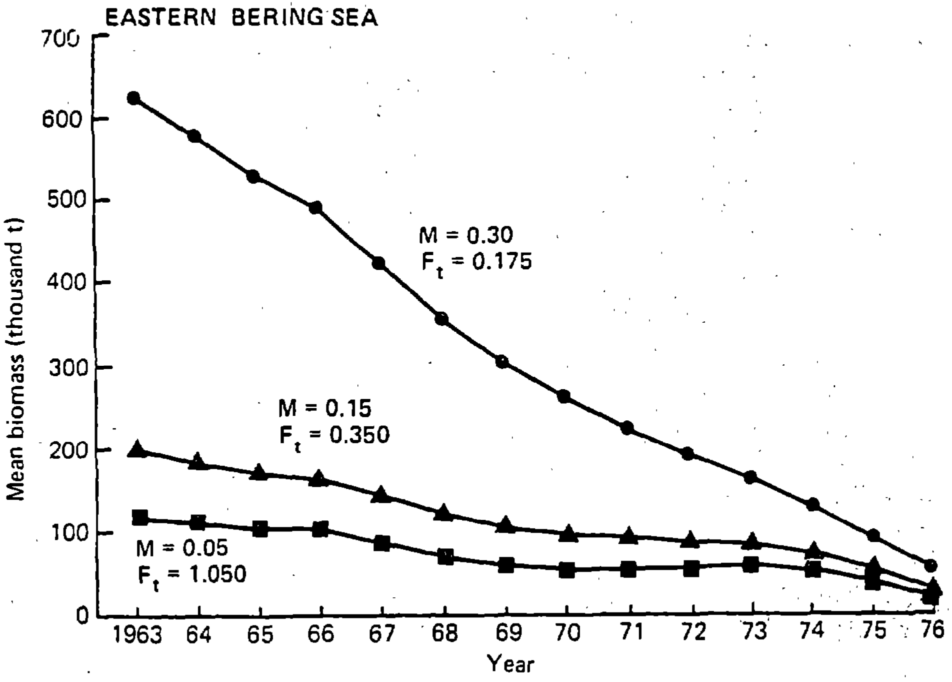

Figure 29.--Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by cohort analyses using various estimates of natural (M) and terminal fishing mortalities (F_t).

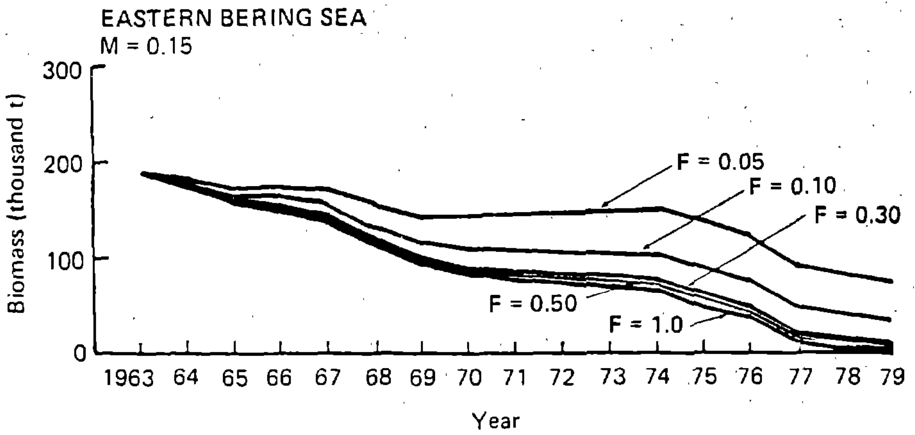

Figure 30.-Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by virtual population analyses. using various estimates of fishing mortalities (F).

Age composition employed in the cohort and virtual population analyses were based on data from Chikuni (1975) and the U.S. observer program. Although these data were assumed accurate, recent aging studies indicate that Pacific ocean perch may be much older than previously thought (Beamish 1979; Archibald et al. 1981; Chilton and Beamish 1982). It is beyond the scope of the present report, however, to discuss the consequences of incorrect age data on the cohort and virtual population analysis results.

Stock Reduction Analysis (SRA)--Kimura and Tagart (1982) developed a biomass-based method of stock assessment (SRA) that links the exponential form of the catch equations when age data are insufficient or unavailable. Essentially, given n years of catch data (in biomass) and an estimate of M, SRA provides estimates of B(1) (the initial population biomass); P (the ratio of final biomass to initial biomass); and R (recruitment biomass), consistent with the catch history and expected levels of recruitment. Independent estimates of any of these factors (e.g., modeling, hydroacoustic surveys, or analysis of CPUE) can then be used to provide new estimates or be examined in relation to other factors for consistency. The basic SRA model was further modified to explicitly incorporate growth and variable recruitment (Kimura et al. 1984), as well as to allow for forecasting of stock biomass (Kimura 1984).

Although SRA does not require detailed age composition data, estimates of the age at recruitment, the natural mortality rate, and the Brody growth coefficient are required. The age at recruitment was assumed to be k = 9 yr aid natural mortality M = 0.05 (Archibald et al. 1981). Growth data from Archibald et al. (1983) was used to estimate a Brody weight coefficient of p= 0.38. These parameter values are consistent with the older ages derived from sectioned and break/burned otoliths.

Balsiger et al. (1985) carried out the SRA under a variety of model parameters. The results from each parameter set provided an historical trace of the fishable biomass (Fig. 31,). With the exception. of the constant recruitment scenario, the results indicated that the stock has maintained itself at a fairly low but constant level since the early 1970s. Under the constant recruitment condition (i.e., r = 0.0), biomass appears to have increased since 1977. Although this suggests that the stock is rebuilding, the reader should keep in mind that a constant recruitment scenario reflects the most optimistic view. That is, recruitment to the fishable biomass will be the same year after year regardless of the population size.

The results also indicated that the virgin fishable biomass in the eastern Bering Sea was between 210,000 and 27,0,000 t. This is not a statistical interval, but an interval consistent with various model parameter scenarios.

Sustainable yield curves (Fig. 32) were calculated using the formulas described in Kimura et al. (1984). Estimates of MSY were then taken as the peak on each curve (i.e., curves where r = 0.5). Under the constant recruitment scenario (i.e., r = 0.0), MSY was estimated at the point on the curve where F = M. The F = M constraint was employed because it is unrealistic to assume that recruitment would remain constant at low biomass levels and because of the precedence of this relationship in the groundfish stock assessment literature (Gulland 1970; Francis 1974). The high estimate of MSY was obtained under the constant recruitment situation; this estimate amounted to

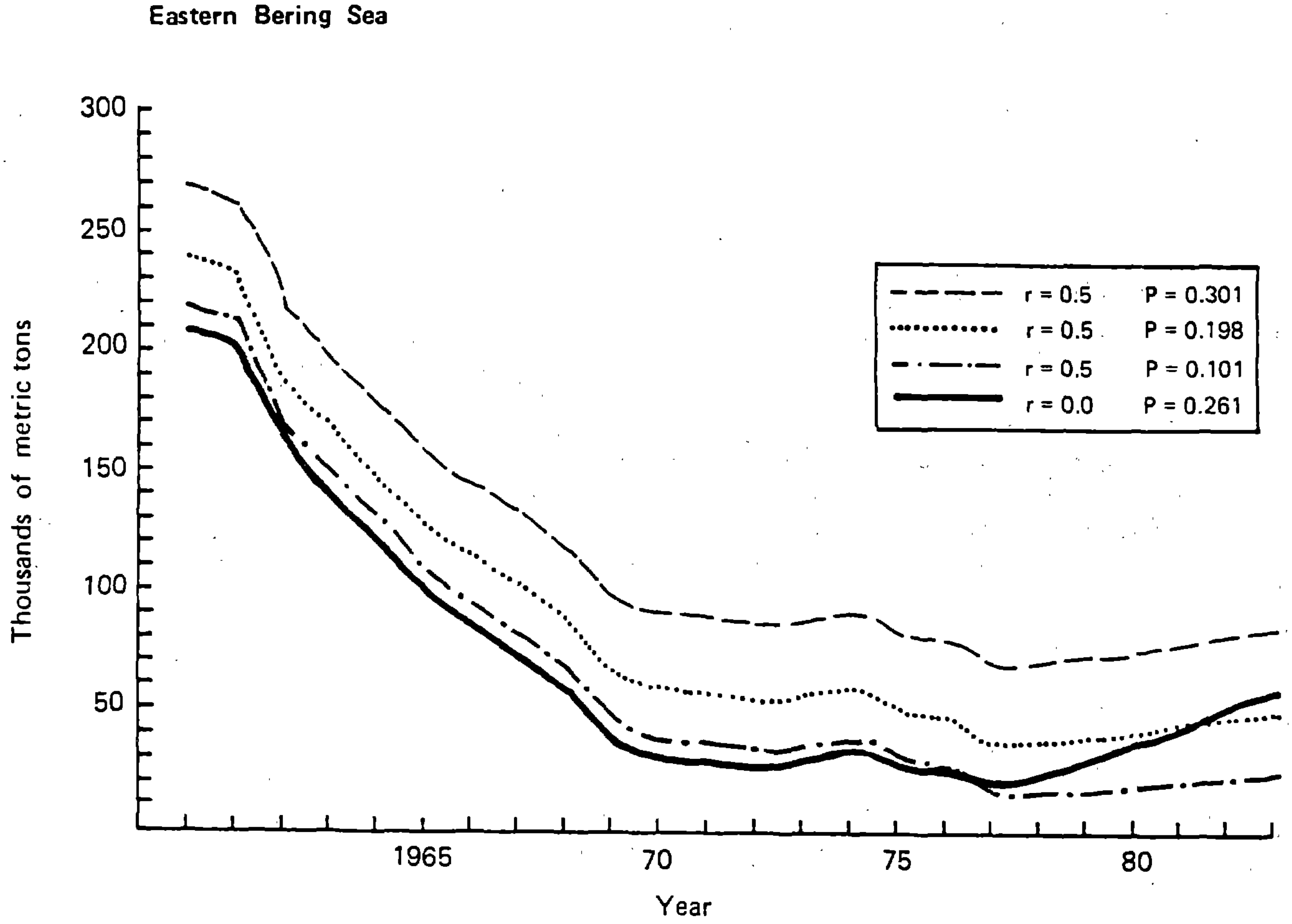

Figure 31.--Estimated population biomass for Pacific ocean perch from the eastern Bering Sea region (assuming M = 0.05 p = 0.38) over time for various SRA fits (from Balsiger et al. 1985).

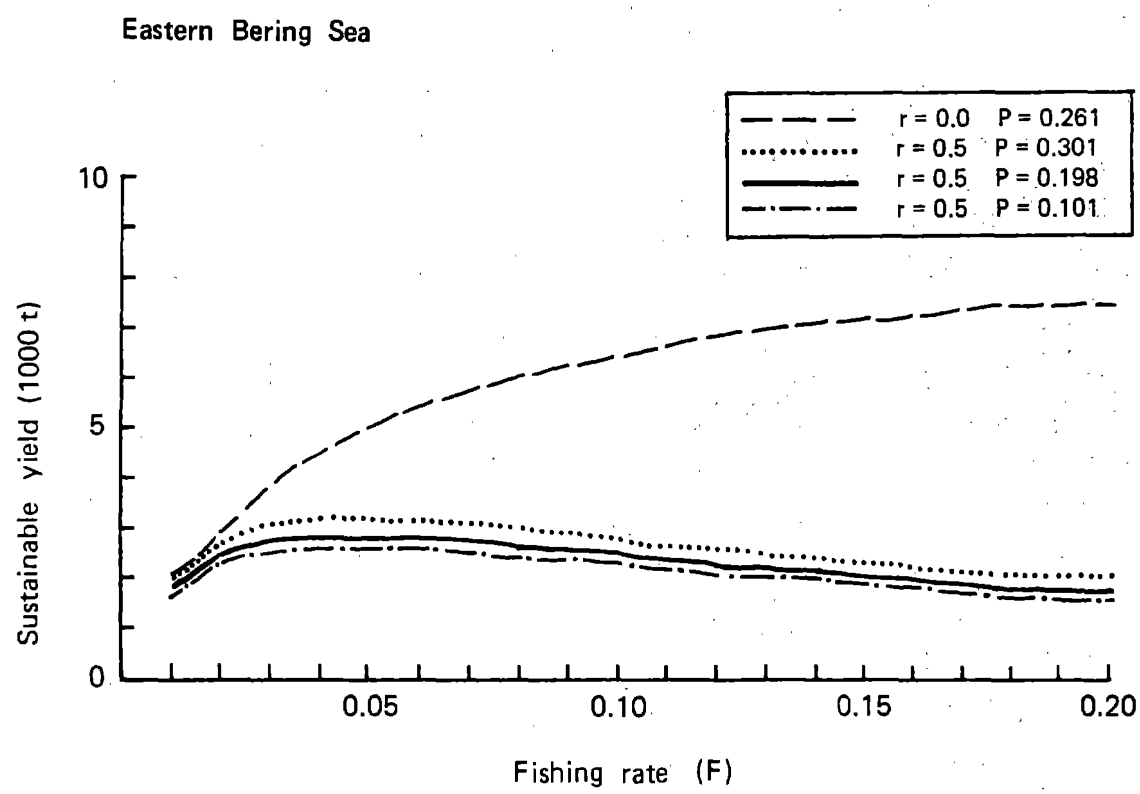

Figure 32.--Estimated sustainable yield for Pacific ocean perch from the eastern Bering Sea region (assuming M = 0.05 and p = 0.38) for a given fixed instantaneous fishing mortality rate F, calculated for various SRA fits (from Balsiger et al. 1985).

4,984 t. A low estimate of MSY was calculated by assuming a P value of about 0.20 with moderate recruitment (i.e., r = 0.5). The estimate in this case totaled 2,840 t. One property of SRA relevant here is that if r = 1.0, no sustainable yield is possible regardless of the value of P.

Length and Age Composition

Length data collected by Japan during the U.S.-Japan trawl surveys show that Pacific ocean perch ranged in length from 10 to 56 cm; the average lengths in 1979, 1981, and 1982 were 36.4, 34.0, and 35.0 cm, respectively. The 1981 and 1982 length distributions suggest the possible recruitment of a relatively strong year-class (Fig. 33). This recruitment is shown by modal peaks at 26 cm in 1981 and 28 cm in 1982. The relative strength of this year-class cannot be determined because of the absence of comparative data for year other than 1979.

To determine the year-class represented by the incoming modes in 1981 and 1982, modal peak lengths were inserted into the von Bertalanffy growth equation with growth parameters calculated by Ito (1982) and Chikuni (1975) and the equation solved for age. The age represented by the 1981 mode was between 5.88 and 6.63 yr, based on the two sets of growth parameters. The 1982 mode represented an age between 6.81 and 7.63 yr. Assuming the mode in 1981 represented an age of 6 yr and in 1982 an age of 7 yr, the modes would represent the 1975 year-class.

Aleutian Islands Region

Relative Abundance

The CPUE data from stern trawlers of the Japanese mothership, longline, and North Pacific trawl fisheries suggest that abundance in the Aleutian region has declined to very low levels (Table 38). Vessels of classes 4 and 7, which account for the majority of the Pacific ocean perch catch by stern trawlers, show drastic reductions in CPUE. From 1969 to 1979, the CPUE of vessel class 4 dropped 94.6% and has remained at or below the 1979 level for the past 6 yr. Vessel class 7 CPUE reached its lowest level in 1984, falling 98.4% from its peak level in 1968.

Catch and effort data from the landbased dragnet fishery also indicate decreasing stock abundance. Catch per unit of effort fell from 322.7 kg/h (h) in 1969 to 5.3 kg/h in 1984 (Table 39). The CPUE data from 1977 to 1984, however, may not be a reliable index of population size because the proportion of Pacific ocean perch in catches was low during this period, accounting for less than 5% of the total catch of all species combined.

Catch rate information collected by U.S. observers aboard Japanese small trawlers (<1,500 gross tons) indicate that abundance has continued to decline since 1977 (Table 40). The CPUE in units of kg/day and kg/h fell 98.7 and 98.3%, respectively, from 1977 to 1984. With the exception of 1982 and 1983, Pacific ocean perch ranked among the top six species in the catch by small trawlers. For years other than 1982 and 1983, CPUE should be a fairly good index of stock size.

The Aleutian region was subdivided into five areas (Fig. 28) to examine catch and CPUE trends in greater detail. Annual CPUE was calculated based on data from all stern trawlers combined in the Japanese mothership-longline-

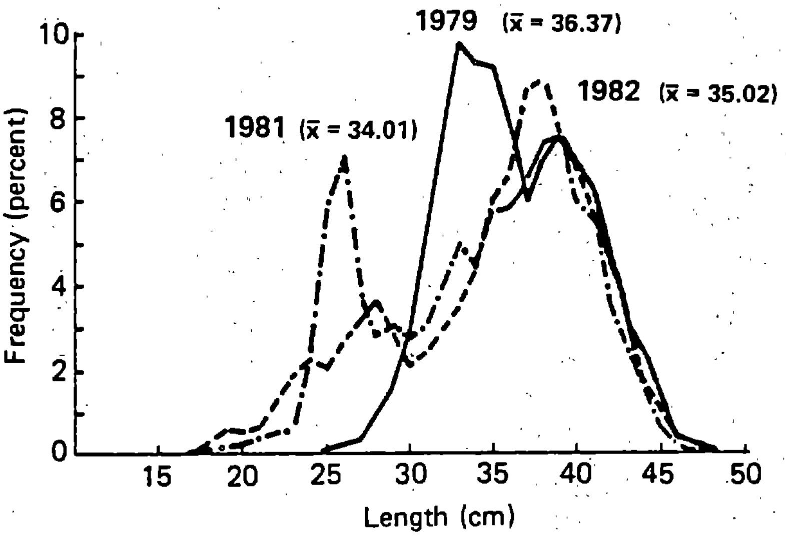

Figure 33.--Size composition of Pacific ocean perch in the eastern Bering Sea as shown by data collected on Japanese trawlers during the cooperative U.S.-Japan demersal trawl surveys in 1979, 1981 and 1982.

