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U.S. DEPARTMENT OF COMMERCE
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ABSTRACT

This report contains assessments of the condition 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 1984. Estimates of maximum sustainable yields and equilibrium yields are presented to guide management of the 1985 fishery. Table A summarizes results of these assessments.

Pacific cod, yellowfin sole, other flatfish, and Atka mackerel are in excellent condition with current populations at or near recorded high levels of abundance. The abundance of the adult stock of pollock remains relatively high, but is declining because of the recruitment of a recent series of weak year-classes. Poor recruitment has also reduced the abundance of adult Greenland turbot. There has been some improvement in sablefish stocks, but Pacific ocean perch stocks remain at low levels with no signs of improvement. Estimates of equilibrium yield for the groundfish complex as a whole decreased slightly from 2.25 million metric tons (t) in 1984 to 2.19 million t in 1985.

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 1984.

Species	Estimated biomass	MSY	EY	Stock condition	Abundance trend
Pollock	8,900	1,600	1,200		
(Eastern Bering Sea)[a]	(7,900)	(1,500)	(1,100)	Fair	Abundance declining and recruitment poor
(Aleutians)	(1,000)	(100)	(100)	Good	
Pacific cod	1,176	--	347.4	Very good	Abundance starting to decline from historic high
Yellowfin sole	3,366	150-175	310	Very good	Abundance starting to decline from historic high
Turbots	290	86.7	57.5		
(Arrowtooth flounder)	(123)	(19.7)	(20.0)	Good	Abundance increasing
(Greenland turbot)	(167)	(67.0)	(37.5)	Fair	Abundance below average
Other flatfish	2,087	88-150	150		
(Alaska plaice)	(727)	(45-70)	(70)	Very good	Abundance above average and stable
(Rock sole-flathead sole-other flatfish)	(1,360)	(43-80)	(80)	Very good	Abundance above average and stable
Sablefish	119.5	15.1	6.0		
(Eastern Bering Sea)	(52.3)	(13.0)	(2.6)	Improved	Although improved, below historic levels
(Aleutians)	(67.2)	(2.1)	(3.4)	Improved	
Pacific ocean perch	127.5	9.4-16.9	12.8		
(Eastern Bering Sea)	(13.6)	(2.8- 5.0)	(1.4)	Poor	Abundance low and stable
(Aleutians)	(113.9)	(6.6-11.9)	(11.4)	Poor	Abundance low and stable
Other rockfish	89.5	30-60	8.9		
(Eastern Bering Sea)	(11.2)	(7-15)	(1.1)	Unknown	Unknown
(Aleutians)	(78.3)	(23-45)	(7.8)	Unknown	Unknown
Atka mackerel	300	38.7	38.7	Good	Abundance above average
Squid	-	>10	10	--	Unknown
Other species	467	67.2	46.7	Good	Abundance average and stable
TOTAL GROUNDFISH	16,922	2,095-2,220	2,188		

[a]Numbers in parentheses give estimates for individual management areas where appropriate and for individual species making up a 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 1985 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 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 independently. 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 fishing oh Bowers Ridge in INPFC area 3 (Fig. 1) is included with catches from the Aleutians.