Table 38.--Pacific ocean perch catch and effort data from stern trawlers of the Japanese mothership-longline-North Pacific trawl fishery in the Aleutian region, by vessel class, 1968-84.

	Vessel class[a]					
Year	4	5	6	7	8	9
(A) Catch (metric tons, t)						
1968	12,157	280	32	2,711	6,787	532
1969	7,290	440	0	4,839	1,125	144
1970	2,384	1,227	0	7,741	249	82
1971	3,322	889	1,038	4,984	2,249	449
1972	3,527	1,318	645	2,035	188	135
1973	4,596	0	995	1,881	0	0
1974	10,679	1,564	1,326	2,507	25	16
1975	3,916	972	764	1,815	666	0
1976	4,862	838	786	1,600	83	0
1977	2,802	771	219	580	37	0
1978	2,342	480	140	855	183	0
1979	2,265	691	50	696	141	16
1980	1,733	188	6	420	56	79
1981	1,590	279	96	298	2	46
1982	325	103	252	284	13	0
1983	234	41	116	116	15	9
1984	121	0	--	42	--	3
(B) Fishing effort (hours trawled)						
1968	8,575	155	8	216	759	772
1969	1,952	333	0	910	178	38
1970	1,755	600	0	976	161	25
1971	4,546	634	383	720	785	174
1972	6,533	546	492	388	114	56
1973	3,989	0	658	530	36	0
1974	13,908	1,816	964	529	70	22
1975	12,333	1,233	543	521	509	0
1976	10,179	897	698	561	251	0
1977	7,594	1,095	248	400	89	0
1978	8,820	957	206	595	315	0
1979	9,484	1,097	67	631	213	29
1980	7,303	325	12	387	211	778
1981	8,920	1,206	376	561	481	318
1982	6,607	889	1,003	228	516	236
1983	5,550	1,163	538	320	127	361
1984	1,610	103	--	196	--	315

Table 38. --Continued.

	Vessel class[a]					
Year	4	5	6	7	8	9
(C) Catch per unit of effort (t per hour trawled)						
1968	1.4	2.4	4.0	12.6	8.9	0.7
1969	3.7	1.3	--	5.3	6.3	3.8
1970	1.4	2.0	--	7.9	1.5	3.3
1971	0.7	1.4	2.7	6.9	2.9	2.6
1972	0.5	2.4	1.3	5.2	1.6	2.4
1973	1.2	--	1.5	3.5	--	--
1974	0.8	0.9	1.4	4.7	0.4	0.7
1975	0.3	0.8	1.4	3.5	1.3	--
1976	0.5	0.9	1.1	2.9	0.3	--
1977	0.4	0.7	0.9	1.5	0.4	--
1978	0.3	0.5	0.7	1.4	0.6	--
1979	0.2	0.6	0.7	1.1	0.7	0.6
1980	0.2	0.6	0.5	1.1	0.3	0.1
1981	0.2	0.2	0.3	0.5	0.0	0.1
1982	Tr[b]	0.1	0.3	1.2	Tr[b]	0.0
1983	Tr[b]	Tr[b]	0.2	0.4	0.1	Tr[b]
1984	0.1	0	--	0.2	--	Tr[b]

[a] 1973-84 data converted to pre-1973 gross tonnage classification of:
4 = 301-501 7 = 1,501-2,500
5 = 501-1,000 8 = 2,501-3,500
6 = 1,001-1,500 9 = 3,501 and above

[b] Less than 0.1.

Table 39.--Pacific ocean perch (POP) catch and effort;data from stern trawlers of the Japanese landbased:dragnet fishery in the Aleutian region, 1969-84.

Year	Catch of Pacific ocean perch (t)	Catch of all species (t)	POP in total catch (%)	Total effort (h)	CPUE[a] of POP (kg/h)
1969	1,246	5,478	22.7	3,861	322.7
1970	1,956	4,549	43.0	5,079	385.1
1971	1,664	5,977	27.8	6,578	253.0
1972	651	17,781	3.7	17,145	38.0
1973	1,873	16,230	11.5	12,791	146.4
1974	5,571	24,851	22.4	22,629	246.2
1975	1,268	8,067	15.7	8,634	146.9
1976	2,633	8,514	30.9	9,611	274.0
1977	1,317	27,157	4.8	40,475	32.5
1978	760	25,940	2.9	40,539	18.8
1979	1,401	45,759	3.1	77,515	18.1
1980	856	64,841	1.3	69,367	12.3
1981	958	47,533	2.0	56,453	17.0
1982	367	41,384	0.9	59,289	6.2
1983	35	29,375	0.1	49,469	0.7
1984	52	30,556	0.2	9,904	5.3

[a] CPUE = catch per unit of effort.

Table 40.--Catch rates for Pacific ocean perch and the dominant species taken by Japanese small trawlers in the Aleutian region as shown by U.S. observer data, 1977-84.

	Pacific ocean perch			First three species caught in order of abundance
Year	Rank	kg/day	kg/hour	
1977	1	4,665	642	Pacific ocean perch Atka mackerel Northern rockfish
1978	6	580	50	Greenland turbot Walleye pollock Pacific cod
1979	2	1,319	106	Greenland turbot Pacific ocean perch Arrowtooth flounder
1980	3	1,256	171	Walleye pollock Squid Pacific ocean perch
1981	3	978	102	Walleye pollock Greenland turbot Pacific ocean perch
1982	7	129	10	Rattail - unidentified Walleye pollock Greenland turbot
1983	15	26	2	Rattail - unidentified Walleye pollock Greenland turbot
1984	6	60	11	Walleye pollock Greenland turbot Arrowtooth flounder

North Pacific trawl fishery; these indices were then plotted for each subarea (Fig. 34). To evaluate the significance of the CPUE trends, the percentage of Pacific ocean perch in the total groundfish catch was plotted as well. If Pacific ocean perch comprised greater than 80% of the total groundfish catch, it was assumed that this species was the primary target for the trawl fishery. In such cases, CPUE should function well as an index of stock abundance.

The greatest reductions in CPUE occurred in subareas 2, 3, and 4 (Fig. 34). The CPUE in subarea 2 dropped 92% during the 11-yr period from 1964 to 1974. Yet during this period, Pacific ocean perch accounted for over 95% of the total groundfish catch. Subareas 3 and 4 showed similar declines in CPUE. From 1963 to 1971, CPUE in subareas 3 and 4 fell 86 and 76%, respectively; Pacific ocean perch averaged well over 80% of the total groundfish catch in both subareas. With the five subareas combined, CPUE declined 79% during 1963-71. The CPUE declined further after 1971, but these values may not be indicative of actual changes in stock abundance. The percent composition of Pacific ocean perch in the total groundfish catch has not exceeded 80% since 1971.

Estimates of Absolute Abundance

Trawl Surveys--During the summer-fall of 1980 and 1983, the NWAFC in cooperation with the Japan Fishery Agency, conducted groundfish surveys in the Aleutian Islands region from Unimak Pass to Attu Island. These were the first comprehensive resource assessment surveys of groundfish in the Aleutian Islands region.

The exploitable biomass of Pacific ocean perch in the Aleutian Islands region (long. 170° E to 170° W) was estimated at about 107,800 t in 1980 and 119,920 t in 1983. Overlapping confidence intervals between the two estimates indicate that this increase was not significant. The point estimates do indicate, however, that biomass has stabilized at an average of about 113,860 t during the 3-yr period from 1980 to 1983.

Both the 1980 and 1983 cooperative surveys sampled the Aleutian Islands portion (long. 165° W to 170° W) of the eastern Bering Sea management area, an area not covered by the 1979-84 eastern Bering Sea surveys. The estimate of biomass in this area was 7,600 t in 1980 and 95,242 t in 1983. Such a large increase appears unrealistic. The 95% confidence intervals, ranging from 0 to 23,000 t in 1980 and 0 to 274,312 t in 1983, tend to confirm the suspicion of survey error.

Cohort Analysis--As with the Bering Sea cohort analysis, the catch and age data (1964-79) used in the cohort analysis for the Aleutian stock were derived from Chikuni (1975), foreign reported catches, and U.S. observer data bases. Natural and terminal fishing mortalities were estimated from the literature. If M = 0.15 and F(t) = 0.35 is assumed to represent reasonable parameter estimates, the cohort analysis indicates that mean stock biomass in the Aleutians declined from 453,046 t in 1964 to 40,104 t in 1976. This was a reduction of about 91%.

Because of the uncertainty regarding the true values of the input parameters, Ito (1982) examined the effect of various values of natural and terminal fishing mortalities on results of the cohort analysis. These values ranged from 0.05 to 0.30 for M, and from 0.175 to 1.050 for F(t).

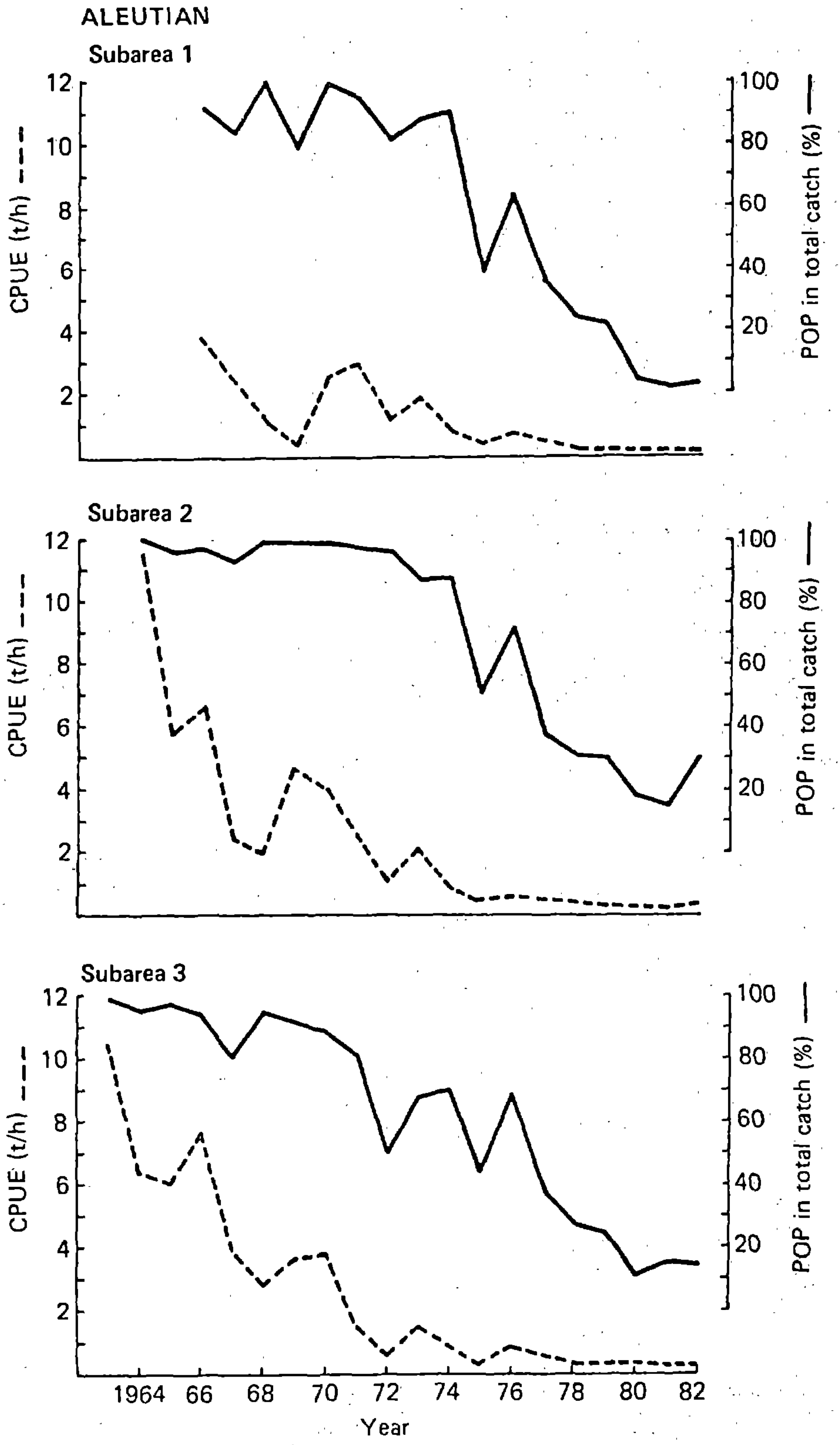

Figure 34.--Annual changes in the percentage of Pacific ocean. perch (POP) in the total groundfish catch and POP catch per unit of effort (CPUE) in the subareas of the Aleutian Islands.

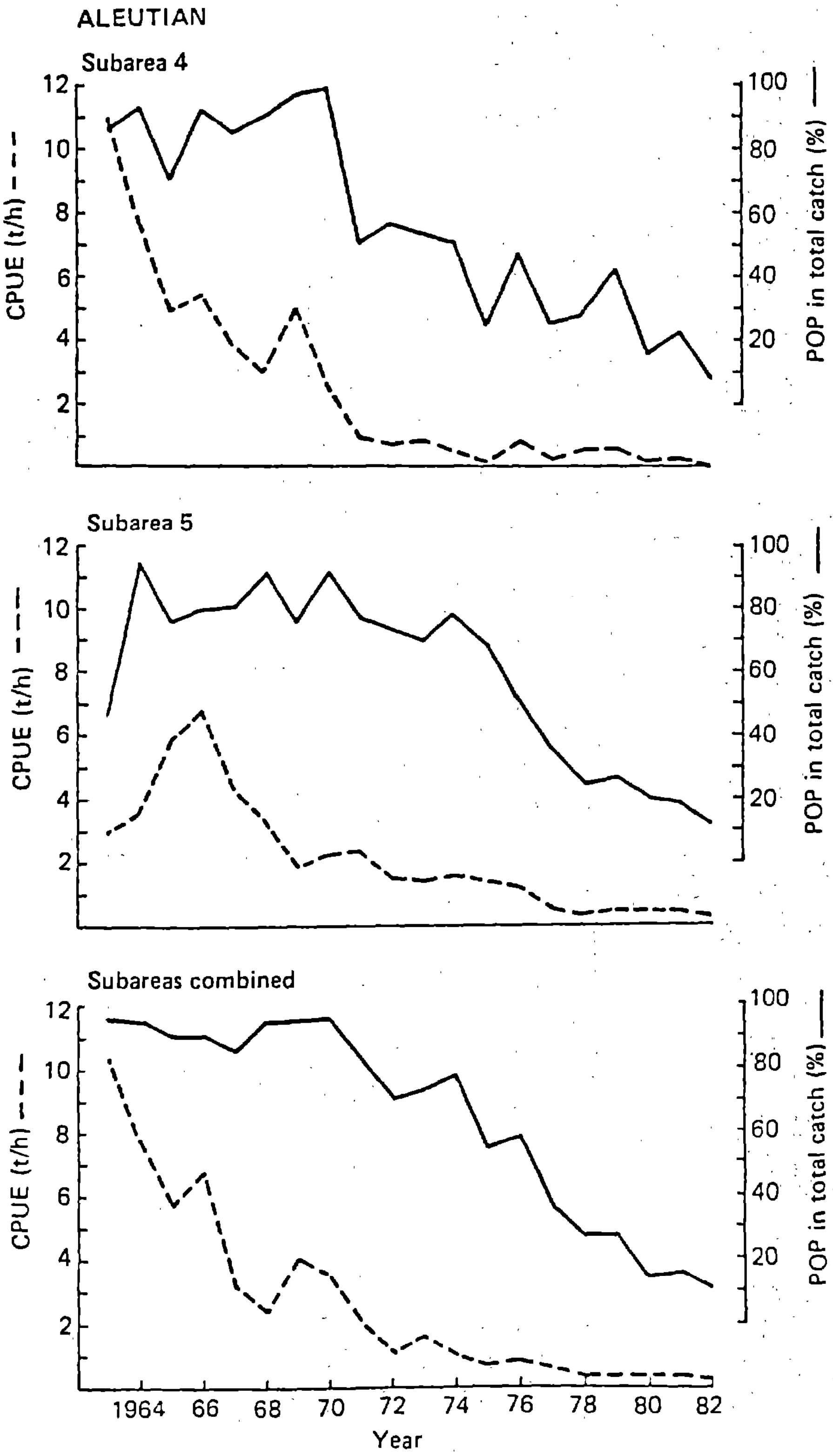

Figure 34 .--Continued.

The paired values of M = 0.05, F(t) = 1.050 and M = 0.30, F(t) = 0.175 yielded the lowest and highest estimates of stock abundance, respectively, for any given year. Abundance estimates based on these two parameter sets established a "range" about the base population estimate (M = 0.15, F(t) = 0.350) (Fig. 35). The trend in mean biomass, regardless of the parameter set employed, was downward. When M = 0.30 and F(t) = 0.175 were used, the decline in biomass was much steeper than when the other two parameter sets were employed. Like results from the eastern Bering Sea cohort analysis, the abundance estimates from the Aleutian region were highly sensitive to changes in M, more so than to changes in F(t).

The 1976 biomass estimate from the cohort analysis base run probably underestimates the true population size of Pacific ocean perch. This estimate is about 67,700 t less than the 1980 U.S.-Japan trawl survey estimate and suggests that the value of M used in the cohort analysis was too low and/or the value of F(t) was too high. Regardless of which parameter values are employed, however, the trend in mean biomass is downward..

Virtual Population Analysis (VPA)--Virtual population analysis was applied to the Aleutian Islands catch-at-age data. The same assumptions and parameter values employed in the eastern Bering Sea VPA were adhered to in the Aleutian Islands VPA. Again, the linking of the cohorts was arranged so as to fully utilize the convergence properties of virtual population analysis.

The results indicated a long-term decreasing trend in biomass for the Aleutian stock (Fig. 36). Depending on the initial F-value chosen, this stock declined 76.7-98.2% from 1964 to 1979. Regardless of the F-value employed, however, the resulting biomass trends converged back toward a level of about 535,000 t. If the estimate of M = 0.15 and the catch-at-age data are accurate, this convergence point is probably a good estimate of virgin biomass.

Maximum sustainable yield was also estimated from the VPA results using the same technique as used for the eastern Bering Sea stock. The virgin biomass of the exploitable stock, assuming knife-edge recruitment at 9 yr, was estimated at 386,000 t in 1964. This corresponds to an MSY estimate of about 28,950 t under the assumption of M = 0.15.

As previously mentioned, there is a controversy on methods of age determination for rockfish. Until this controversy is settled, the results from the current cohort and virtual population analyses should be viewed with caution.

Stock Reduction Analysis (SRA)--The same SRA methodology and parameter values used for the eastern Bering Sea stock were applied to the Aleutian stock. The age at recruitment was assumed to be 9 yr; M was assumed equal to 0.05; and the Brody weight coefficient was estimated at 0.38. The&parameter values are consistent with the greater age range derived from sectioned and break/burned otoliths.

Similiar to results from SRA for the eastern Bering Sea stock, the Aleutian stock appears to have maintained itself at a fairly low but constant level since the early 1970s. (Fig. 37). Under the constant recruitment scenario (i.e., r = 0.01, however, biomass appears to have increased since 1977. Again the reader is reminded that a constant recruitment situation reflects the most optimistic view. Estimates of virgin biomass ranged from 50,000 to 620,000 t.

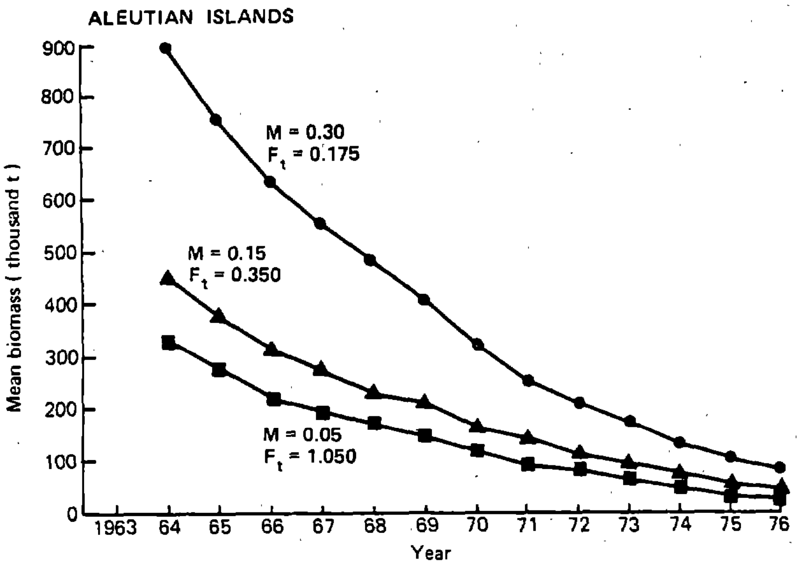

Figure 35.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by cohort analysis using various estimates of natural (M) and fishing mortalities (F_t).

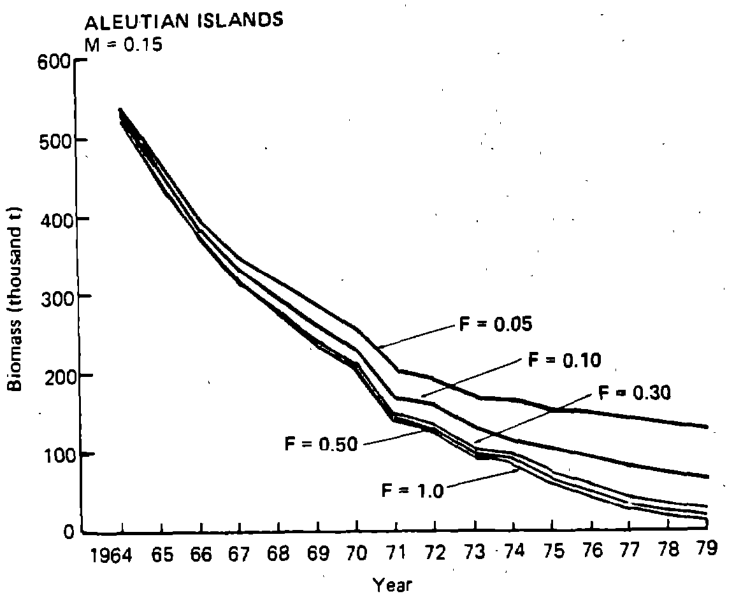

Figure 36.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by virtual population analysis using various estimates of fishing mortalities (F).

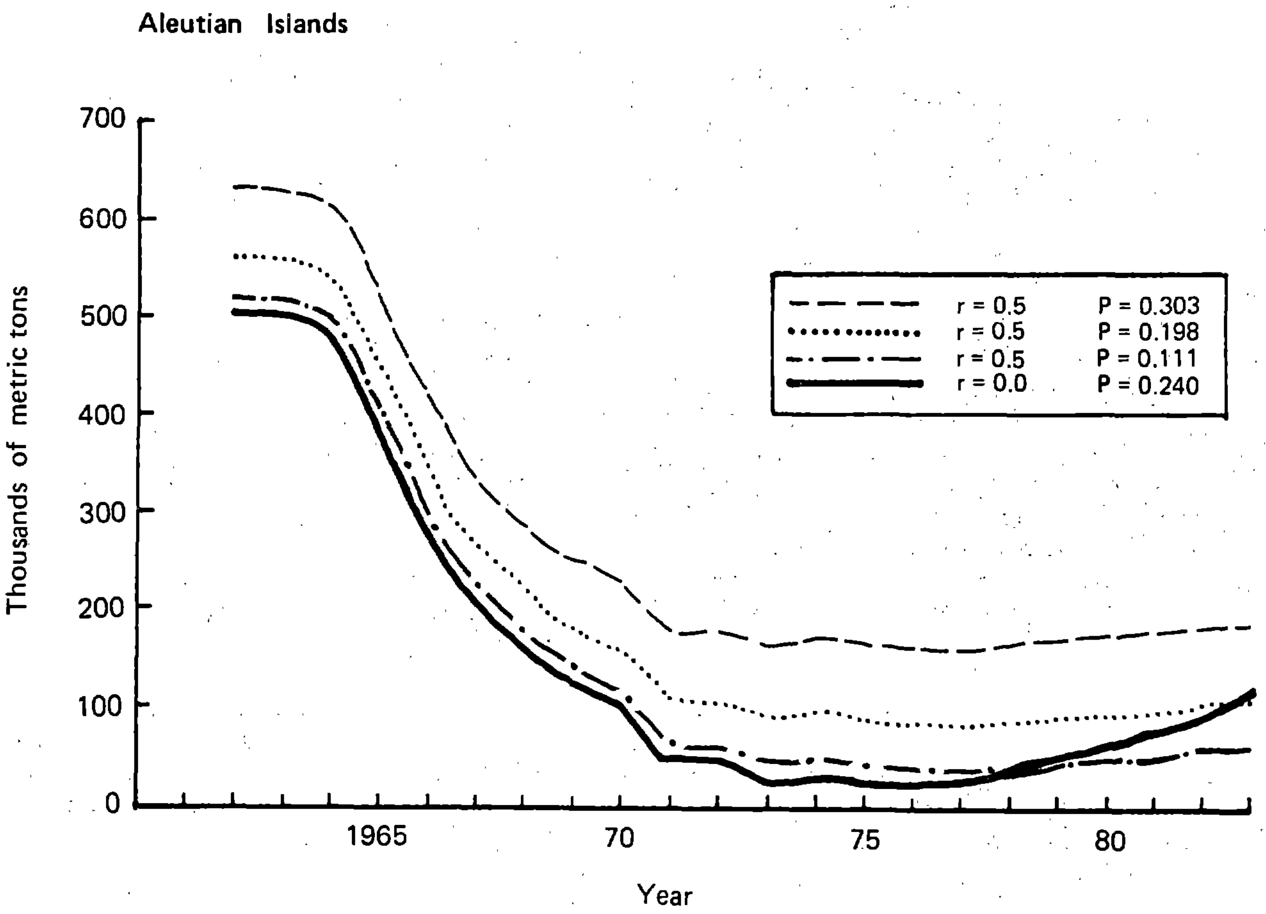

Figure 37.--Estimated population biomass for Pacific ocean perch from the Aleutian region (assuming M = 0.05 and P = 0.38) over time for various SRA fits (from Balsiger et al. 1985).

The sustainable yield curves for SRA (Fig. 38) indicate that MSY conceivably ranges from 6,627 to 11,864 t. It should be noted again, however, that if recruitment is proportional to biomass (i.e., r = 1.0), no sustainable yield is possible regardless of the value of P.

Length and Age Composition

Age and length data collected by U.S. observers aboard foreign fishing vessels extend back to 1977. These data were collected primarily aboard small Japanese stern trawlers (<1,500 gross tons). Only data collected from these vessels were examined.

Pacific ocean perch caught by these trawlers ranged in length from 16 to 50 cm. The average size increased from 30.8 cm in 1977 to 33.2 cm in 1981 and then decreased sharply to 30.1 cm in 1982 (Fig. 39). Based on aging methods employed at the NWAFC, the commercial fishery appears to be dependent on a wide range of ages, 4 to 20 yr. From 1978 to 1980, the average age in the catch decreased from 11.0 to 9.2 yr. The dominant mode in the 1982 length distribution with a peak at 28 cm indicates that the 1975 year-class is relatively strong in the Aleutians; this year-class also appears strong in the eastern Bering Sea.

Condition of Stocks Summary

In this report the eastern Bering Sea and Aleutian Islands Pacific ocean perch stocks were evaluated using a wide variety of stock assessment techniques. Because different stock assessment methods may be subject to different sources of error, it is possible for two independent methods to yield conflicting results. Hence, it is prudent to examine changes in stock by more than one method.

Two major types of assessments were employed in this study--relative and absolute abundance assessment techniques. Relative abundance indices were calculated from commercial fishery and trawl survey catch/effort statistics and the resulting trends analyzed in detail. Trawl surveys, cohort analysis, virtual population analysis, and stock reduction analysis provided estimates of absolute abundance. The results from each assessment method support the belief that both stocks are at extremely low levels of abundance relative to earlier years. Reductions in biomass of 60 to 98% from levels present in the early 1960s were indicated by these analyses.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) was previously estimated at 32,000 t for the eastern Bering Sea slope stock and 75,000 t for the Aleutian Islands stock (Chikuni 1975). Clearly, sustained exploitation at these levels was not possible (Table 33). The eastern Bering Sea slope region has produced catches in excess of 32,000 t only once. Pacific ocean perch harvests from the Aleutian region exceeded 75,000 t only three times during the 22 yr history of this fishery. More recent estimates of MSY from virtual population (VPA) and stock reduction analysis (SRA) techniques suggest that MSY levels are much lower than those estimated by Chikuni (1975) (Table 41).

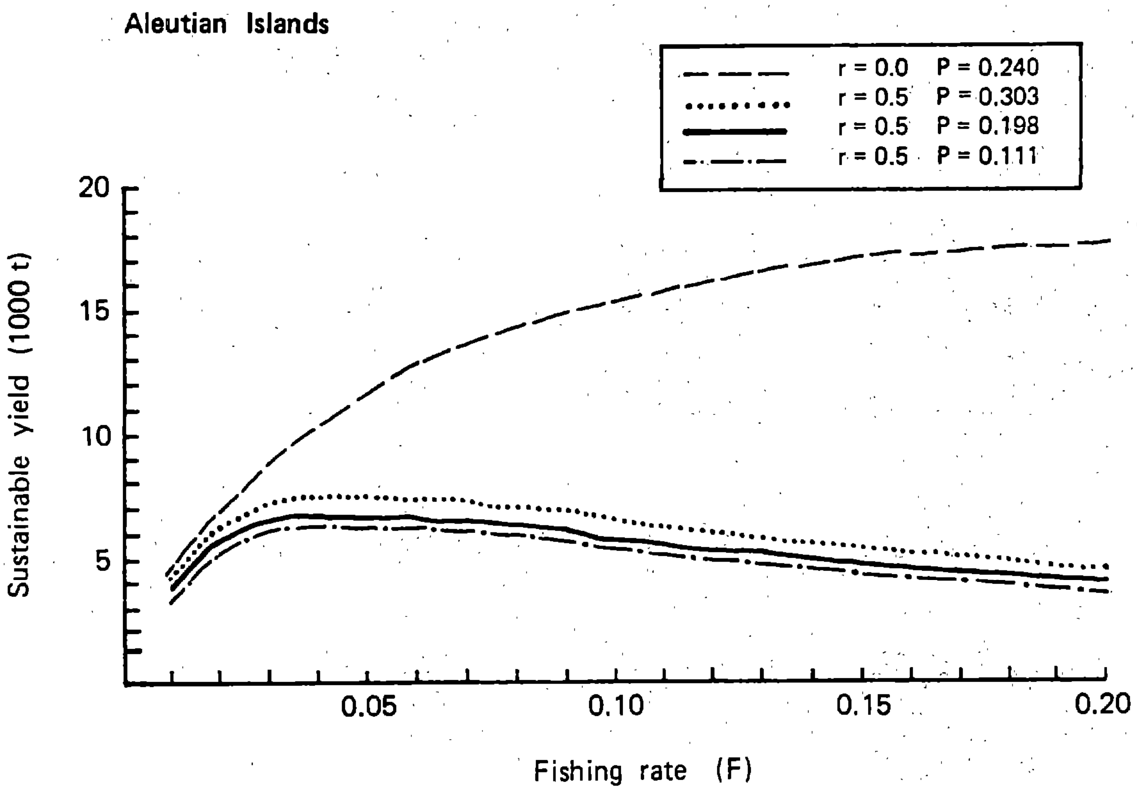

Figure 38.--Estimated sustainable yield for Pacific ocean perch from the Aleutian region (assuming M = 0.05 and p = 0.38) for a given fixed instantaneous fishing mortality rate F, calculated for various SRA fits (from Balsiger et al. 1985).