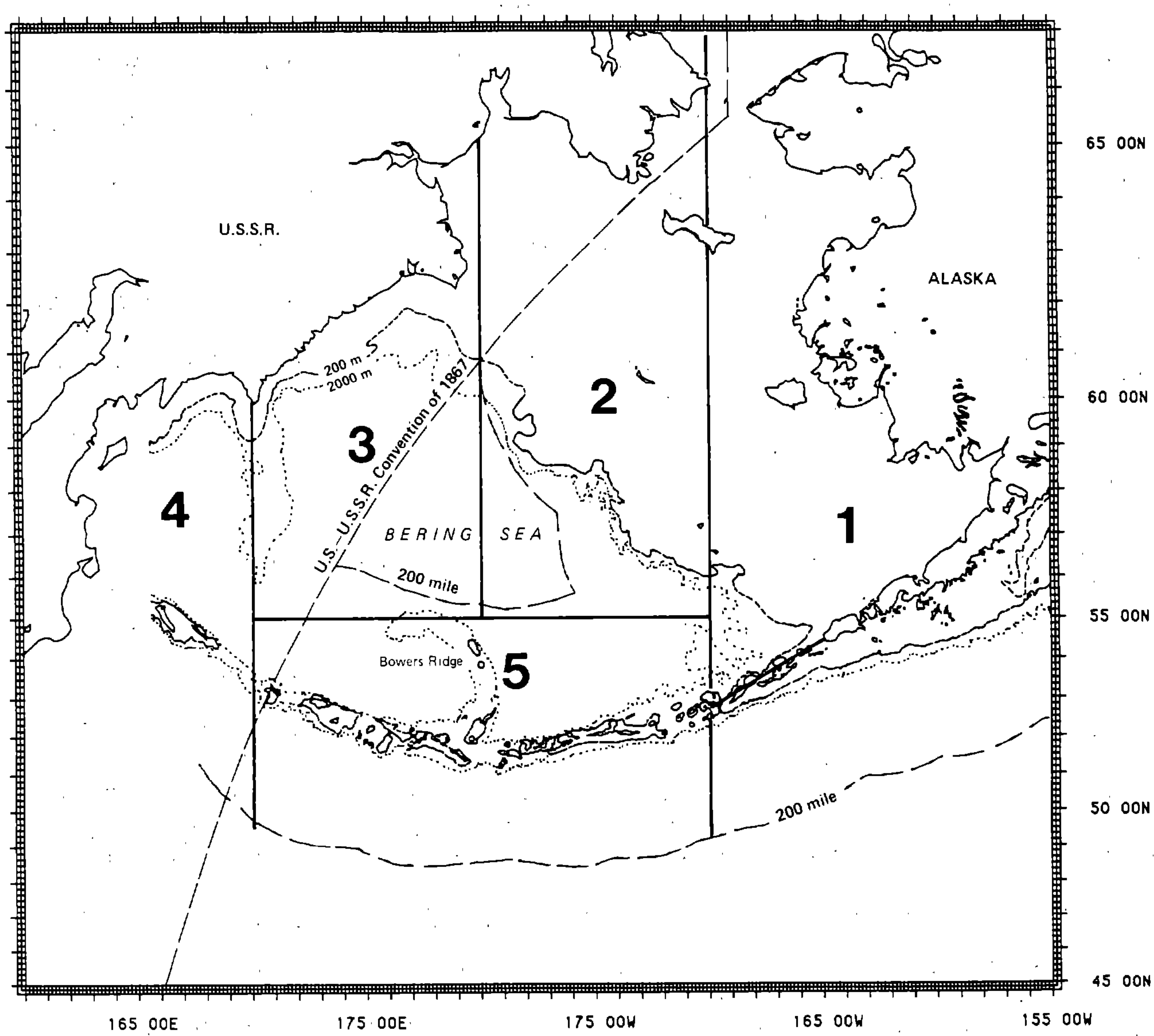

Figure 1 .--Bering Sea showing U.S. 200-mile fishery conservation zone and eastern Bering Sea (areas 1 and 2) and Aleutian Islands region (area 5) management areas. Areas 1-5 are International North Pacific Fisheries Commission statistical areas.

Species of Concern

The North Pacific Fisheries Management Council (NPFMC) has established four categories of finfishes and invertebrates for management purposes (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. Catch records for this species category must be maintained by the fishery and a total allowable catch is established by the NPFMC for this group.

A second category of noncommercial species, "nonspecified species," which includes fish and invertebrates of no current or foreseeable economic value, has also been established by the NPFMC (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.

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

Table 1.--Species categories established for management of Bering Sea-Aleutian finfish and invertebrate resources (North Pacific Fishery Management Council 1983).

Prohibited species[a]	Target species[b]	Other species[c]	Nonspecified species	
		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.	

[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.

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 684,000 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 about 1.2 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 111,000 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 have come from the pelagic population in the Aleutian Basin prior to and during the spawning season in winter and spring.

Table 2.--Annual catches of groundfish and squid in the eastern Bering Sea, 1954-83.[a]

Year	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						12,562
1955						14,690						14,690
1956						24,697						24,697
1957						24,145						24,145
1958	6,924	171	32			44,153					147	51,427
1959	32,793	2,864	393			185,321					380	222,751
1960			1,861	6,100		456,103	36,843					500,907
1961			26,182	47,000		553,742	57,348					684,272
1962			28,521	19,900		420,703	58,226					527,350
1963			18,404	24,500		85,810	31,565	35,643				195,922
1964	174,792	13,408	8,262	25,900		111,177	33,729	30,604			736	398,608
1965	230,551	14,719	8,240	16,800		53,810	9,747	11,686			2,218	347,771
1966	261,678	18,200	11,981	20,200		102,353	13,042	24,864			2,239	454,557
1967	550,362	32,064	13,731	19,600		162,228	23,869	32,109			4,378	838,341
1968	702,181	57,902	18,853	31,500		84,189	35,232	29,647			22,058	981,562
1969	862,789	50,351	18,588	14,500		167,134	36,029	34,749			10,459	1,194,599
1970	1,256,565	70,094	12,501	9,900		133,079	32,289	64,690			15,295	1,594,413
1971	1,743,763	43,054	15,240	9,800		160,399	59,256	92,452			33,496	2,157,460
1972	1,874,534	42,905	15,368	5,700		47,856	77,633	76,813			110,893	2,251,702
1973	1,758,919	53,386	7,615	3,700		78,240	64,497	43,919			55,826	2,066,102
1974	1,588,390	62,462	5,158	14,000		42,235	91,127	37,357			60,263	1,900,992
1975	1,356,736	51,551	3,422	8,600		64,690	85,651	20,393			54,845	1,645,888
1976	1,177,822	50,481	3,296	14,900		56,221	78,329	21,746			26,143	1,428,938
1977	978,370	33,335	2,109	6,600	1,678	58,373	37,162	23,602		4,926	35,902	1,182,057
1978	979,431	42,543	1,139	2,200	12,222	138,433	45,781	42,947	832	6,886	61,537	1,333,951
1979	913,881	33,761	1,389	1,700	10,097	99,017	42,919	35,599	1,985	4,286	38,767	1,183,920
1980	958,279	45,861	2,171	800	1,367	87,391	62,618	20,457	4,697	4,040	33,949	1,221,630
1981	973,505	51,996	2,578	1,200	1,110	97,301	66,394	23,428	3,028	4,179	35,551	1,260,270
1982	955,964	55,040	3,030	600	862	95,712	54,908	32,666	328	3,837	18,200	1,221,147
1983	982,363	83,212	2,604	200	461	108,385	53,659	35,239	116	3,455	11,062	1,280,756

[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, 1962-83[a].

Year	Pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Turbots	Atka mackerel	Squid	Other species	Total all species
1962				200						200
1963				20,800		7				20,807
1964		241	975	90,300		504			66	92,086
1965		451	360	109,100		300			768	110,979
1966		154	1,107	85,900		63			131	87,355
1967		293	1,383	55,900		394			8,542	66,512
1968		289	1,661	44,900		213			8,948	56,011
1969		220	1,804	38,800		228			3,088	44,140
1970		283	1,277	66,900		559	949		10,671	80,639
1971		2,078	2,741	21,800		2,331			2,973	31,923
1972		435	3,576	33,200		14,197	5,907		22,447	79,762
1973		977	3,009	11,800		12,371	1,712		4,244	34,113
1974		1,379	2,520	22,400		11,983	1,377		9,724	49,383
1975		2,838	1,617	16,600		3,754	13,326		8,288	46,423
1976		4,190	1,634	14,000		3,437	13,126		7,053	43,440
1977	7,625	3,262	1,717	5,900	9,587	4,488	20,975	1,808	16,170	71,532
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	781	5,500	14,543	12,847	21,279	2,252	12,934	85,233
1980	58,156	5,788	267	3,700	1,366	8,299	15,793	2,332	13,004	108,705
1981	55,516	10,462	377	3,500	1,394	8,040	16,661	1,762	7,274	104,986
1982	57,978	11,526	808	1,500	2,792	8,732	19,546	1,201	5,167	109,250
1983	59,026	9,955	574	600	1,140	7,869	11,610	524	3,193	94,487

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

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.

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. Species accounting for the major part of this increase have been pollock, yellowfin sole, and Pacific cod.

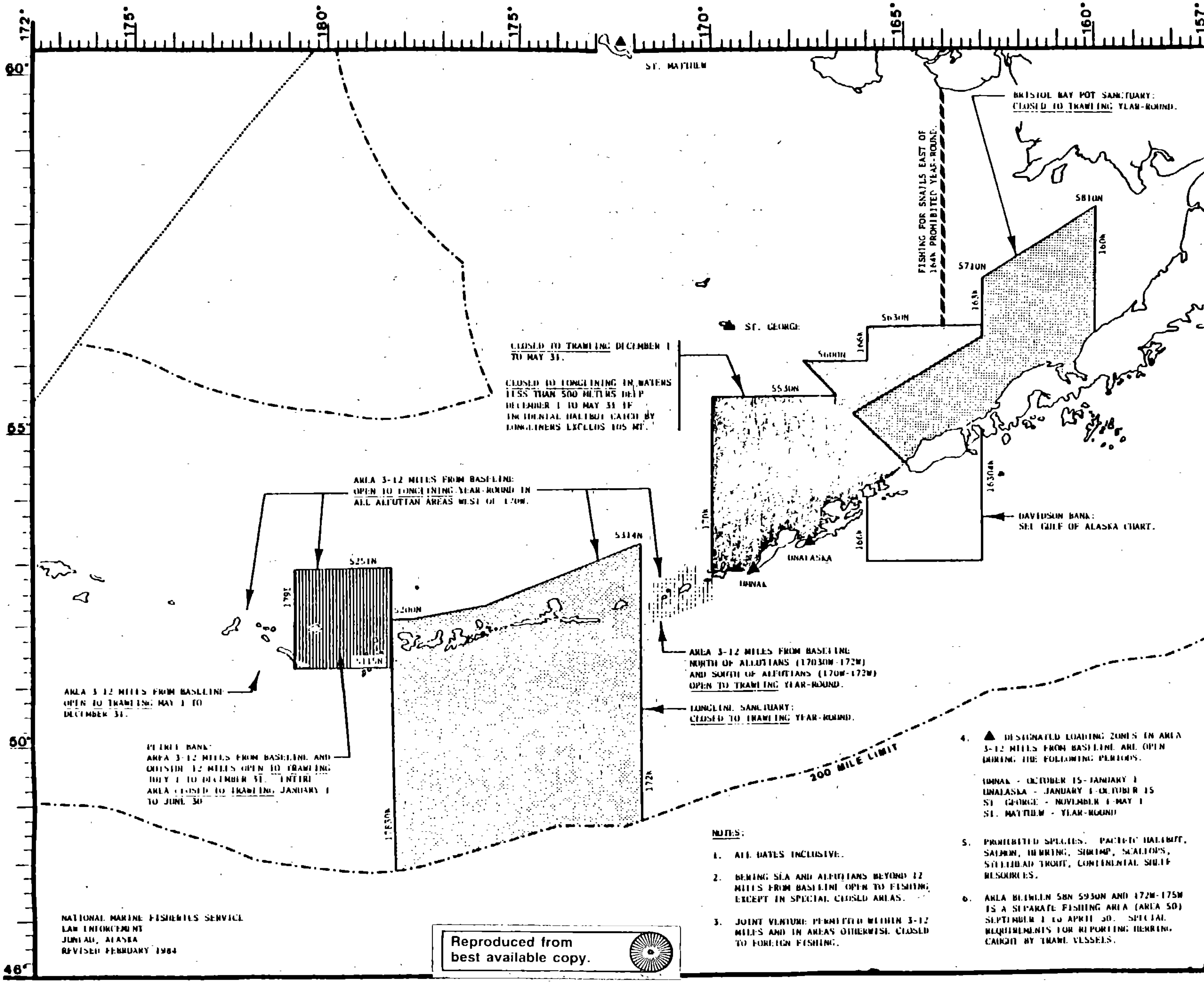

Figure 2.--Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions.

Table 4.--Optimum yields (t) for groundfish of the eastern Bering Sea and Aleutian Islands region 1977-1984.

	1977	1978	1979	1980	1981	1982	1983	1984
Eastern Bering Sea[a]								
Pollock	950,000	950,000	950,000	1,000,000	1,000,000	1,000,000	1,000,000	1,200,000
Yellowfin sole	106,000	126,000	126,000	117,000	117,000	117,000	117,000	230,000
Turbots	-	-	-	90,000	90,000	90,000	90,000	59,610
Other flounders[b]	100,000	159,000	159,000	61,000	61,000	61,000	61,000	111,490
Pacific cod	58,000	70,500	70,500	70,700	78,700	78,700	120,000	210,000
Sablefish	5,000	3,000	3,000	3,500	3,500	3,500	3,500	3,740
Pacific ocean perch	6,500	6,500	6,500	3,250	3,250	3,250	3,250	1,780
Other rockfish	-	-	-	7,727	7,727	7,727	7,727	1,550
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
Other species	59,600	66,600	66,600	74,249	74,249	74,249	77,314	40,000
Aleutians[a]								
Pollock	-	-	-	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
Pacific ocean perch	15,000	15,000	15,000	7,500	7,500	7,500	7,500	2,700
Other rockfish	-	-	-	-	-	-	-	5,500
Atka mackerel	-	24,800	24,800	24,800	24,800	24,800	24,800	23,130
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

[a]Except for pollock in 1980-1984, "other species" in 1977-1979, other rockfish in 1984, and sablefish and Pacific ocean perch for all years, catch limitations apply to the eastern Bering Sea and Aleutian Islands areas combined.
[b]Excludes halibut but includes turbot until 1980.
[c]After 1979 herring no longer considered a species of groundfish.