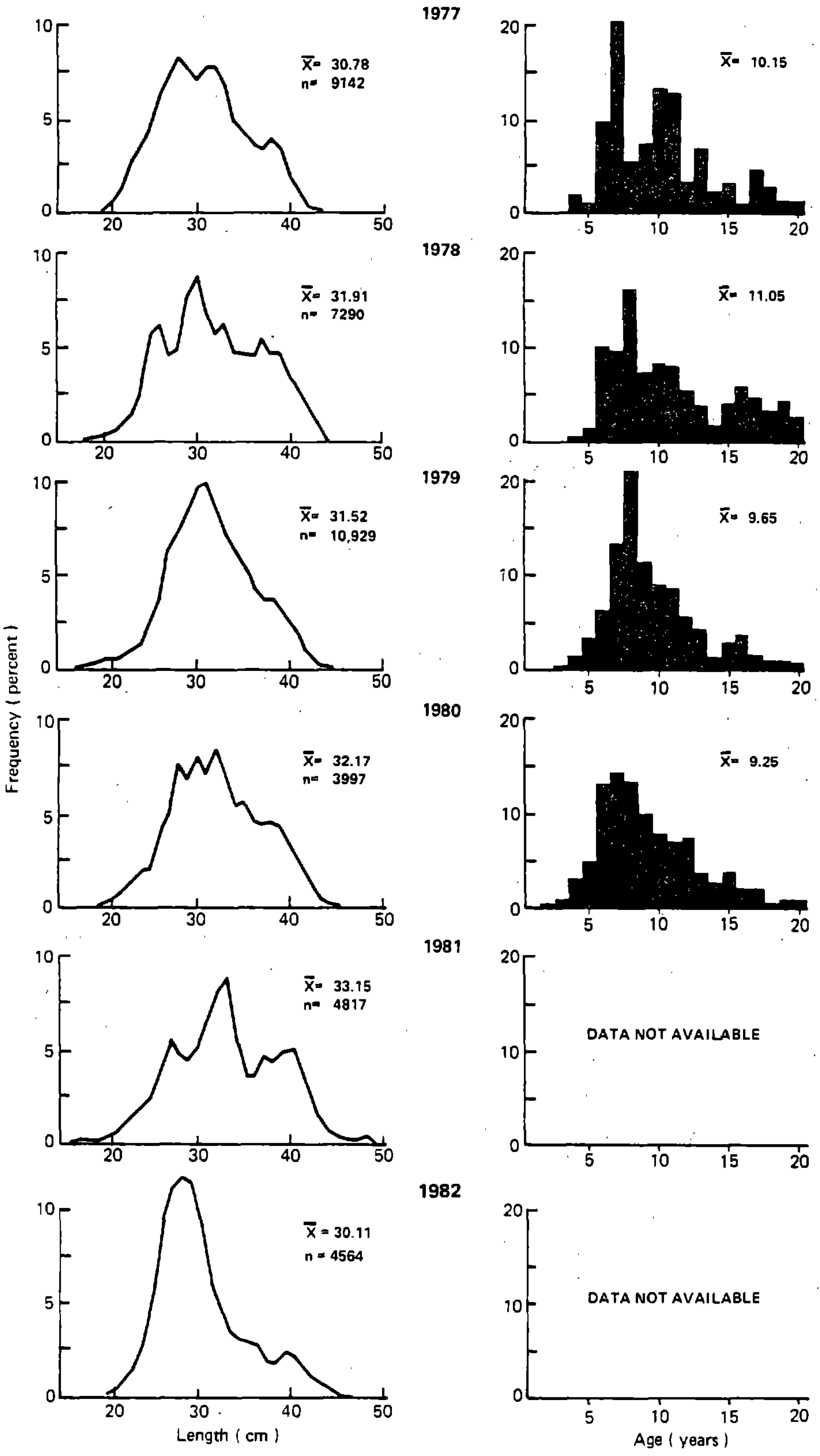

Figure 39.--Length and age composition of Pacific ocean perch in the Aleutian region as shown by data taken by U.S. observers from catches, aboard Japanese small stern trawlers, 1977-82.

Table 41.--Maximum sustainable yield (MSY) estimates for Pacific ocean perch. in the eastern Bering Sea and Aleutian Islands regions.

Region	MSY	Source
Eastern Bering Sea	32,000	Chikuni (1975)
	10,050	VPA[a] (This study)
	2,840-4,984	SRA[b] (This study)
Aleutian Islands	75,000	Chikuni (1975)
	28,950	VPA (This study)
	6,627-11,864	SRA (This study)
Regions combined	12,000-17,000	Low (1974)

[a] VPA = Virtual population analysis

[b] SRA = Stock reduction analysis.

The MSY estimates from VPA were based on a natural mortality of 0.15, which is compatible with maximum ages (about 30 yr) obtained from surface readings of scales and otoliths. However, recent aging techniques using sectioned or broken and burned otoliths suggest longevity may be as much as 90 yr. To be consistent with this greater age range, MSY estimates from SRA were based on a natural mortality value of 0.05. The combined MSY estimates from SRA of 9,467-16,848 t for the eastern Bering Sea and Aleutian Islands regions compare well with estimates of Low (1974) of 12,000-17,000 t (Table 41).

EQUILIBRIUM YIELD

Balsiger et al. (1985) modified the SRA model to project future biomass by incorporating the Deriso (1980) delay-difference equation. This model was used to estimate equilibrium yield (EY) by examining levels of fishing mortality (F) that would stabilize the population at its current level. By assuming that the S. alutus stock had declined to between 10 and 30% of virgin biomass and that a moderate stock-recruitment relationship prevailed, current biomass was estimated to be between 22,000 and 81,000 t for the eastern Bering Sea stock and between 58,000 and 191,000 t for the Aleutian stock. By projecting the current estimates of biomass into the future using the modified SRA model, a fishing mortality of about $F = 0.05$ was estimated to stabilize future biomass. Calculating the exploitation rate corresponding to this value of F (exploitation rate = $F(1.0 - \exp(-F-M)/(F+M)) = 0.0476$) and then multiplying this exploitation rate by the estimates of current biomass resulted in estimates of EY of between 1,047 and 3,845 t for the eastern Bering Sea stock and between 2,760 and 9,088 t for the Aleutian Islands stock.

Trends in catches and CPUE, results from trawl surveys, and sequential-type population analyses have all shown substantial declines in abundance. Although the 1975 year-class may be relatively strong in both the eastern Bering Sea and the Aleutians, there is no evidence as yet that this year-class has substantially increased abundance, despite reduced annual catch levels in 1978-82 of only 200-2,200 t in the eastern Bering Sea and 1,000 - 5,500 t in the Aleutian region. Ito (1982) points out that even incidental catches made while seeking other groundfish species may be sufficiently great to keep Pacific ocean perch stocks in a depleted state. In order to promote rebuilding, it is advisable to set catch levels below EY.

OTHER ROCKFISH

by

Daniel H. Ito

INTRODUCTION

Rockfish catches have traditionally been reported either as Pacific ocean perch, _Sebastes alutus_, or as "other rockfish". Since 1979, however, the North Pacific Fishery Management Council (NPFMC) has permitted the catches of five red rockfish species to be combined and reported under the category of the Pacific ocean perch (POP) complex: Pacific ocean perch, S. _alutus_; rougheye rockfish, S. _aleutianus_; sharpchin rockfish, S. _zacentrus_; shortraker rockfish, S. _borealis_; and northern rockfish, S. _polyspinis_. All species of _Sebastes_ and _Sebastolobus_ not included in this complex, are reported as "other rockfish."

Previous assessments of "other rockfish" stocks in the Bering Sea and Aleutian Islands have not recognized the NPFMC classification system. Rather, all species of rockfish other than S. _alutus_ have been included in the assessments. This year's report represents a departure from previous assessments in that the rockfish classifications established by the NPFMC are adhered to.

Commercial catch and effort data have not been available for individual species of the POP complex and other rockfish until 1977, when species of rockfish began to be identified in commercial catches by U.S. observers. This has provided a means of estimating the annual harvest of individual species. This report describes how these data, as well as available abundance data, have been used to assess the condition of the stocks of "other rockfish" from the eastern Bering Sea and Aleutian Islands region in 1977-84.

COMMERCIAL CATCHES

The methods of sampling and estimating commercial catches of rockfish from the U.S. observer data have been described by Nelson et al. (1980, 1981a, 1981b, 1982, 1983a). U.S. observers have identified 32 species of rockfish in groundfish catches from the eastern Bering Sea and Aleutian Islands region (Table 42). Although all observers were trained in species identification and instructed in the use of fish identification keys, errors in the identification of some rockfish species could have occurred.

The 1977-84 estimated catches of all rockfish from the eastern Bering Sea and Aleutian Islands regions are listed in Tables 43 and 44, respectively. These catches were separated into two major rockfish categories, POP complex and "other rockfish." Catches of "other rockfish," separated by individual species, are presented in Tables 45 and 46 for the eastern Bering Sea and Aleutian Islands regions, respectively.

Table 43. --Estimated catches (t) of rockfish from the eastern Bering Sea as determined by U.S. observer coverage of foreign and joint venture type. fisheries.

	1977	1978	1979	1980	1981	1982	1983	1984
FOREIGN								
POP complex:	4,021	11,759	9,707	1,946	2,000	788	332	339
Pacific ocean perch	2,654	2,211	1,718	1,050	1,221	212	116	156
Northern rockfish	322	119	126	58	31	68	10	19
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99
Sharpchin rockfish	--	--	6	3	4	4	tr[a]	0
Shortraker rockfish	1	8,792	2,726	652	444	354	148	65
Other rockfish:	311	2,607	2,059	456	332	262	212	123
Subtotal	4,332	14,366	11,766	2,402	2,332	1,050	544	462
JOINT VENTURE								
POP complex:	--	--	--	59	1	17	121	147
Pacific ocean perch	--	--	--	47	1	3	97	134
Northern rockfish	--	--	--	11	0	2	24	13
Rougheye rockfish	--	--	--	tr	0	tr	tr	tr
Sharpchin rockfish	--	--	--	1	0	0	0	0
Shortraker rockfish	--	--	--	0	0	12	tr	tr
Other rockfish:	--	--	--	3	0	6	8	8
Subtotal	--	--	--	62	1	28	129	155
COMBINED								
POP complex:	4,021	11,759	9,707	2,005	2,001	805	453	486
Pacific ocean perch	2,654	2,211	1,718	1,097	1,222	215	213	290
Northern rockfish	322	119	126	69	31	70	34	32
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99
Sharpchin rockfish	--	--	6	4	4	4	tr	0
Shortraker rockfish	1	8,792	2,726	652	444	366	148	65
Other rockfish:	311	2,607	2,059	459	332	273	220	131
Grand Total	4,332	14,366	11,766	2,464	2,333	1,078	673	617

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[a] tr = trace quantities

Table 44.--Estimated catches (t) of rockfish from the Aleutian Islands region as determined by U.S. observer coverage of foreign and joint venture type fisheries.

	1977	1978	1979	1980	1981	1982	1983	1984
FOREIGN								
POP complex:	14,625	13,102	15,513	5,645	4,684	1,690	371	414
Pacific ocean perch	8,080	5,286	5,487	4,700	3,618	1,012	272	356
Northern rockfish	5,311	3,782	997	374	138	193	28	12
Rougheye rockfish	1,128	2,938	4,538	469	477	159	22	19
Sharpchin rockfish	3	1	73	tr[a]	tr	14	1	0
Shortraker rockfish	103	1,095	4,418	102	451	312	48	27
Other rockfish:	3,042	921	4,517	416	328	2,114	1,041	42
Subtotal	17,667	14,023	20,030	6,061	5,012	3,804	1,412	456
JOINT VENTURE								
POP complex:	--	--	--	tr	7	2	11	451
Pacific ocean perch	--	--	--	tr	4	2	8	273
Northern rockfish	--	--	--	0	2	0	tr	173
Rougheye rockfish	--	--	--	0	1	0	2	5
Sharpchin rockfish	--	--	--	0	0	0	tr	0
Shortraker rockfish	--	--	--	0	0	0	1	tr
Other rockfish:	--	--	--	0	0	0	4	14
Subtotal	--	--	--	tr	7	2	15	465
COMBINED								
POP complex:	14,625	13,102	15,513	5,645	4,691	1,692	382	865
Pacific ocean perch	8,080	5,286	5,487	4,700	3,622	1,014	280	629
Northern rockfish	5,311	3,782	997	374	140	193	28	185
Rougheye rockfish	1,128	2,938	4,538	469	478	159	24	24
Sharpchin rockfish	3	1	73	tr	tr	14	1	0
Shortraker rockfish	103	1,095	4,418	102	451	312	49	27
Other rockfish:	3,042	921	4,517	416	328	2,114	1,045	56
Grand Total	17,667	14,023	20,030	6,061	5,019	3,806	1,427	921

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[a]tr = trace quantities

Table 45.--Catches in metric tons (t) of "other rockfish" in the eastern Bering Sea groundfish fishery, 1977-84[a].

Common name	Foreign fishery								Joint venture fishery				
	1977	1978	1979	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
Black rockfish		0.7	12.2	0.1									
Blackgill rockfish					0.4	0.9	1.6	2.1				1.0	
Blue rockfish	1.2	8.9	0.2										
Darkblotched rockfish	2.4	39.4	62.8	33.0	55.1	7.2	9.3	1.0					
Dusky rockfish	3.1	56.5	92.4	18.9	13.7	13.9	4.8	18.1	1.2	tr	1.3	6.6	5.1
Harlequin rockfish		2.2		10.1	50.0	2.4							
Longspined thornyhead		0.4	16.2	0.3	3.3	1.0	0.4	2.6					
Redbanded rockfish		1.8	12.8	3.3	1.3								
Redstripe rockfish		65.6	78.9	0.2	8.5	8.5	3.0	2.7			4.6		1.2
Shortspine thornyhead	292.2	2,288.8	1,585.6	389.2	195.9	219.4	178.4	91.4			4.9	0.3	0.4
Silvergray rockfish		0.8											
Splitnose rockfish						4.8	10.6						
Misc. rockfish	12.0	149.3	247.3	1.3	3.1	3.7	3.9	3.5	1.4	___	tr[b]	0.5	1.7
TOTAL	310.9	2,614.4	2,108.4	456.4	331.3	261.8	212.0	121.4	2.6	tr	10.8	8.4	8.4

[a] Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a; Berger et al. 1984, 1985b.
[b] tr = trace amounts

Table 46 .--Catches in metric tons (t) of "other rockfish" in the Aleutian Islands groundfish fishery, 1977-84[a]

Common name	Foreign fishery								Joint venture fishery				
	1977	1978	1979	1980	1981	1982	1983	1984	1980	1981	1982	1983	1984
Black rockfish		1.6	2.3										
Blackgill rockfish						4.8	3.8	0.7					
Darkblotched rockfish	0.4	42.2	1,641.8	86.3	7.0	7.6	1.7	0.1					
Dusky rockfish	2,932.9	11.3	54.8	2.8	10.6	3.8	1.0	2.6		tr[b]		0.9	8.3
Harlequin rockfish	1.0	8.1	51.6	60.8	8.4	0.4							
Longspined thornyhead		0.2	2.2			2.1	0.7	0.4					
Redbanded rockfish		81.8	40.0	6.8	tr								
Redstripe rockfish		127.0	997.1	51.3	5.1	2.2	2.2	0.8				3.4	0.8
Shortspine thornyhead	89.1	546.8	1,709.6	210.7	276.3	2,089.1	982.6	36.5	tr				
Silvergray rockfish			1.0										
Splitnose rockfish						3.3	44.0						
Misc. rockfish	19.1	102.0	16.2	2.0	20.8	0.7	5.0	1.1		tr			5.0
TOTAL	3,042.5	921.0	4,516.6	420.7	328.2	2,114.0	1,041.0	42.2	tr	tr	0.0	4.3	14.1

[a] Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a, Berger et al. 1984, 1985b.
[b] tr = trace amounts.

Total rockfish catches in the eastern Bering Sea since 1977 peaked at 14,366 metric tons (t) in 1978 (Table 43). Catches since then have decreased and reached an all time low of 617 t in 1984. The "other rockfish" catches follow this trend, peaking in 1978 at about 2,600 t and then dropping to an all time low of 130 t in 1984. The average catch of "other rockfish" during the period of observer coverage was 800 t and averaged only about 17% of the total rockfish catch during this period.

Shortspine thornyheads, *Sebastolobus alascanus*, have consistently dominated the "other rockfish" catches in the eastern Bering Sea (Table 45). This species alone has comprised over 80% of the "other rockfish" catch from 1977 to 1984. Darkblotched rockfish, *Sebastes crameri*; dusky rockfish, *Sebastes ciliatus*; and redstripe rockfish, *Sebastes proriger*, have also made up significant portions of the "other rockfish" catch during the past 8 yr.

With the exception of 1978, total rockfish catches from the Aleutian region (Table 44) have exceeded those from the eastern Bering Sea. Harvests of all rockfish from the Aleutian region since 1977 peaked in 1979 at 20,030 t and then declined to a historic low of 921 t in 1984. The catches of "other rockfish" averaged 1,555 t during the period from 1977 to 1984. As in the eastern Bering Sea, shortspine thornyheads have usually dominated catches of "other rockfish," but darkblotched, dusky, and redstripe rockfish have also made up significant portions of the "other rockfish" catch during some years of observer coverage (Table 46).

BIOMASS ESTIMATES

Data from the 1979-83 cooperative U.S.-Japan trawl surveys provide biomass estimates for "other rockfish" in the eastern Bering Sea and Aleutian Islands region. The surveys in the eastern Bering Sea were conducted both on the continental shelf and the continental slope, but almost all catches of "other rockfish" were taken by Japanese research trawlers fishing on the slope at depths greater than 200 m. For this reason, only data collected by Japanese research vessels were employed to calculate "other rockfish" abundance estimates.

Both the continental shelf and continental slope of the eastern Bering Sea were again sampled during the 1985 U.S.-Japan cooperative trawl survey. However, this information was not yet available for data analysis at the time of this writing.

Survey results indicate that the biomass of "other rockfish" in the eastern Bering Sea increased from 3,251 t in 1979 to 4,975 t in 1981 and then declined slightly to 4,381 t in 1982. These abundance estimates should be viewed with caution, however, because of their relatively low degree of precision. The 1980 and 1983 cooperative U.S.-Japan surveys of the Aleutian region indicated an average of about 1,300 t of "other rockfish" in the Aleutian Islands portion of International North Pacific Fisheries Commission (INPFC) area 1 (the north side of the Aleutians between long. 165° W and 170° W). Thus, an overall estimate for the eastern Bering Sea region, based on the mean of the 1980 and 1983 Aleutian estimates and the mean of the 1979-82 eastern Bering Sea survey data, is 5,500 t. The estimated biomass for the POP complex (excluding S. *alutus*) in this region amounted to about 6,000 t.