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. 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 tenfold between 1964 and 1972 (from 175,000 metric tons (t) to nearly 1.9 million t; Table 1). Catches have since declined, ranging between 914,000 t and 982,000 t in 1977-83, due in part to catch restrictions placed on the fishery as a result of declining stock abundance. An additional 55,500 - 59,000 t were taken annually in 1980-83 in the Aleutian Islands region (Table 2).

Japanese fisheries have historically accounted for over 80% of annual catches since 1970, but their proportion declined to 67% in 1983. 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 170,000 t in 1983. Catches by joint venture operations between U.S. fishing vessels and processing vessels from Japan, Poland, R.O.K., Federal Republic of Germany, (F.R.G.), and the U.S.S.R. have also increased, reaching 146,500 t in 1983.

Table 1 .--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]	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	0	104,942	3,367	48,391	9,580	41,938		973,505
1982	746,972	0	150,525	4,220	0	1,625	52,622		955,964
1983	654,939	0	170,007	0	0	10,038	146,467	912	982,363

[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) and for 1980-83 from U.S. observer estimates as reported by French et al. 1981, 1982; Nelson et al. 1983, 1984.

[b]Republic of Korea.

[c]Federa1 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 2.--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	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

[a]Catch data for 1977-79 as reported by fishing nations and for 1980-83 from French et al. 1981, 1982; Nelson et al. 1983, 1984.

[b]Federal Republic of Germany and Taiwan.

CONDITION OF STOCK

Relative Abundance

Trends in abundance shown by the various sources of data are similar, indicating a rapid decline in abundance from the early to mid-1970s and then relative stability through 1982 (Table 3). All of the available catch per unit of effort (CPUE) estimates increased in 1983 and 1984 from those in 1982.

Trends in CPUE (Table 3) from large-scale Northwest and Alaska Fisheries Center (NWAFC) trawl surveys (Fig. 1) 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 influence abundance estimates from survey trawls with vertical openings of 1.5-2.3 m more severely than fishery trawls with vertical openings of 7-12 m. The sharp decline in abundance indicated by survey data in 1980 is believed to have overestimated the severity of the decline which may have been more accurately reflected by fishery data. The 1983 survey data indicated a major increase in abundance which was believed to represent an extraordinary availability of large pollock to the survey bottom trawls rather than to an actual increase in abundance of the overall population (Bakkala and Traynor 1984). The corresponding increase in CPUE from the 1983 fishery also reflects the greater availability of these large pollock to the fishery trawls, but as might be expected, the magnitude of the increase shown by the fishery data was less than shown by the survey data.

The CPUE from the 1984 survey [99 kg/hectare (ha)] was 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. This relatively high value reflects the continued dominance of large pollock in the eastern Bering Sea population.

Table 3.--Relative indices of walleye pollock stock abundance in the eastern Bering Sea, 1964-84.[a]

	Japanese pair trawl data			
Year	U.S. method[b] (t/1,000s of horsepower hours)	Japanese method[c] (t/h)	INPFC[d] workshop method[e] (% 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	--	121	133.0
1984	--	--	--	98.7

[a]In the process of updating catch per unit of effort (CPUE) values for the U.S. method and International North Pacific Fisheries Commission (INPFC) workshop procedure, some values calculated in previous years (Bakkala and Traynor 1984) could not be duplicated. An examination of the current data base revealed some differences from the data base previously used to calculate these CPUE values, the most significant of which was a change in the 1975 base year data for the INPFC workshop procedure. This change had occurred following the original calculations of CPUE by Low and Ikeda (1980). Trends in abundance shown by the old and new values are the same except in 1968-71 for the INPFC workshop procedure where the new values are substantially lower than the previous values.

[b]Alton and Fredin (1974).

[c]Okada et al. (1982).

[d]International North Pacific Fisheries Commission.

[e]Low and Ikeda (1980).

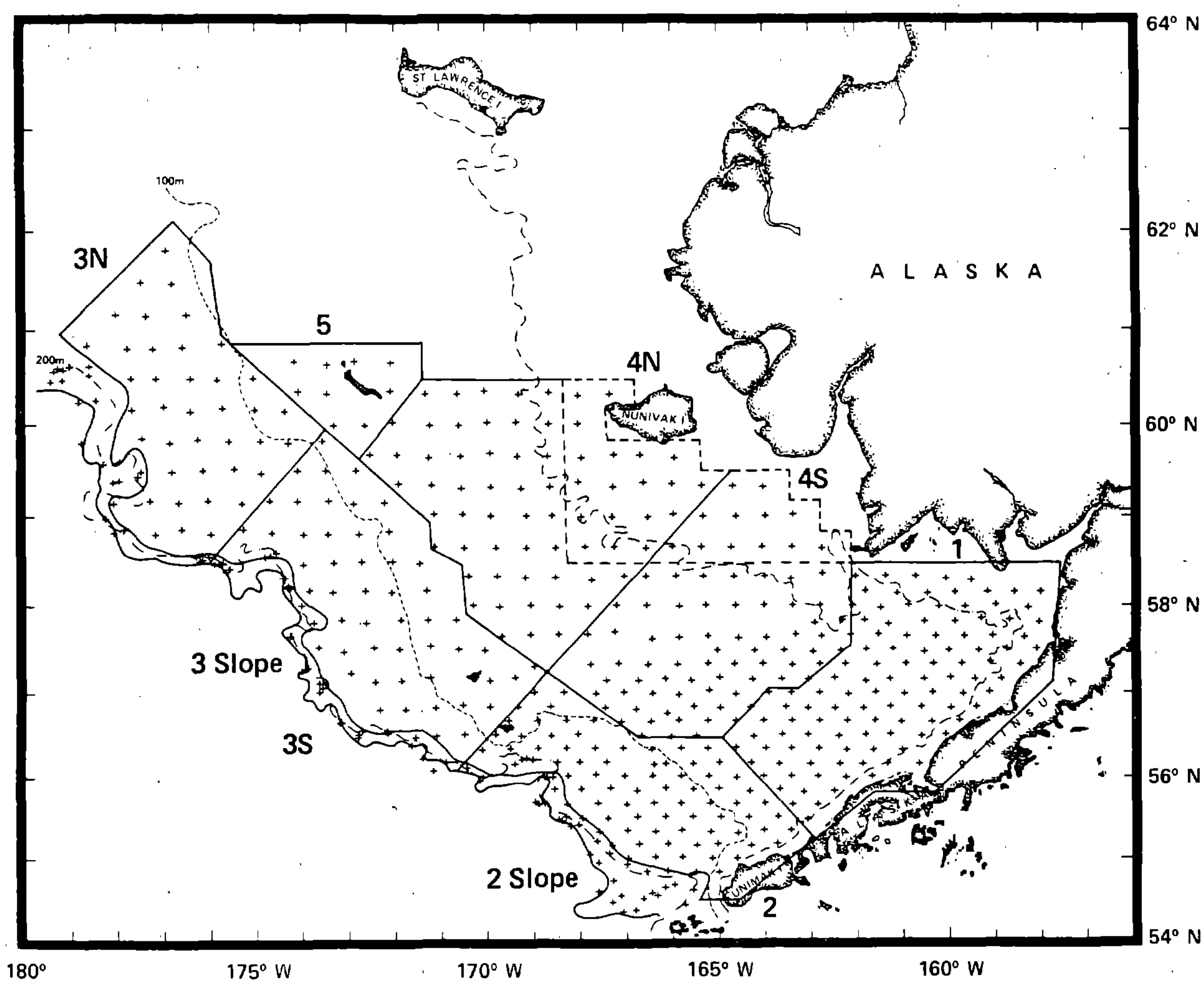

Figure 1 .--Area of the eastern Bering Sea generally sampled during large-scale surveys by the Northwest and Alaska Fisheries Center in 1975 and 1979-84. Survey subareas are delineated by the solid lines and subarea numbers are shown adjacent to the subareas. Area within the dashed lines in the vicinity of Nunivak Island was not sampled during the 1981 survey.

Biomass Estimates

Survey Based Estimates

In 1982, a 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.

Estimated population numbers from the combined bottom trawl-hydroacoustic surveys were less than observed in 1979 (Table 4). Most of the reduction was due to lower abundance of age 1 and 2 fish. The 1982 population estimates for age 1 and 2 pollock (1981 and 1980 year-classes) were 1.0 and 5.6 billion, respectively, compared to 1979 values of 76.9 billion for age 1 (1978 year-classes) and 46.9 billion for age 2 fish (1977 year-class). 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 total estimated biomass of pollock from the combined bottom trawl-hydroacoustic surveys in 1979 was 11.1 million t (7.5 million t in midwater; 3.6 million t demersal). In 1982, the demersal estimate was 2.9 million t and the midwater estimate 4.9 million t for a total of 7.8 million t. In 1979, 86.0% by number (67.6% by weight) of the population occupied midwater, whereas in 1982, 64.9% by number (63.1% by weight) were observed in midwater.

Table 4.--Population number estimates (billions) of walleye pollock derived from bottom and hydroacoustic midwater trawl surveys in the eastern Bering Sea, 1979 and 1982.

Age	1979			1982		
(yr)	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

Mean biomass estimates from all large-scale bottom trawl and hydroacoustic surveys that have sampled the major part of the eastern Bering Sea since 1975 have been as follows:

Year	Type of survey	Mean biomass estimates (t)[a]
1975	U.S. bottom trawl	2,426,000
1979	U.S.-Japan bottom trawl	3,552,000
	U.S. hydroacoustic	7,458,000
1980	U.S. bottom trawl	1,509,000
1981	U.S.-Japan bottom trawl	2,768,500
1982	U.S.-Japan bottom trawl	2,869,000
	U.S. hydroacoustic	4,900,700
1983	U.S. bottom trawl	6,050,600
1984	U.S. bottom trawl	4,585,400

The biomass estimates from the 1983 and 1984 bottom trawl surveys were 6.1 and 4.6 million t, respectively, which were lower than the combined bottom trawl-hydroacoustic estimate in 1982 but which far exceeded any of the previous estimates based solely on bottom trawl data. The reason for these larger estimates was believed to be the result of the high abundance of large fish, which are more vulnerable to survey trawls, in the 1983 and 1984 populations 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 (Yamaguchi 1984). An area swept method was used to derive the following estimates:

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[a] 1979 and 1981-82 values include estimates from the continental slope while estimates from bottom trawl data in other years are from-the continental shelf region only.

Year	Biomass estimates (t)
1976	10,398,000
1977	10,971,200
1978	10,056,900
1979	8,215,800
1980	13,118,000
1981	9,337,400
1982	7,793,000
1983	10,684,800
Mean	10,071,900

The 1979 estimate of 8.2 million t 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 Japanese and U.S. surveys were identical at 7.8 million t. The increase in biomass (10.0 million t) shown by the 1983 Japanese survey apparently reflects, as did other sources of abundance data, the greater vulnerability of older pollock to bottom trawling gear.

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	412,900	151,200

Assuming that pollock occupy midwater in the Aleutians as they do in the eastern Bering Sea, this estimate 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.

Cohort Analysis Based Estimates

Results of the cohort analysis for eastern Bering Sea pollock reported by Wespestad and Terry (1984) were updated through 1983 for this report. Methods of analysis used were the same as in the above report. New catch at age data for 1981-83 (Table 5) were derived from catch and age data collected by U.S. observers from the pollock fishery. Catch-at-age data for the period 1975-78 were also recalculated because of discrepancies noted in the data for certain years and to standardize methods of producing these data with those used in the more recent period of 1979-83.