Biomass estimates of "other rockfish" from the 1980 and 1983 U.S.-Japan cooperative trawl surveys of the Aleutian Islands region indicate a decrease from 22,300 t in 1980 to 15,900 t in 1983. These estimates, however, were characterized by relatively wide variances, and the 95% confidence intervals overlapped extensively, indicating that the point estimates may not be significantly different. Nevertheless, the mean of these trawl estimates (19,100 t) indicates a much larger stock size than that found in the eastern Bering Sea. Biomass for the POP complex (excluding 2. alutus) in the Aleutian region was estimated at about 59,300 t.

The abundance results from the surveys probably underestimate the true population size of the "other rockfish" stocks. Some of the species in the "other rockfish" category likely occupy the water column above that sampled by bottom trawls and inhabit areas of rough bottom which were avoided during the surveys to prevent damage to the trawls. Unfortunately, that portion of the population unavailable to the trawl gear cannot be precisely determined at this time.

MAXIMUM SUSTAINABLE YIELD

Information is not yet available to provide a reasonable estimate of maximum sustainable yield (MSY) for the "other rockfish" stocks in the eastern Bering Sea or Aleutian Islands regions.

EQUILIBRIUM YIELD

Estimates of equilibrium yield (EY) were calculated by assuming that a 5% exploitation rate is sustainable and that the, estimates of biomass from the surveys may be underestimated by as much as 50%. A similar exploitation rate was estimated to maintain the stocks of Pacific ocean perch at current levels (refer to the Pacific ocean perch section of this report), and, therefore, seems reasonable as an estimate for the "other rockfish" stocks. To conform with current NPFMC management policies, EY estimates were determined for both the "other rockfish" and the POP complex (excluding S. alutus).

The biomass of the "other rockfish" stock in the eastern Bering Sea was estimated at about 5,500 t; for the POP complex, (excluding S. alutus) the estimate was about 6,000 t. The 1980 and 1983 biomass estimates for "other rockfish" in the Aleutian region averaged about 19,100 t and for the POP complex (excluding S. alutus), about 59,300 t. Using the assumption that these estimates represent about one-half the actual biomass, EY values were 550 t in the eastern Bering Sea and 1,900 t in the Aleutian Islands region for "other rockfish." For the POP complex (excluding S. alutus), EY was. estimated at 600 t for the eastern Bering Sea and 5,900 t for the Aleutian. region.

ATKA MACKEREL

by

Lael L. Ronholt and Daniel K. Kimura

INTRODUCTION

Atka mackerel, Pleurogrammus monopterygius, are found from the east coast of the Kamchatka Peninsula, throughout the Komandorskiye and Aleutian Islands, north to the Pribilof Islands in the eastern Bering Sea, and eastward through the Gulf of Alaska to southeast Alaska. Commercial catches in the Bering Sea area occur in both the eastern Bering Sea and Aleutians, the largest landings coming from the Aleutian region which, from 1978 to 1984, produced 93% of the total Bering Sea landings (Table 47). Based on the 1983 cooperative U.S.-Japan groundfish resource assessment survey, Atka mackerel is the third most abundant species in the Aleutian Islands region after walleye pollock, Theragra chalcogramma, and grenadiers (rattails, family Macrouridae).

Levada (1979a) compared 21 morphological and meristic characters in a study of the stock structure of Atka mackerel from the Aleutian region and the Gulf of Alaska. Although the author felt that further studies were needed, differences in meristic and morphological characters between areas suggested the existence of distinct populations in the Gulf of Alaska and Aleutian Islands. Characters that showed differences between the Atka mackerel of the two regions, in their order of significance, were: number of vertebrae, rostral length, greatest body height, number of rays in the anal fin, and head length. Atka mackerel populations in the Aleutians and Gulf of Alaska. are managed as separate stocks, and Levada's study, although far from conclusive, supports the validity of this management policy.

CATCH STATISTICS

The total annual landings of Atka mackerel in the Bering Sea and Aleutian region increased during the 1970s, reaching an initial peak of 24,250 metric tons (t) in 1978 (Table 48). From 1979 to 1982 catches gradually declined and then dropped sharply to 11,726 t in 1983. We believe that the decline in Atka mackerel landings from 1980-83 was due to changes in interests by fishing nations, rather than changes in stock abundance. In 1984, Atka mackerel catches increased substantially to a new record high of 36,054 t. Although significant landings came from the eastern Bering Sea area during 1978-81, the vast majority of the catches have been from the Aleutian Islands region (Table 47).

During the 1970s, Atka mackerel landings were made almost exclusively by the U.S.S.R. (Table 48). In the early 1970s, catches by the Soviet fleet were made primarily west of long. 180°. During 1978 and 1979, the Soviet fleet moved progressively eastward (Table 49), making significant catches in the central and eastern portions of the Aleutian region.

Table 47.--Atka mackerel catches in metric tons by International North Pacific Fisheries Commission areas in the Bering Sea and Aleutians.

Year	Eastern Bering Sea I	Eastern Bering Sea II	Central Bering Sea (III)	Aleutians (V)	Total
1978	422	410	0	23,418	24,250
1979	1,653	332	0	21,279	23,264
1980	4,235	462	0	15,793	20,490
1981	2,307	721	0	16,661	19,689
1982	155	173	0	19,546	19,874
1983	21	95	0	11,610	11,726
1984	23	18	0	36,013	36,054

Table 48.--Atka mackerel catches in metric tons by nation, in the eastern Bering Sea and Aleutian Islands regions.

Year	U.S.S.R.	Japan	R.O.K.[a]	W. Germany	Poland	U.S.J.V.[b]	Total
1970	949	--	--	--	--	--	949
1971	--	--	--	--	--	--	--
1972	5,907	--	--	--	--	--	5,907
1973	1,712	--	--	--	--	--	1,712
1974	1,377	--	--	--	--	--	1,377
1975	13,326	--	--	--	--	--	13,326
1976	13,126	--	--	--	--	--	13,126
1977	20,975	--	--	--	--	--	20,975
1978	22,622	1,531	97	--	--	--	24,250
1979	20,277	1,656	1,329	--	2	--	23,264
1980	937	1,719	17,483	42	44	265	20,490
1981	0	5,615	12,385	38	18	1,633	19,689
1982	0	888	6,385	126	--	12,475	19,874
1983	0	280	910	24	--	10,512	11,726
1984	0	103	8	--	tr[c]	35,943	36,054

[a] Republic of Korea.
[b] U.S. joint venture.
[c] tr = trace.

Table 49.--Annual foreign and domestic landings in metric tons (t) of Atka mackerel by 1° of longitude in the Aleutian region between long. 170° E and 170° W.

Year	East longitude										West longitude										Total
	170°	171°	172°	173°	174°	175°	176°	177°	178°	179°	179°	178°	177°	176°	175°	174°	173°	172°	171°	170°	
1977	81	143	112	141	385	13,058	3,789	327	195	111	557	34	0	393	0	0	2	10	34	290	19,662
1978	426	0	0	0	400	11,684	275	0	41	34	6,703	0	0	0	955	0	0	21	1,509	0	22,048
1979	58	34	6,694	4,236	30	121	111	18	65	67	770	20	8	1	1,919	1	42	4,972	1,941	42	21,150
1980	125	26	110	35	95	171	107	56	121	296	185	119	26	52	41	98	449	10,867	2,635	748	16,363
1981	268	68	104	84	180	490	250	163	210	459	283	108	35	10	60	69	303	7,968	1,874	820	13,523
1982	53	28	37	26	33	74	86	42	31	35	92	49	0	0	7	34	66	5,147	7,346	230	13,416
1983	15	4	21	3	13	32	17	17	18	26	159	5	4	2	0	1	2,753	5,492	737	83	9,402
1984	0	0	8	tr	0	0	0	0	tr	tr	5,182	401	16	9	0	214	2,544	23,907	342	0	32,624

In addition to the Soviet Union, significant catches have been made by Japan (1978-81) and the Republic of Korea (1980-82). However, the joint venture fisheries which began in 1980 have steadily grown, and in 1984 accounted for virtually all landings (Table 48).

Since 1980, the major catches of Atka mackerel (75-96%) have occurred east of long. 180° primarily between long. 171° and 174° W in the Aleutian region (Table 49). In 1984; the joint venture fisheries landed 73% of their total catches from a single 0.5° latitude by 1° longitude block bounded by lat. 52°30° N and 53° N and long. 172° W and 173° W.

SURVEY BIOMASS ESTIMATES

Because Atka mackerel occur in large localized concentrations and are poor acoustic targets, they are difficult to survey either hydroacoustically or with trawls. Although survey data (Table 50) show a marked building of stocks from 1974-75 through 1983, it is difficult to know if this increase is real or the result of changes or improvements in survey techniques. For example, the joint U.S.-Japan trawl surveys showed a large increase in biomass between 1980 and 1983, but most of this increase can be attributed to fish in the 1-100 m depth range that appeared only in 1983 (Table 51). Nevertheless, the most recent survey results indicate that Atka mackerel stocks in the Aleutian region are presently healthy, if not at an historically high biomass level. The biomass estimate from the 1983 U.S.-Japan survey, which was 304,132 t for the Aleutian region, is a key statistic from which we shall estimate maximum sustainable yield (MSY) values.

BIOLOGICAL STATISTICS

Biological statistics for Atka mackerel in the Aleutian region are available from Levada (1979b), the U.S. Observer Program's sampling of commercial catches (1977-84), U.S.-Japan cooperative trawl surveys for 1980 and 1983, and a Soviet trawl survey for 1982. Because catches were small in other regions, the statistics we present are from only the Aleutian region.

Because the Atka mackerel population in the Aleutian region is currently in a dynamic state, the growth curves and length-weight relationships presented in this section should be reexamined at a later date.

Length-Frequencies

Length-frequencies from commercial catches (Fig. 40) are available from Levada (1979b) and the U.S. Observer Program. In 1980 and 1981, the U.S. Observer sample sizes were small, so commercial samples taken by the Republic of Korea (R.O.K.) were also used. Generally, sample sizes appeared to be large enough, and the length-frequencies consistent enough, to be meaningful. These length-frequency data showed a dramatic but gradual increase in the size of fish taken in the commercial fishery (Fig. 40). In 1975 nearly all sampled fish were under 30 cm, but by 1979 nearly all were over 30 cm. Mean size increased

Table 50.--Survey biomass estimates in metric tons for Atka mackerel in the Aleutian Islands region.

Nation	Year	Type	Biomass estimates	95% Confidence interval
1. U.S.S.R.	1974-75	Hydroacoustic	35,000-110,000	--
2. U.S.S.R.	1980	Hydroacoustic	180,000-200,000	--
3. Joint U.S.-Japan	1980	Trawl	129,500	--
4. Joint U.S.-Japan	1983	Trawl	304,132	121,000-487,000

Table 51.--Estimated biomass in metric tons (t) and average size by area and depth for Atka mackerel in the Aleutian region from the cooperative U.S.-Japan groundfish surveys in 1980 and 1983.

		Southwest[a]		Northwest[b]		Southeast[c]		Northeast[d]		All areas	
Depth (m)	Year	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)
1-100	1980	182	-	0	-	0	-	13,581	31.4	30,157	31.4
	1983	15,321	34.0	41,235	34.0	65,814	38.3	18,182	34.9	140,553	35.7
101-200	1980	90,218	35.3	4,788	35.4	10,642	32.3	8,965	30.3	114,613	34.4
	1983	120,990	32.5	5,571	33.0	853	40.2	34,983	38.7	162,399	33.3
All Depths	1980	90,880	35.3	5,102	35.2	10,746	32.2	22,784	30.9	129,512	34.0
	1983	138,788	32.9	46,840	34.2	66,869	38.7	54,281	37.3	306,781	34.3

[a] Southwest - South of the Aleutian Islands west of 180° longitude.
[b] Northwest - North of the Aleutian Islands west of 180° longitude.
[c] Southeast - South of the Aleutian Islands from 170° W to 180° longitude.
[d] Northeast - North of the Aleutian Islands from 170° W to 180° longitude.

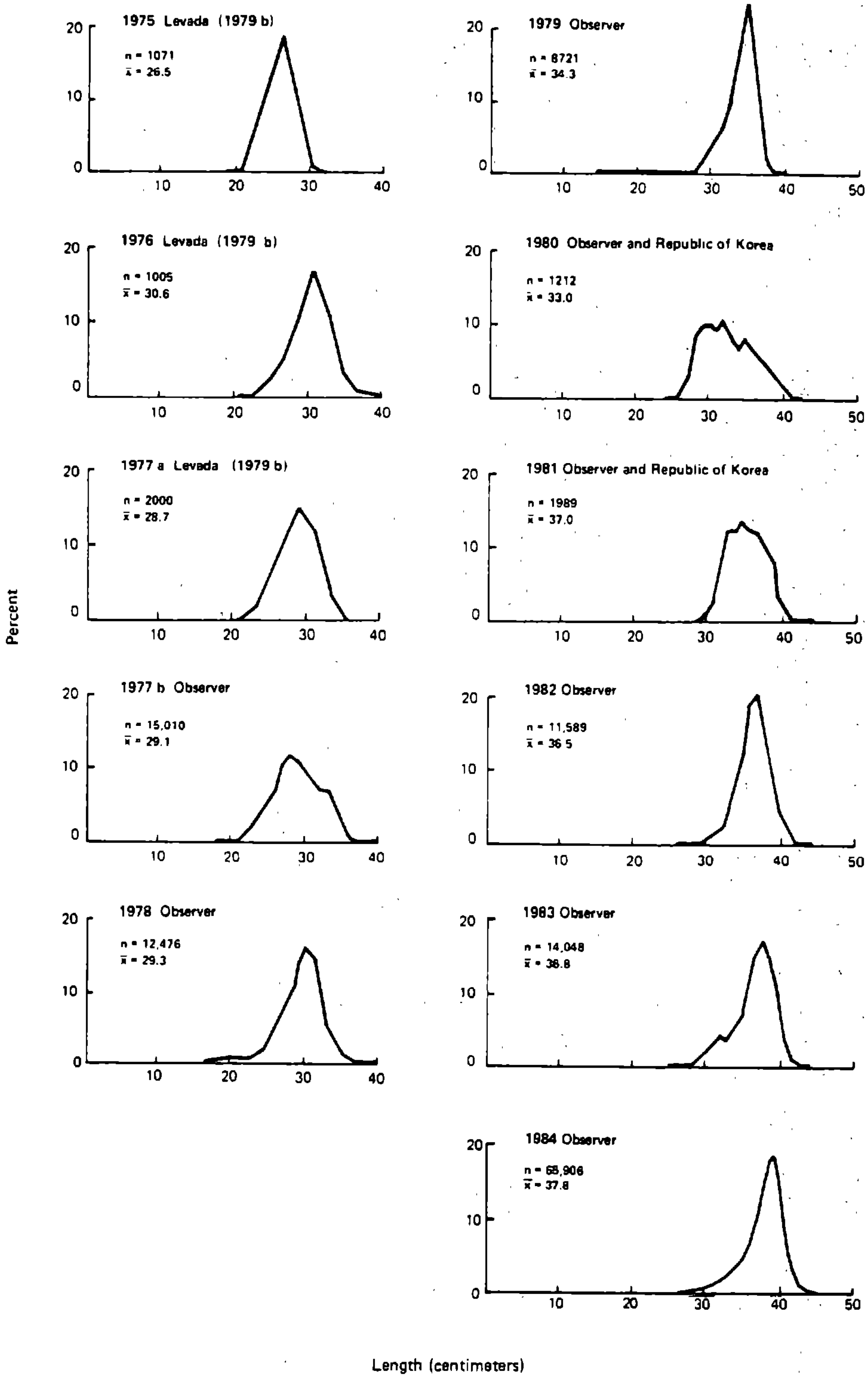

Figure 40.-- Length frequency data from Levada (1979b) and the U.S. Observer Program for Atka mackerel in the Aleutian Islands Region.

from 33.0 cm in 1980 to 37.8 cm in 1984. This increase in size indicates that increasingly older fish were being taken in the fishery, and possibly that the catches were being dominated by a few year-classes.

An interpretation of the length frequencies of Atka mackerel is made difficult by the apparent geographic stratification of stocks by size. During the 1980 U.S.-Japan trawl survey, fish in the western Aleutians averaged 35.2-35.3 cm, and fish in the eastern Aleutians averaged 30.9-32.2 cm (Fig. 41). Thus in 1980, the largest fish were found in the west and most of the recruitment occurred in the east.

The 1983 U.S.-Japan trawl survey, however, shows a very different situation (Fig. 41), indicating the dynamic nature of these stocks. In the southeast, the length frequencies show a narrow band of large fish averaging 38.7 cm. These large fish were also present in the northeast, but a mode of smaller fish in the 34 cm range was also evident. In the southwest, a large number of younger fish less than 30 cm in size were apparent, with fewer of the over 35 cm fish that were abundant in the east. And finally, fish under 30 cm were available in the northwest, but fish in the 34 cm range were most abundant. Thus in 1983, the largest fish were found in the east, with most of the recruitment appearing in the west.

Age Distributions

Age determination methods for Atka mackerel have not been fully investigated. Levada (1979b), while using scales and tail ossicles to age these fish, noted:

> While discussing age in Atka mackerel one cannot but point out a number of difficulties arising in its determination. There are many subsidiary rings, which hamper age determination. In the fish above [age] 6, ring pattern becomes unsystematic which also interferes with age determination.