In the cohort analysis, the 1983 terminal fishing mortalities (F) were modified until the relative age composition of the 1982 population approximated that from the 1982 bottom trawl-hydroacoustic surveys (Table 41, under the assumption that the 1982 survey data were representative of the age composition of the actual population. These terminal F values were then furtheradjusted to approximate the population change observed between 1979 and 1982 in the bottom trawl-hydroacoustic survey data. Terminal fishing mortalities for age 9, the terminal age in years prior to 1983, were the average fishing mortalities computed for ages 7 and 8. Terminal fishing mortalities were further adjusted to smooth variation in F values within year-classes. The F values from the analysis along with age-specific values of natural mortality (M) used are shown in Table 6.

Results of the cohort analysis for the years 1975-83 are shown in numbers by age in Table 7 and biomass by age in Table 8. Total population numbers, after peaking in 1980 at 41 billion due mainly to the recruitment of the strong

Table 5.--Catch at age in number of walleye pollock for the years 1975-83.

Age	1975	1976	1977	1978	1979
2	833,663,705	884,555,706	1,073,816,172	722,678,783	958,318,125
3	3,817,149,225	1,618,900,824	1,195,774,141	1,097,359,561	1,235,419,499
4	458,942,403	1,355,235,503	847,525,659	944,443,475	682,467,001
5	53,732,729	128,829,194	274,558,181	391,272,633	540,965,602
6	84,055,063	47,727,250	74,979,679	94,394,232	231,774,924
7	95,631,209	55,630,057	32,114,379	26,330,318	53,803,793
8	70,129,796	57,155,435	45,992,258	17,719,477	22,826,600
9	53,429,920	38,315,592	41,234,111	19,145,347	29,169,814

Age	1980	1981	1982	1983
2	1,120,060,875	76,514,479	25,378,068	96,175,159
3	1,041,523,325	1,442,684,307	214,940,910	187,229,665
4	430,156,165	662,889,545	1,466,504,870	429,962,151
5	228,463,365	149,673,091	389,070,688	912,078,907
6	153,058,035	74,749,419	62,695,091	207,847,468
7	75,204,515	45,412,822	21,177,588	32,995,774
8	51,415,520	38,000,626	23,989,227	13,305,595
9	21,146,821	23,281,868	14,936,765	9,054,704

Table 6.--Estimated fishing mortality (F) for walleye pollock by age and year from the cohort analysis and age-specific estimates of natural mortality used in the analysis.

Age	Fishing mortality (F) 1975	1976	1977	1978	1979	1980	1981	1982	1983	Natural mortality (M)
2	0.0868	0.0974	0.1217	0.1049	0.0957	0.0574	0.0105	0.0063	0.0000	0.45
3	0.6035	0.2960	0.2246	0.2138	0.3219	0.1729	0.1174	0.0442	0.0700	0.30
4	0.3174	0.5059	0.2789	0.3126	0.2233	0.1966	0.1770	0.1874	0.1300	0.30
5	0.0408	0.1526	0.1986	0.2238	0.3338	0.1200	0.1076	0.1665	0.1900	0.30
6	0.0600	0.0512	0.1387	0.1075	0.2237	0.1640	0.0579	0.0664	0.1400	0.30
7	0.0774	0.0568	0.0489	0.0732	0.0914	0.1164	0.0741	0.0231	0.0500	0.30
8	0.0877	0.0671	0.0675	0.0380	0.0930	0.1317	0.0879	0.0564	0.0200	0.30
9	0.0900	0.0700	0.0700	0.0400	0.0900	0.1300	0.0900	0.0500	0.0300	0.30

Table 7.--Estimated numbers (billions) of pollock by age in the eastern Bering Sea in 1975-83 based on cohort analysis.

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983
2	12,558	11.939	11.732	9.085	13.150	25.138	9.163	5.078	a
3	9.788	7.341	6.907	6.623	5.216	7.620	15.135	5.781	3.218
4	1.961	3.966	4.045	4.087	3.962	2.801	4.748	9.970	4.098
5	1.563	1.057	1.771	2.267	2.215	2.348	1.704	2.947	6.124
6	1.678	1.112	0.672	1.076	1.343	1.175	1.543	1.134	1.848
7	1.492	1.170	0.783	0.434	0.716	0.785	0.739	1.078	0.786
8	0.970	1.023	0.819	0.552	0.299	0.484	0.524	0.508	0.781
9	0.721	0.658	0.709	0.567	0.394	0.202	0.314	0.356	0.356
Total[b]	30.730	28.267	27.438	24.692	27.294	40.563	33.870	26.853	17.210

[a]Not determined.

[b]Differences in sums by age and totals are due to rounding.

Table 8.--Estimated biomass (1000 t) of walleye pollock in the eastern Bering Sea by age based on cohort analysis in 1975-83.

Age	1975	1976	1977	1978	1979	1980	1981	1982	1983
2	1,319	1,254	1,232	954	1,381	2,640	962	533	[a]
3	2,457	1,843	1,734	1,662	1,309	1,913	3,799	1,451	808
4	802	1,622	1,654	1,672	1,620	1,145	1,942	4,078	1,676
5	883	597	1,001	1,281	1,252	1,326	963	1,665	3,460
6	1,090	723	437	699	873	764	1,003	737	1,201
7	1,191	934	624	346	571	635	590	861	627
8	866	912	731	492	266	432	468	453	696
9	682	622	670	536	372	190	297	336	336
Total[b]	9,288	8,507	8,083	7,643	7,644	9,045	10,023	10,115	8,805

[a] Not determined.

[b] Differences in sums by age and totals are due to rounding.

1978 year-class at age 2, have since declined sharply to 17 billion in 1983. This decline has been the result of poor recruitment since at least 1981.

Trends in biomass in recent years have differed from those shown by population numbers. Based on the cohort analysis, biomass was relatively stable in 1976-79 ranging from 7.6 to 8.5 million t and then increased to 10.1 million t in 1982. The estimates then declined to 8.8 million t in 1983. Biomass continued to increase through 1982, although population numbers declined, because of the growth in weight of the large 1978 year-class. The decline in biomass in 1983 reflects the decreasing abundance of the 1978 year-class and the poor recruitment of later year-classes.

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. 2). From 1975 to 1980, 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. Age 5 and older fish were relatively rare in both survey and fisheries catches. Beginning in 1981 and continuing through 1983, 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 in 1982 and 1983 at the relatively advanced ages of 4 and 5, and the low abundance of the 1979, 1980, and 1981 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. 2).

Length-frequency data from NWAFC bottom trawl surveys in 1979 and 1981-84 and the 1984 fishery were used to further examine recruitment and abundance of

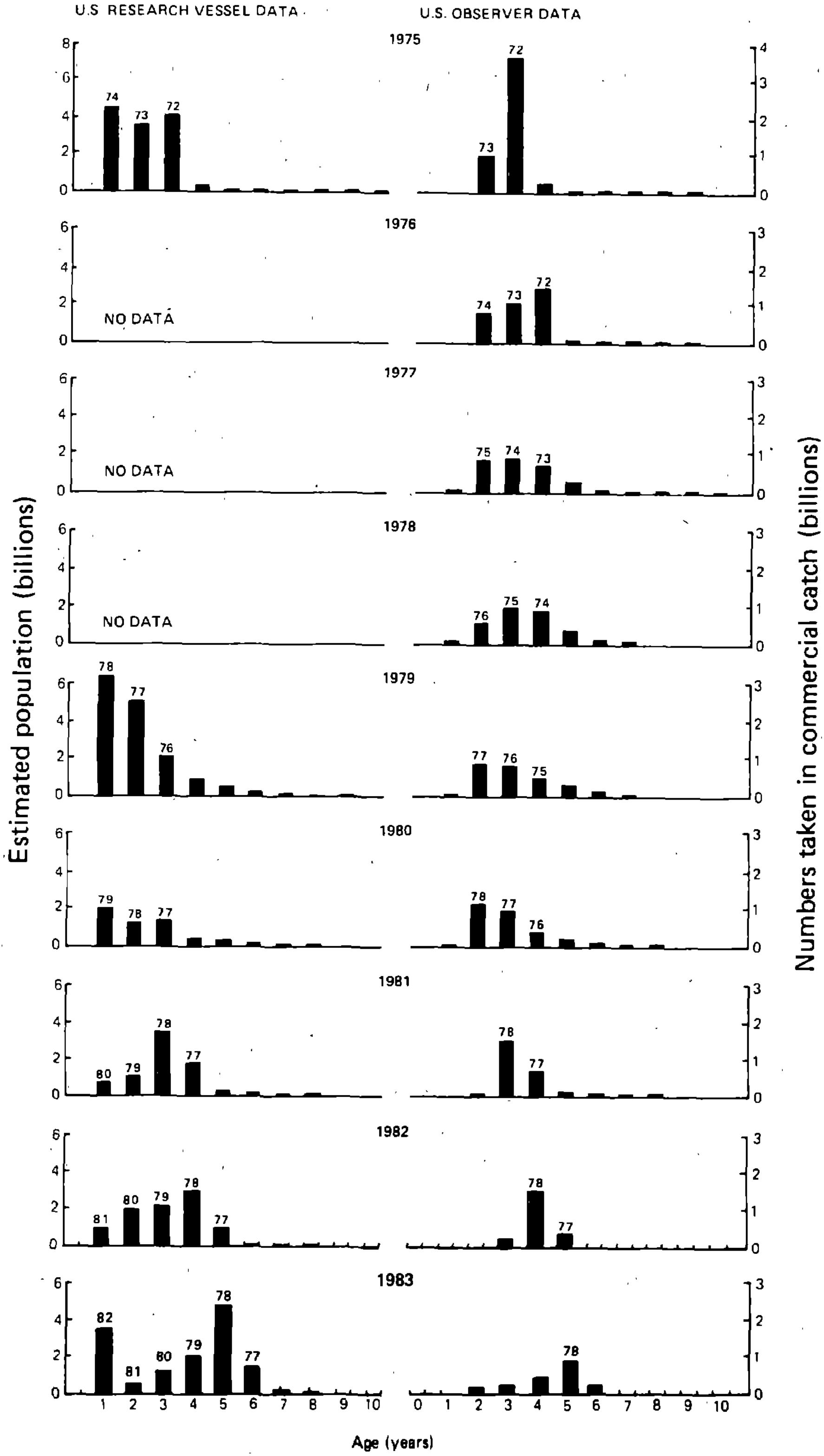

Figure 2.--Age composition of walleye pollock in the Eastern Bering sea as shown by data from the Northwest and Alaska Fisheries Center research vessel surveys and by data collected in the commercial fishery by U.S. observers. Numbers above the bars indicate the principal. year-classes.

age groups through 1984 (Fig. 3). A high proportion of the population numbers in the 1984 survey catches consisted of pollock from about 35 cm to 55 cm. Two age groups may form the bulk of the fish in this length range. The mode with a peak at 46 cm is believed to mainly represent age 6 fish of the 1978 year-class. There is an apparent secondary mode with a peak at about 40 cm which may represent age 5 pollock of the 1979 year-class.

These findings illustrate a continuation in 1984 of the anomolous age structure in the pollock population relative to age compositions previously observed. In additon to the dominance of relatively old fish in the population, there were extremely low population numbers of 10 to 35 cm fish in the 1984 survey catches.