Until investigations have been made verifying the age determination methodology for Atka mackerel, age data must be considered questionable.

In the Aleutian region, Atka mackerel is a summer-fall spawning fish which apparently does not lay down an otolith annulus in the first year. Adding 1 yr to ages determined from otoliths by the Northwest and Alaska Fisheries Center (NWAFC) Ageing Unit makes our growth data consistent with ages obtained from tail ossicles by Gorbunova (1962). All the age data presented in this report have been corrected in this way.

Age frequencies were obtained for Atka mackerel in the Aleutian region from both observer (1977-79 and 1984) and survey (1980, 1982, and 1983) data (Fig. 42). As suggested by the length-frequency data, catches of Atka mackerel appear to be dominated by strong year-classes. Both the 1975 and 1977 year-classes appear to have been exceptionally strong.

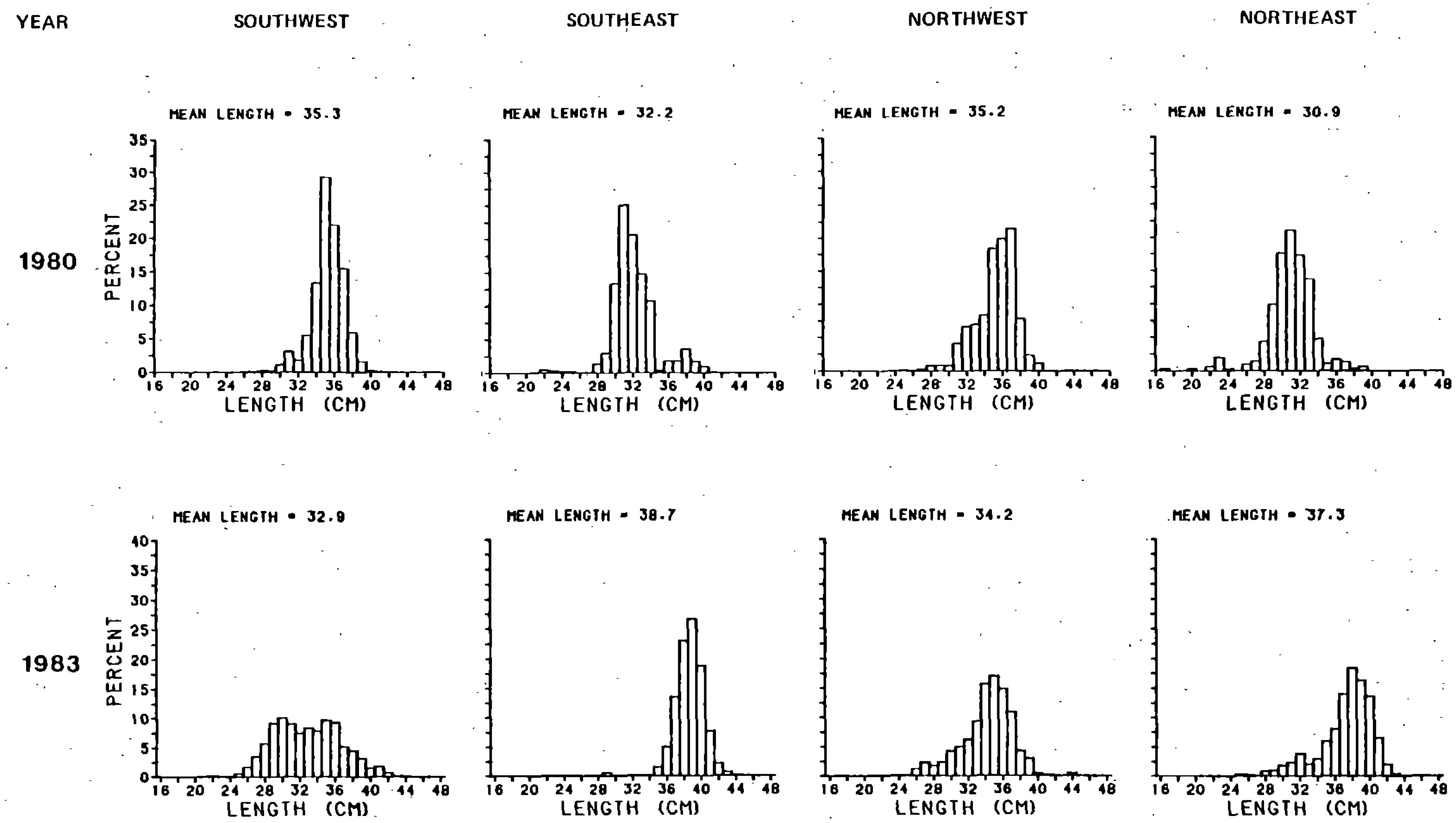

Figure 41.-- Size composition of Atka mackerel in the Aleutian Islands. from the cooperative U.S .-Japan groundfish surveys of 1980 and 1983.

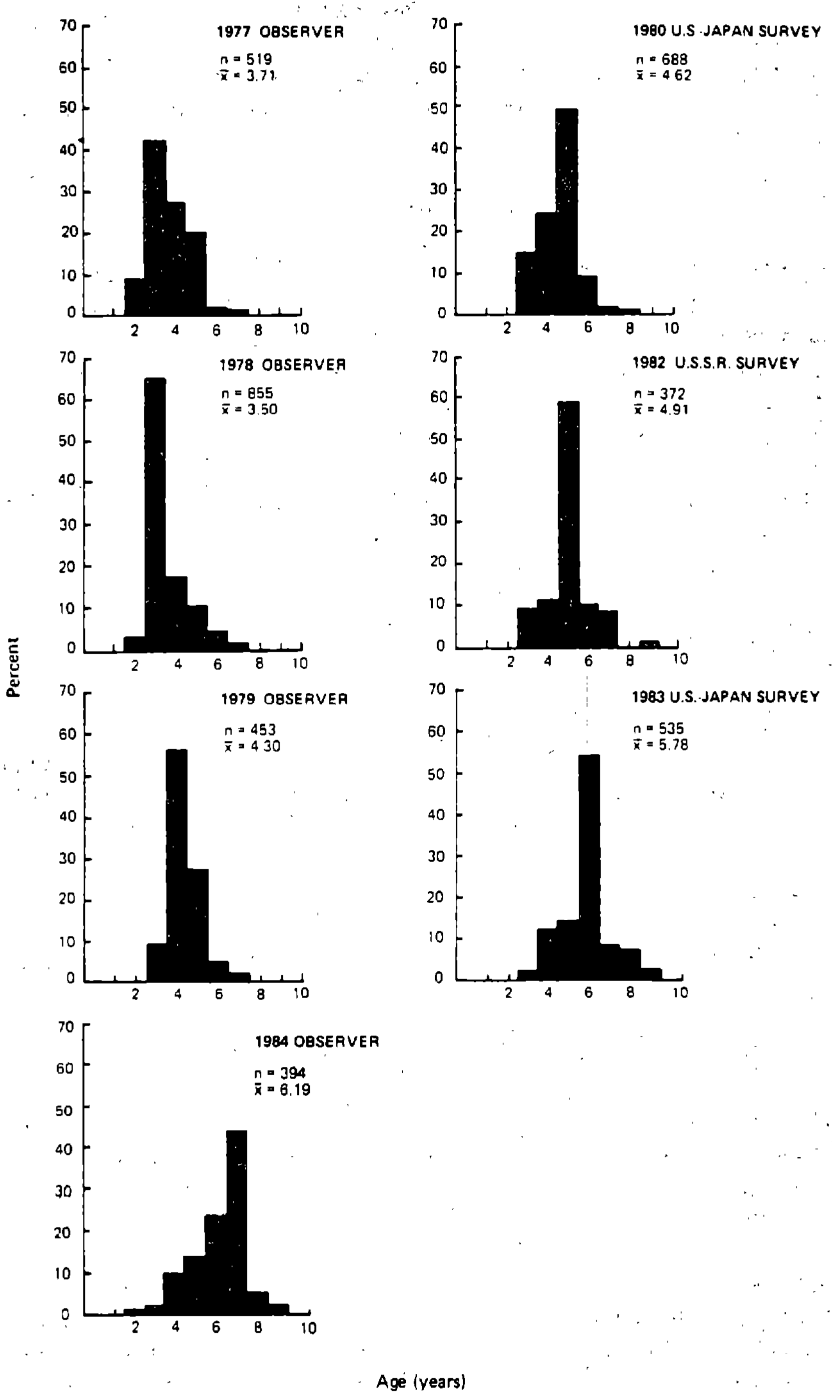

Figure 42. --Estimated age frequency of commercial catches of Atka mackerel in the Aleutian Islands region, sampled by the U.S. Observer Program (1977-1979, and 1984) and during bottom trawl surveys, (1980, 1982, and 1983). Ages were determined by the Northwest and Alaska, Fisheries Center Aging Unit.

Besides these two exceptional year-classes, it is important to note that 6-yr-olds never appeared in abundance until 1983. This abundance of older fish in 1983 also seems to appear in the length-frequencies (Fig. 40). Although the available age data are limited, 7-yr-olds appear to dominate the 1984 landings. This phenomenon is important because the abundance of Atka mackerel in the Aleutian region may decline sharply as the strong 1977 year-class passes out of the fishery.

Von Bertalanffy Growth

The von Bertalanffy growth curve has proven to be a useful description of growth in fishes. In this study, we fitted the von Bertalanffy curve in order to provide a summary of growth in Atka mackerel, and also because an estimate of the von Bertalanffy K parameter is required in the Alverson and Carney (1975) estimate of the instantaneous natural mortality rate (M). An estimate of M is required for our estimates of MSY.

Nonlinear least squares was used to fit the von Bertalanffy growth curve to average length-at-age for the 1977-83 age data (Fig. 42). The resulting parameter estimates were:

males: $L = 36.80$ $K = 0.72$ $t_o = 0.73$

females: $L = 37.23$ $K = 0.62$ $t_o = 0.56$

The differences in these parameters were tested using a likelihood ratio test (Kimura 1981), which yielded a nonsignificant chi-square statistic of 0.642 with df = 3. We therefore conclude that the combined curve:

sexes combined: $L = 37.06$ $K = 0.66$ $t_o = 0.64$

provides an adequate description of growth for Atka mackerel in the Aleutians region (Fig. 43).

Length-Weight Relationship

In addition to the von Bertalanffy growth curve, we examined the length-weight relationship for Atka mackerel. This relationship will not be used in the current study, but provides basic biological information that may be useful in future studies.

For the length-weight relationship, we used nonlinear least squares to fit the usual curve, $w = al^b$, where length (1) was measured in centimeters and weight (w) was measured in decagrams. The average weight-at-length data used was collected from observer data (1977-79) in the Aleutian region. The resulting parameter estimates were:

males: $a = 0.000144$ $b = 3.581$
females: $a = 0.00047\ 1$ $b = 3.227$.

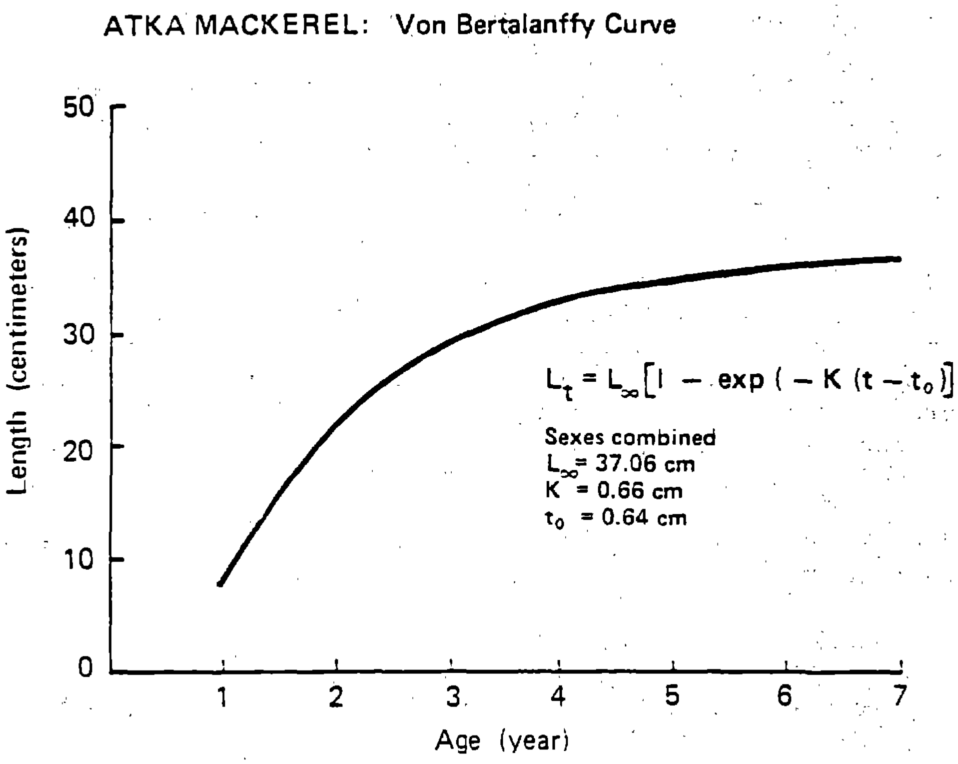

Figure 43.-- Estimated von Bertalanffy growth curve (sexes combined) for Atka mackerel in the Aleutian Islands region.

Using a likelihood ratio test, these curves were found to be significantly different ($\alpha = 0.001$), with a chi-square value of 41.919 with df = 2. Nevertheless, the fitted curves (Fig. 44) were quite similar, and the combined curve:

sexes combined: $a = 0.000270$ $b = 3.393$

may still be preferred. Unlike most species, the weight of females was lower than that of males for large length fish. This may be due to large numbers of spawned-out females being present in the samples.

Natural Mortality Bate Estimates

The proportion of a fish stock that can be taken on a sustainable basis is largely dependent on the natural mortality rate which is experienced by the population. The instantaneous natural mortality rate (M). is generally estimated from the age composition of the virgin stock. In the case of Atka mackerel, age data are not available from the virgin stock, there are few ages in the sampled population, and the age distributions seem to be characterized by variability in availability and recruitment.

For these reasons, we used an indirect estimate of M based on the Alverson and Carney (1975) formula:

$$M = 3K/[\exp(t_{mb}K)-1],$$

where t_{mb} is the age of maximum biomass for the cohort and K is the von Bertalanffy rate parameter.

For Atka mackerel, the estimation of both t_{md} and K presents problems. Although we estimated K = 0.66 for the Aleutians stock, Efimov (1984) estimated K = 0.285 for the Gulf of Alaska stock. Using growth data presented by Efimov, we also estimated K = 0.285. Therefore, differences in sampling, growth, and possibly age determination have caused differences in K estimates.

Although many authors use the Alverson and Carney (1975) formula $t_{mb} = 0.25\ t_m$ to estimate t_{mb} (where t_m is the oldest age found in the unfished population), the appropriateness of this formula should be questioned. Apparently, this formula assumes M = K, and Alverson and Carney (1975) themselves conclude that the estimate $t_{mb} = 0.38\ t_m$ better fits biologically-based estimates of M found in the literature.

Finding an appropriate estimate of t_m is also difficult. Efimov (1984) used $t_m = 12$ yr for the Gulf of Alaska stock, which seems appropriate in light of Gorbunova (1962) reporting 11 yr as the maximum observed age in the Kamchatka region. In the data for the exploited Aleutian stock, fish older than 8 yr are rare, and it seems reasonable to consider a t_m of 10 yr.

Given these uncertainties , we found a wide range of possible estimates for M (Table 52). The instantaneous natural mortality rate estimates range from 0.10 to 0.47 for K = 0.66, or from 0.32 to 0.82 for K = 0.285. We feel that Efimov's (1984) estimate of M = 0.63, based on K = 0.285, $t_{mb} = 0.25\ t_m$, and $t_m = 12$ yr, is too high for the Aleutian stock. Using our Aleutian age information, we feel M = 0.18 based on K = 0.66, $t_{mb} = 0.38\ t_m$, and $t_m = 10$ yr is more realistic. Nevertheless, there is obviously room for considerable error in this estimate.

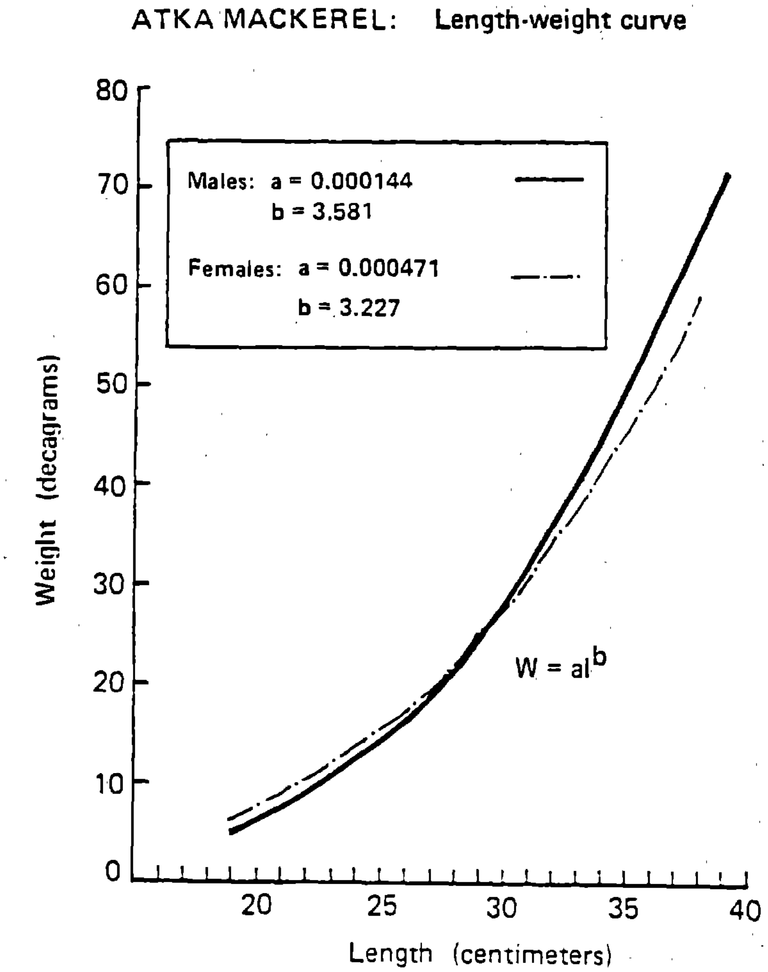

Figure 44.-- Estimated length-weight relationship for male and female Atka mackerel in the Aleutian Islands region.

Table 52.--Estimates of the instantaneous natural mortality rate (M) for Atka mackerel in the Aleutian Islands region based on the method of Alverson and Carney (1975).

Von Bertalanffy (K)	Age of maximum biomass (t_{mb})	Maximum age in the unfished population (t_m)	Estimates of M
0.66 (present study)	0.25 t_m	10	0.47
		12	0.32
	0.38 t_m	10	0.18
		12	0.10
0.285 Efimov (1984)	0.25 t_m	10	0.82
		12	0.63
	0.38 t_m	10	0.44
		12	0.32

ESTIMATES OF MAXIMUM SUSTAINABLE YIELD

Maximum Sustainable Yield (MSY) was estimated for Atka mackerel stocks in the Aleutian region using Stock Reduction Analysis (SRA) (Kimura and Tagart 1982; Kimura et al. 1984). In the assessment presented here, SRA was used to estimate the average recruitment level from 1974 to 1983. For this analysis, we require annual commercial catches in weight, survey biomass estimates at two points in time, and an estimate of M. Catch, data were used from the years 1974-82 (Tables 47 and 48), and all catches from the years 1974-77 were assumed to be from the Aleutian region.

Given the commercial catches, an estimate of M (Table 52), and an initial population biomass at the beginning of 1974 of 100,000 t (Table 50), the average recruitment biomass level required to obtain a given final population biomass (at the beginning of 1,983) can be calculated by solving the SRA equations. Once the average recruitment level has been estimated, equilibrium biomass estimates and MSY estimates can be calculated from simple formulas (Kimura et al. 1984). The MSY was assumed to be achieved at the fishing intensity F = M (Gulland 1970; Francis 1974), which reduces the standing biomass to about one-half the unfished biomass level.

Table 53 shows the results of the SRA stock assessment for four possible levels of instantaneous natural mortality (0.1, 0.2, 0.3 and 0.6), an initial biomass of 100,000 t, and final biomass of 100,000 t, 300,000 t, and 500,000 t. These final biomasses approximate the 1983 survey biomass estimate and the 95% confidence interval around this estimate (Table 50).

Several comments should be made concerning this assessment. First, the estimated MSY values are relatively insensitive to the 1974 initial biomass estimate, but are sensitive to the final biomass estimate. Second, a Brody coefficient (p) of zero was used in the SRA model, which along with the assumption of constant recruitment makes it unnecessary to specify the age at recruitment. Also, we feel the estimated MSY values for M = 0.60 are unrealistically high and they were included only for comparative purposes.

Using the best available information concerning Atka mackerel stocks in the Aleutian region, MSY is estimated to be 38,734 t (assuming M = 0.20 and a 1983 survey biomass estimate of 300,000 t). Intervals around this MSY estimate can be considered by varying either 1983 survey biomass estimates, natural mortality rate estimates, or both. Varying the 1983 survey biomass estimates in the 100,000 to 500,000 t range affects MSY estimates considerably more than varying M between 0.10 and 0.30 (the probable range for both parameters) (Table 54). Therefore, the estimated MSY of 38,734 t can probably be achieved if the 1983 survey biomass is correct.

This MSY was estimated using data from the past 10 yr when recruitment appeared to be unusually strong. For this reason, long-term MSY may have been overestimated.

Table 53.--Estimates of recruitment, equilibrium biomass (assuming F = 0 and F = M) and maximum sustainable yield for Atka mackerel in the Aleutian Islands region. All biomass estimates are in metric tons.

Presumed natural mortality rate (M)	Presumed intial biomass 1974	Presumed final biomass 1983	SRA P-value	SRA$^{1/}$ recruitment biomass	Equilibrium biomass under no fishing	Equilibrium biomass assuming F = M	Exploitation rate assuming F = M	MSY assuming F = M
M = 0.10	100,000	100,000 low	1	25,678	269,833	141,657	0.091	12,891
		300,000 middle	3	57,766	607,024	318,675	0.091	28,999
		500,000 high	5	89,842	944,090	495,627	0.091	45,102
M = 0.20	100,000	100,000 low	1	34,000	187,130	103,130	0.165	17,000
		300,000 middle	3	77,469	427,370	234,982	0.165	38,734
		500,000 high	5	120,910	667,019	366,750	0.165	60,455
M = 0.30	100,000	100,000 low	1	41,283	159,282	91,498	0.226	20,641
		300,000 middle	3	96,912	373,915	214,793	0.226	48,456
		500,000 high	5	152,496	588,375	337,987	0.226	76,248
M = 0.60	100,000	100,000 low	1	58,397	129,429	83,567	0.349	29,199
		300,000 middle	3	149,171	330,618	213,466	0.349	74,586
		500,000 high	5	239,842	531,578	343,217	0.349	119,921

[1/] Since p = zero in the SRA model, "recruitment" includes both growth in the fishable biomass and the recruitment biomass of new fish.

Table 54.--Intervals around the estimated MSY of Atka mackerel in the Aleutian Islands region (summarized from Table 51).

	Estimated MSY (t)		
	Varying 1983[a] survey biomass (M = 0.2)	Varying estimates[b] of M (1983 biomass = 300,000 t)	Varying both 1983[c] survey biomass and estimates of M
Low	17,000	28,999	12,891
Middle	38,734	38,734	38,734
High	60,455	48,456	76,248

[a] Low, medium, and high estimates of 1983 biomass are 100,000 t, 300,000 t, and 500,000 t (Table 49).

[b] Low, medium, and high estimates of M are 0.10, 0.20, and 0.30 (Table 50).

[c] Parameters were selected as in footnotes a and b, to provide the greatest range possible.

EQUILIBRIUM YIELD

Under current stock conditions, it appears that the estimated MSY of 38,734 t is attainable. Nevertheless, a final warning should probably be repeated concerning the length-frequency (Fig. 40) and age-frequency (Fig. 42) data. These data seem to indicate that no new, strong recruitment has occurred and that strong year-classes are about to leave the fishery, perhaps leading to a substantial stock decline. If this should happen, the stock should be reassessed and the allowable catch possibly reduced.

The present estimates of yield are based on biomass estimates from the joint U.S.-Japan trawl surveys in 1980 and 1983. These surveys provided biomass estimates for the entire Aleutian region. In the 1980 and 1983 surveys, the majority of the total biomass, 74.1% and 60.5%, respectively, were located west of 180° longitude. This contrasts with the fisheries, whose removals during this time period have been mainly from a 3° longitudinal strip east of 180° (long. 171° -174° W). If the yield in the Aleutian region were apportioned according to the results of the 1983 survey, 23,434 t would be assigned west of 180°, and 15,300, t east of 180°.

If the geographic size distribution found in the 1983 U.S.-Japan trawl survey is still correct (Fig. 41), fishing Atka mackerel west of 180° will mean catching more small fish. Nevertheless, it is probably desireable to reduce the fishing pressure in the 3° longitudinal band in the eastern Aleutian region where all the large catches have occurred, thereby preserving some spawning stock for the area. If the fishery is allowed to continue harvesting the majority of its catch from this 3° longitudinal band, and there is no significant recruitment or migration to the area, the fishery will be forced to move anyway when the dominant 1977 year-class leaves the fishery. In this case we may be left with a much reduced brood stock for this potentially productive area.

SQUID

by

Richard G. Bakkala

INTRODUCTION

With the exception of some recent publications (Bubblitz 1981; Mercer 1981; Fiscus and Mercer 1982; Wilson and Corham 1982), there is little information available on distribution, abundance, and biology of squid stocks in the eastern Bering Sea and Aleutian Is-lands regions. Squid are generally taken incidentally or are temporarily targeted by trawl fisheries when large concentrations are encountered. *Berryteuthis magister* and *Onychoteuthis borealijaponicus* are the major components of squid catches. B. *magister* predominates in catches made in the eastern Bering Sea, whereas O. *borealijaponicus* is the principal species encountered in the Aleutian Islands region.

After reaching 9,000 metric tons (t) in 1978, total all-nation catches of squid declined to 3,100 t in 1984 (Table 55). The distribution of catches shows that the major fishing ground is on the continental slope of the eastern Bering Sea where squid have been mainly taken by the landbased dragnet fishery, surimi factory trawlers, and frozen fish factory trawlers. In this region, catch per unit of effort (CPUE) values standardized over the three vessel types (Okada 1985) have shown some fluctuations but have generally been relatively stable. as shown below:

Year	1976	1977	1978	1979	1980	1981	1982	1983	1984
CPUE	0.025	0.026	0.044	0.027	0.022	0.024	0.024	0.025	0.034

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) is unknown but is believed to be at least equal to the highest catch of record. A minimum estimate of MSY has therefore been established at 10,000 t.

EQUILIBRIUM YIELD

Catches of 10,000 t are believed to be sustainable.

Table 55.--Catches of squid in metric tons (t) by nation in the Aleutian Islands region and eastern Bering Sea 1977-84.[a]

	Aleutian Islands Region				Eastern Bering Sea				
Year	Japan	R.O.K.	Others	Total	Japan	R.O.K.	Others	Total	Regions Combined
1977	1,808			1,808	4,926			4,926	6,734
1978	2,085			2,085	6,821	34	31	6,886	8,971
1979	2,250	2		2,252	2,886	1,359	41	4,286	6,538
1980	2,328		4	2,332	2,313	1,620	107	4,040	6,372
1981	1,697	65		1,762	2,983	1,032	164	4,179	5,941
1982	1,177	11	13	1,201	3,308	484	45	3,837	5,038
1983	452	52	20	524	3,346	104	5	3,455	3,979
1984	325		1	326	2,614	110	74	2,798	3,124

[a] Catches in 1977-79 from data submitted to the United States by fishing nations; 1980-84 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a.

[b] Republic of Korea.

[c] Taiwan, Federal Republic of Germany, Poland, and U.S. joint ventures.

OTHER SPECIES

by

Richard G. Bakkala

INTRODUCTION

The "other species" category has been established by the North Pacific Fishery Management Council to account for species which are currently of slight economic value and not generally targeted, but have potential economic value or are important ecosystem components. Because there is insufficient data to manage each species separately, they are considered collectively. Catch records of this species category as a whole must be maintained by the fishery and a "total allowable catch" is established by the council for this group.

The "other species" category consists of five groups of species: sculpins, sharks, skates, smelts, and octopuses. Numerous species of sculpins occur in the Bering Sea. Cooperative U.S.-Japan surveys identified 34 species in the eastern Bering Sea in 1979, and 22 species in the Aleutian Islands region in 1980 (Bakkala et al. 1985a; Ronholt et al. 1985). Species of smelt occurring in the regions are capelin, *Mallotus villosus*; rainbow smelt, *Osmerus mordax*; and eulachon, *Thaleichthys pacificus*. Sharks are rarely taken during demersal trawl surveys in the Bering Sea; the species normally caught is spiny dogfish, *Squalus acanthias*, but one occurrence of Pacific sleeper shark, *Somniosus pacificus*, has also been recorded. Two species of octopuses have been recorded, with *Octopus dofleini* the principal species and *Opisthoteuthis californiana* appearing intermittently in catches.

COMMERCIAL CATCHES AND ABUNDANCE ESTIMATES

Reported catches in the "other fish" category reached a peak of 133,340 metric tons (t) in 1972, but have since substantially declined and were only 10,200 t in 1984 (Table 56). The species composition of these catches is unknown, and it is likely that they include species from both the "other fish" and "nonspecified species" categories (see Table 1 for species included in this latter category).

Data from large-scale surveys of the eastern Bering Sea in 1975 and 1979-85 and the Aleutian Islands region in 1980 and 1983 provide abundance estimates for the "other species" category and the relative importance of the various species comprising this category (Table 57). The estimates illustrate that sculpins are the major component of the "other species" category, but that skates have become an increasingly important component in the eastern Bering Sea. The estimates indicate that the abundance of the group as a whole, may have doubled in the eastern Bering Sea between 1975 and 1979, increased further through 1981, and then declined to below the 1979 level in 1985.

Table 56.--All-nation catches of other fish in metric tons, 1964-84.[a]

Year	Aleutian Island region	Eastern Bering Sea	Total
1964	66	736	802
1965	768	2,218	2,986
1966	131	2,239	2,370
1967	8,542	4,378	12,920
1968	8,948	22,058	31,006
1969	3,088	10,459	13,547
1970	10,671	15,295	25,966
1971	2,973	33,496	36,469
1972	22,447	110,893	133,340
1973	4,244	55,826	60,070
1974	9,724	60,263	69,987
1975	8,288	54,845	63,133
1976	7,053	26,143	33,196
1977	16,170	35,902	52,072
1978	12,436	61,537	73,973
1979	12,934	38,767	51,701
1980	13,004	33,949	46,953
1981	7,274	35,551	42,825
1982	5,167	18,200	23,367
1983	3,193	11,062	14,255
1984	1,669	8,508	10,177

[a] Data for 1964-80 from catches reported to the United States by fishing nations: 1981-84 data from French et al. 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a.

Table 57.--Biomass estimates (in metric tons) of other species from large-scale demersal trawl surveys in 1975 and 1979-85.[a]

Area	Year	Species Group					
		Sculpins	Skates	Smelts	Sharks	Octopuses	Total
Eastern Bering Sea	1975	122,500	42,000	28,700	0	8,600	201,800
	1979	251,800	88,700	11,700	200	49,500	401,900
	1980	281,100	114,900	15,500	0	17,400	428,900
	1981	350,200	246,800	4,200	0	13,100	614,300
	1982	291,300	168,000	10,100	0	13,100	482,500
	1983	277,000	188,200	5,100	0	3,400	473,700
	1984	237,100	187,800	10,000	0	2,600	437,500
	1985	174,744	298,122	2,686	407	2,828	478,787
Aleutian Islands Region	1980	39,400	13,700	0	800	2,800	56,700
	1983	20,500	12,100	0	0	200	32,800

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[a] The biomass estimates for the eastern Bering Sea are from the approximate area shown in Figure 4. The 1979, 1981, 1982 data include estimates from continental slope waters (200-1,000 m), but other year's data do not.

It should be pointed out that smelts may be poorly sampled by demersal trawls because species of this family may primarily inhabit pelagic waters. The abundance of this family is, therefore, assumed to be substantially underestimated. Estimates indicate that the "other species" group may be from 7-13% as abundant in the Aleutian Islands region as they are in the eastern Bering Sea (Table 57).

MAXIMUM SUSTAINABLE YIELD

In view of the apparent major increase in abundance of the "other species" category in the eastern Bering Sea (Table 57), this aggregation of stocks in 1981 may have been somewhere between a level that produces MSY and the level of the virgin population size. Using 1) the assumption that the combined biomass estimates from the 1981 eastern Bering Sea and 1980 Aleutian surveys approximated virgin biomass and 2) a natural mortality coefficient of 0.2, the Alverson and Pereyra (1969) yield equation would indicate that MSY (i.e., MSY = 0.5 x 0.2 x 671,000 t) is 67,100 t.

EQUILIBRIUM YIELD

Based on the combined biomass estimates (359,200 t) from the 1985 eastern Bering Sea and 1983 Aleutian Islands surveys, the MSY of 67,200 t would represent an exploitation rate of 19%. Due to the uncertainties in the assumptions for estimating MSY, it is recommended that the equilibrium yield (EY) for the "other species" category be set at 10% of the current biomass estimate or 35,900 t. This estimate is well above current catch levels.

REFERENCES

Alton, M. S., and R. A. Fredin.
1974. Status of Alaska pollock in the eastern Bering Sea. Unpubl. manuscr., 10 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish.. Serv., NOAA,, 2725 Montlake Blvd. E., Seattle, WA 98112.

Alverson, D. L., and M. J. Carney.
1975. A graphic review of the growth and decay of population cohorts. J. Cons., Cons. Int. Explor. Mer 36:133-143.

Alverson, D. L., and W. T. Pereyra.
1969. Demersal fish explorations in the northeastern Pacific ocean--an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26: 1985-2001.

Archibald, C. P., D. Fournier, and B. M. Leaman.
1983. Reconstruction of stock history and development of rehabilitation strategies for Pacific ocean perch in Queen Charlotte Sound, Canada. N. Am. J. Fish. Manage. 3: 283-294.

Archibald, C. P., W. Shaw, and B. M. Leaman.
1981. Growth and mortality estimates of rockfishes (Scorpaenidae) from B.C. coastal waters, 1977-79. Can. Tech. Rep. Fish. Aquat. Sci. 1048, 57 p.

Bakkala, R. G.
1984. Pacific cod of the eastern Bering Sea. Int. North Pac. Fish. conun., Bull. 42:157-179.

1985a. Other flatfish. In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 83-95. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

1985b. Greenland turbot and arrowtooth flounder. In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 6.7-81. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

Bakkala, R., L. Low, and V. Wespestad.
1979. Condition of groundfish resources in the Bering Sea and Aleutian area. Unpubl. manuscr., 105 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Bakkala, R. G., and J. J. Traynor.
1984. Walleye pollock. In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1983, p. 1-20. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-53.

Bakkala, R. G., K. Wakabayashi, and T. M. Sample.
1985a. Results of the demersal trawl surveys. In R. G. Bakkala and K. Wakabayashi (editors), Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May-August 1979, p. 39-191. Int. N. Pac. Fish. Comm., Bull. 44.

Bakkala, R. G., and V. G. Wespestad.
1985. Pacific cod. In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1984, p. 37-49 U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-83.

Bakkala, R., V. Wespestad, and L. Low.
1982. The yellowfin sole (Limanda aspera) resource of the eastern Bering Sea--its current and future potential for commercial fisheries. U. S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-33, 43 p.

1985b. Historical trends in abundance and current condition of walleye pollock in the eastern Bering Sea. Unpubl. Manuscr., 39 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Bakkala, R., V. Wespestad, L. Low, and J. Traynor.
1980. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1980. Unpubl. manuscr., 98 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Bakkala, R., V. Wespestad, T. Sample, R. Narita, R. Nelson, D. Ito, M. Alton, L. Low, J. Wall, and R. French.
1981. Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1981. Unpubl. manuscr., 152 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Bakkala, R. G., V. G. Wespestad, and H. H. Zenger Jr.
1983. Pacific cod, In R. G. Bakkala and L. L. Low (editors), Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1982, p. 29-50. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC:42.

Balsiger, J. W., D. H. Ito, D. K. Kimura, D. A. Somerton, and J. M. Terry.
1985. Biological and economic assessment of Pacific ocean perch (Sebastes alutus) in waters off Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-72, 210 p.

Beamish, R. J.
1979. New information on the longevity of Pacific ocean perch (Sebastes alutus)., J. Fish. Res. Board Can. 36:1395-1400.

Berger, J., J. Wall, and R. Nelson, Jr.
1984. summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1983. Unpubl. manuscr., 211 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Berger, J., R. Nelson, and J. Wall.
1985a. Summaries of provisional foreign and joint-venture groundfish catches (metric tons) in the northeast Pacific Ocean and Bering Sea, 1984. Unpubl. manuscr., 179 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Berger, J., J. Wall, and R. Nelson, Jr.
1985b. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, l984. Unpubl. manuscr. Northwest and Alaska. Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Bubblitz, C. G.
1981. Systematics of the cephalopod family Gonatidae from the southeastern Bering Sea. M.S. Thesis, Univ. Alaska, Fairbanks, AK, 177 p.

Chikuni, S.
1975. Biological study on the population of the Pacific ocean perch in the North Pacific. Bull. Far Seas Fish. Res. Lab. (Shimizu) 12:1-119.

Chilton, D. E., and R. J. Beamish.
1982. Age determination methods for fishes studied by the Groundfish Program at the Pacific Biological Station. Can. Spec. Publ. Fish. Aquat. Sci. 60, 102 p.

Deriso, R. B.
1980. Harvesting strategies and parameter estimation for an age-structured model. Can. J. Fish. Aquat. Sci. 37:268-282.

Deriso, R. B.
(In press). Optimal $F_{0.1}$ policies and other. new results in yield theory. Can. J. Fish. Aquat. Sci.

Deriso, R. B., T. J. Quinn II, and P. R. Neal.
1985. Catch-age analysis with auxiliary information. Can. J. Fish. Aquat. Sci. 42: 815-824.

Doubleday, W. G.
1976. A least squares approach to analyzing catch at age data. Int. comm. Northwest Atl. Fish. Res. Bull. 12:68-81.

Efimov, Y. N.
1984. Stock condition and assessment of the maxim&sustainable yield of Atka mackerel in the Gulf of Alaska. Int. North Pac. Fish. Comm., Bull. 42:82-84.

Fabens, A. J.
1965. Properties and fitting of the von Bertalanffy growth curve. Growth 29: 265-289.

Fiscsus, C. H., and R. W. Mercer.
1982. Squids taken in surface gillnets in the North Pacific Ocean by the Pacific Salmon Investigation program, 1955-72. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-28, 32 p.

Forrester, C. R., R. G. Bakkala, K. Okada, and J. E. Smith.
1983. Groundfish, shrimp, and herring fisheries in the Bering Sea and northeast Pacific-historical catch statistics, 1971-1976. Int. N. Pac. Fish. Comm., Bull. 41, 100 p.

Forrester, C. R., A. J. Beardsley and Y. Takahashi.
1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and northeast Pacific-historical catch statistics through 1970. Int. N. Pac. Fish. Comm., Bull. 37, 147 p.

Francis, R. C.
1974. Relationship of fishing mortality to natural mortality at the level of maximum sustainable yield under the logistic stock, production model. J. Fish. Res. Board Can. 31: 1539-1542.

Fredin, R. A.
1985. Pacific cod in the eastern Bering Sea: a synopsis. NWAFC Processed Rep. 85-05, 58 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

French, R., R. Nelson Jr., J. Wall, J. Berger, and B. Gibbs.
1981. Summaries of provisional foreign groundfish catches (metric tons) in the northeast Pacific Ocean and Bering Sea, 1980. Unpubl. manuscr., 188 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1982. Summaries of provisional foreign and joint-venture groundfish catches (metric tons) in the northeast Pacific Ocean and Bering Sea, 1981. Unpubl. manuscr., 183 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Garrod, D. J.
1973. The variation of replacement and survival in some fish stocks. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 164:43-56.

Gorbunova, N. N.
1962. Razmnozhenie i razvite ryb semeistva terpugovykh (Hexagrammidae) (Spawning and development of greenlings (family Hexagrammidae)). Tr. Inst. Okeanol., Akad. Nauk SSSR 59:118 - 182. In Russian. (Transl. by Isr. Program Sci. Transl., 1970, p. 121 - 185 in T. S. Rass (editor), Greenlings: taxonomy, biology, interoceanic transplantation; available from U. S. Dep. Commer., Natl. Tech. Inf. Serv., Springfield, VA., as TT 69 - 55097.)

Grauman, G. B. 1973. Investigations of factors influencing fluctuations in abundance of Baltic cod. Rapp. P.-V. Reun. Cons. Int. Explor. Mer 164:73-76.

Gulland, J. A.
1965. Estimation of mortality rates. Annex to Arctic Fisheries Working Group report (meeting in Hamburg, January 1965). Int. Counc. Explor. Sea, C.M. 1965, Doc. 3.

1970. The fish resources of the ocean. Food Agric. Organ. U.N., Rome, FAO Fish. Tech. Pap. 97,425 p.

International Council for the Exploration of the Sea.
1984. Reports of the Ad Hoc Working Group on the use of effort data in assessments of the working group on methods of fish stock assessments. Int. Counc. Explor. Sea, Coop. Res. Rep. 129, 134 pp.

Ito, D. H.
1982. A cohort analysis of Pacific ocean perch stocks from the Gulf of Alaska and Bering Sea regions.: NWAFC processed Rep. 82-15, 157 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Kimura, D. K.
1977. Statistical assessment of the age-length key. J. Fish. Res. Board Can. 34:317-324.

1981. Likelihood methods for the von Bertalanffy growth curve. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 77:765-776.

1984. Forecasting stock biomass and variability by modeling recruitment. Unpubl. manuscr., 24 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1985a. Fishable biomass virtual population analysis. Unpubl. manuscr., 36 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

1985b. Changes in stock reduction analysis indicated by Schnutes general theory. Can. J. Fish. Aquat. Sci. 42:2059-2060.

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

Kimura, D. K., and J. V. Tagart.
1982. Stock Reduction Analysis, another solution to the catch equations. Can. J. Fish. Aquat. Sci. 39:1467-1472.

Lai, H. L.
1985. Evaluation and validation of age determination for sablefish, pollock, Pacific cod and yellowfin sole: optimum sampling design using age-length key; and implications of aging variability in pollock. Ph.D. Thesis, Univ. Washington, Seattle, WA, 426 p.

Levada, T. P.
1979a. Comparative morphological study of Atka mackerel. Unpubl. manuscr., 7 p. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R.

1979b. Some data on biology and catch of Atka mackerel. Unpubl. manuscr., 13 p. Pac. Sci. Res. Inst. Fish. Oceanogr. (TINRO), Vladivostok, U.S.S.R.

Low, L. L.
1974. A study of four major groundfish fisheries of the Bering Sea. Ph.D. Thesis, Univ. Washington, Seattle, WA, 241 p.

1984. Applications of a Laevastu-Larkins ecosystem model for Bering Sea groundfish management. Food Agric. Organ. U. N., Rome, FAO Fish. Rep. 291 (3):1161-1176.

Low, L. L., R. Bakkala, H. Larkins, S. Mizroch, V. Wespestad, and J. Akada.
1978. Information on groundfish resources in the Bering Sea and Aleutian region. Unpubl. manuscr., 92 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Low, L. L., and I. Ikeda.
1980. Average density index for walleye pollock (Theragra chalcogramma), in the Bering Sea. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-743, 11 p.

Low, L. L., J. A. Mizroch, and M. Alton.
1977. Status of Alaska pollock stocks in the eastern Bering Sea. Unpubl. manuscr., 33 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Low, L., and V. Wespestad.
1979. General production models on sablefish in the North Pacific. Unpubl. manuscr., 16 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

MacDonald, P. D. M., and T. J. Pitcher.
1979. Age-groups from size frequency data: a versatile and efficient method of analyzing distribution mixtures. J. Fish. Res. Board Can. 36:987-1001.

Mercer, R. W. (editor).
1981. Proceedings of the squid workshop sponsored by the Resource Assessment and Conservation Engineering Division, Northwest and Alaska Fisheries Center, 19-20 March 1981, Seattle, Wash., NWAFC Processed Rep. 81-11, 34 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Moiseev, P. A.
1953. Treska i kambaly dal' nevostochnykh morei (Cod and flounders of Far Eastern seas.) Izv. Tikhookean. Nauchno-Issled. Inst. Rybn. Khoz. Okeanogr. 40: 1-287 In Russian. (Fish. Res. Board. Can. Transl. No. 119).

Nelson, R. Jr., R. French, and J. Wall.
1979. Summary of U.S. observer sampling of foreign fishing vessels in Bering Sea/Aleutian Islands region, 1978. Unpubl. manuscr., 75 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1980. Summary of U.S. observer sampling on foreign fishing vessels in Bering Sea/Aleutian Islands region, 1979. Unpubl. manuscr., 85 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1981a. Sampling by U.S. observers on foreign fishing vessels in the eastern Bering Sea and Aleutian Islands region, 1977-78. U.S. Natl. Mar. Fish. Serv., Mar. Fish. Rev. 43(5):1-19.

1981b. Summary of U.S. observer sampling on foreign fishing vessels in the Bering Sea/Aleutian Islands Region, 1980. Unpubl. manuscr., 69 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Nelson, R. Jr., R. French, J. Wall, and D. Hennick.
1978. Summary of U.S. observer sampling of foreign fishing vessels in Bering Sea/Aleutian Islands areas, 1977. Unpubl. manuscr., 73 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Nelson, R., Jr., J. Wall, and J. Berger.
1982. Summary of U.S. observer sampling of foreign and joint venture fisheries in the Bering Sea/Aleutian Islands region, 1981. Unpubl. manuscr., 81 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1983a. Summary of U.S. observer sampling of foreign and joint-venture fisheries in the northeast Pacific Ocean and eastern Bering Sea, 1982. Unpubl. manuscr., 224 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Nelson, R., Jr., J. Wall, J. Berger, and B. Gibbs.
1983b. Summaries of provisional foreign and joint-venture groundfish catches (metric tons) in the northeast Pacific and Bering Sea, 1982. Unpubl. manuscr., 167 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

1984. Summaries of provisional foreign and joint-venture groundfish catches (metric tons) in the northeast Pacific Ocean and Bering Sea, 1983. Unpubl. manuscr, 172 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv.; NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

North Pacific Fishery Management Council.
1983. Fishery management plan for the groundfish fishery in the Bering Sea/Aleutian Islands area. North Pac. Fish. Manage. Count., P.O. Box 103136, Anchorage, AK 99510.

Okada, K.
1983. Biological characteristics and abundance of the pelagic pollock in the Aleutian Basin. Unpubl. manuscr., 12 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

1985. Condition of Pacific ocean perch, rockfishes, thornyheads, and squid stocks in the Bering Sea and Aleutian Islands region in 1984. Unpubl. manuscr., 8 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Okada, K., H. Yamaguchi, T. Sasaki, and K. Wakabayashi.
1980. Trends of groundfish stocks in the Bering Sea and the northeastern Pacific based on additional preliminary statistical data in 1979. Unpubl. manuscr., 37 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 1000 Orido, Shimizu 424, Japan.

1982. Trends of groundfish stocks in the Bering Sea and the northeastern Pacific based on additional preliminary statistical data in 1981. Unpubl. manuscr., 80 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 1000 Orido, Shimizu 424, Japan.

Pella, J. J., and P. K. Tomlinson.
1969. A generalized stock production model. Int.-Am. Trop. Tuna Comm. Bull. 13(3):5-22.

Pienaar, L. V., and W. E. Ricker.
1968. Estimating mean weight from length statistics. J. Fish. Res. Board Can. 25:2743-2747.

Pope, J. G.
1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northwest Atl. Fish. Res. Bull. 9:65-74.

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

Rivard, D., and L. J. Bledsoe.
1978. Parameter estimation for the Pella-Tomlinson stock production model under nonequilibrium conditions. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 76:523-534.

Ronholt, L. L., K. Wakabayashi, T. K. Wilderbuer, H. Yamaguchi, and K. Okada.
1985. Results of, the cooperative U.S. -Japan groundfish resource assessment survey in Aleutian Islands waters, June-November 1980. Unpubl. manuscr., 303 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Sasaki, T.

1978. Recalculation of longline effort and stock assessment of blackcod in the north Pacific. Unpubl. rep., 23 p. Far Seas Fish. Res. Lab., Jpn. Fish Agency, 1000 Orido, Shimizu 424, Japan.

1985a. Condition of pollock stock in the eastern Bering Sea in 1984. Unpubl . rep., 21 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 1000 Orido, Shimizu 424, Japan.

1985b. Studies on the sablefish resources in the North Pacific Ocean. Unpubl. manuscr., 108 p. Far Seas Fish. Res. Lab., Japan Fish Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

1985c. Condition of sablefish stocks in the eastern Bering Sea, the Aleutian Region, and Gulf of Alaska in 1984. Unpubl. manuscr., 23 p. Far Seas Fish. Res. Lab., Japan Fish. Agency, 7-1, Orido 5 chome, Shimizu 424, Japan.

Schaefer, M. B.

1954. Some aspects of the dynamics of populations important to the management of commercial marine fisheries. Int.-Am. Trop. Tuna. Comm. Bull. 1(2):25-56.

Smith, G. B.

1981. The biology of walleye pollock. In D. W. Hood and J. A. Calder (editors). The eastern Bering Sea shelf: oceanography and resources, Volume 1, p. 527-551. U.S. Gov. Print. Off., Washington, D.C.

Tagart, J. V.

1982. Status of yellowtail rockfish (Sebastes flavidus) fishery. Wash. Dep. Fish., Tech. Rep. 71, 64 p.

Teshima, K.

1984. Maturation of Pacific cod in the eastern Bering Sea. Bull. Jpn. Soc. Sci. Fish. 51:29-31.

Thomson, J. A.

1962. On the fecundity of Pacific cod (Gadus macrocephalus Tilesius) from Hecate Strait, British Columbia. J. Fish. Res. Board Can. 19:497-500.

Umeda, Y., and R. Bakkala.

1983. Data report: 1980 demersal trawl survey of the eastern Bering Sea continental shelf. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-49, 175 p.

Umeda, Y., T. M. Sample, and R. G. Bakkala.

1983. Recruitment processes of sablefish in the eastern Bering Sea. In Proceedings of the International Sablefish Symposium, p. 291-303. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Fairbanks, Alaska Sea Grant Program, Alaska Sea Grant Rep. 83-8.

Wakabayashi, K.

1975. Studies on resources of yellowfin sole in the eastern Bering Sea. Unpubl. manuscr., 8 p. Far Seas Fish. Res. Lab., Jpn. Fish. Agency, 1000 Orido, Shimizu 424, Japan.

1985. Condition of flounder stocks in the Bering Sea and Aleutian Islands region in 1984. Unpubl. manuscr., 37 p. Far Sea Fish. Res. Lab., Japan.