Findings from the survey are supported by length-frequency data from the 1984 fishery (Fig. 3). These data were based on a sample of about 44,000 length measurements collected from all elements of the pollock fishery on the eastern Bering Sea shelf by U.S. observers in January to June. The length samples were weighted by catches from each vessel type before being combined over vessel types. The length distributions show a single mode with a peak at 46 cm illustrating that fishery catches in the first half of 1984 were principally of the 1978 year-class. As in survey catches, there were very low proportions of 10-35 cm pollock. The 1983 survey data indicated that recruitment from the 1982 year-class was stronger than from the 1979-81 year-classes (Figs. 2 and 3). However, the 1984 length data showed no evidence of substantial numbers of the 1982 year-class which should have formed a mode between 20 and 30 cm. The low numbers of the 1982 year-class in survey and fisheries catches may be the result of age 2 pollock being higher in the water column and less vulnerable to trawls than older fish. The behavior of the 1982 year-class may be similar to that of the 1978 year-class which was not abundant at age 2 in 1980 survey catches

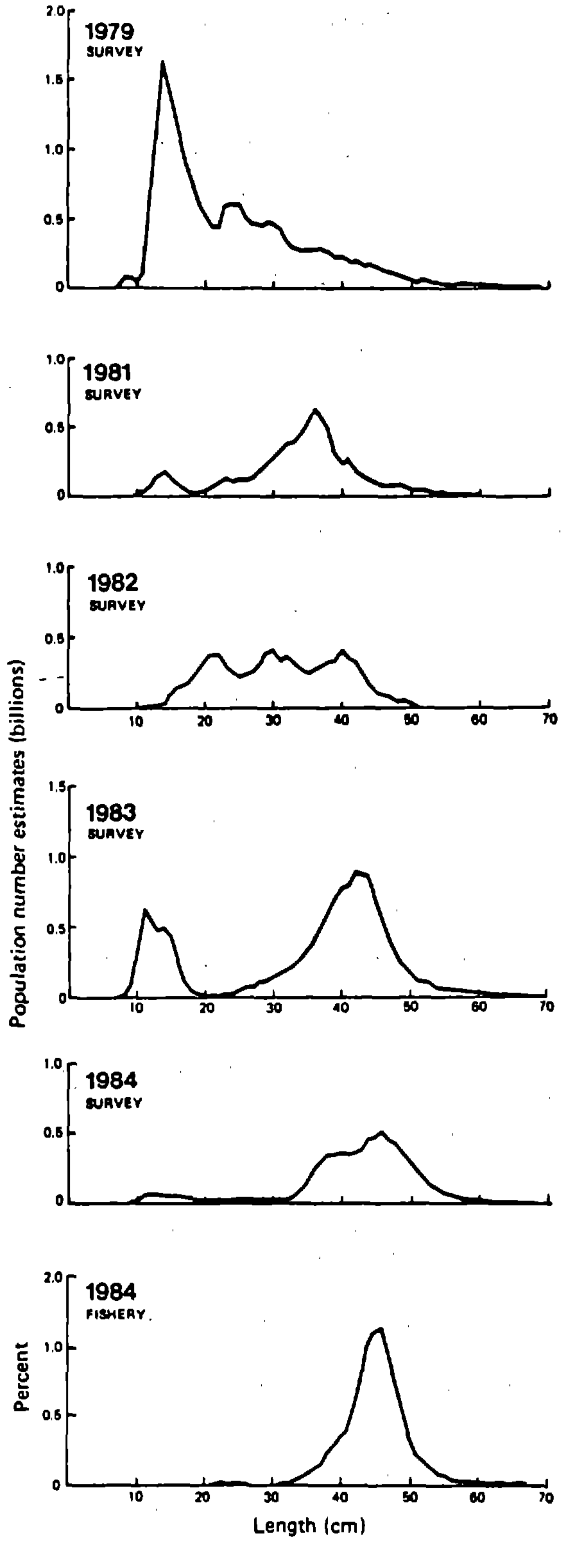

Figure 3.--Population estimates of walleye pollock by centimeter size interval, as shown by Northwest and Alaska Fisheries Center bottom trawl data from the continental shelf of the eastern Bering Sea in 1979-84 and size composition of pollock taken by the commercial fishery during January-June 1984.

(Fig. 2), although it is now apparent that this is an extremely strong year-class.

The size composition data suggest that the abundance of age 1 pollock in 1984 (10-20 cm fish) was extremely low. Population estimates of age 1 pollock from bottom trawl surveys based on age analyses in 1979-83 (Fig. 2) and population numbers under 20 cm from the 1984 survey data (Fig. 3) were as follows:

Year	Year-Class	Population number estimates (billions)
1979	1978	7.8
1981	1980	1.0
1982	1981	0.9
1983	1982	3.6
1984	1983	0.4

Thus, the poor recruitment of age 1 pollock that has been observed in most years since at least 1981 continued in 1984.

PROJECTIONS OF ABUNDANCE

Estimated trends in abundance of pollock through 1983 were examined using a numeric population simulator. The simulation model predicts age-specific abundance through a population decay function:

$$+ 1, j + 1) = N_{ij} e^{-(M+F)}$$

where N_{ij} = number of age i in year j, and

$N_{(i + 1, j + 1)}$ = number of age i in the following year.

The decay function projects numbers at age from a base year using estimates of natural mortality (M), fishing mortality (F), and recruitment.

Base year data used in the simulation model were 1982 population estimates by age from the cohort analysis (Table 7). Estimates of natural mortality were the age-specific values used in the cohort analysis (Table 6).

Recruitment of age 1 fish in 1983 and 1984 was derived by adjusting the estimates of age 1 fish from the bottom trawl survey in those years by the ratio of the estimates of age 1 fish from the 1979 bottom trawl survey to the 1979 estimate from the cohort analysis (8.7/59.0 = 0.147). The estimates thus derived were 24.5 billion in 1983 and 2.7 billion in 1984. The 1985 recruitment used in the model was the average of the 1975-82 values from the cohort analysis.

Results of the projections indicate that the biomass of the exploitable population of pollock (age 2 and older) in the eastern Bering Sea declined to 7.9 million t in 1984 and will decline further to 7.3 million t in 1985 (Table 9). Projected biomass estimates by age indicate that the 1978 year-class at age 7 will contribute about 2.2. million t to the 1985 total (Take 10).

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 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, in the past, been established for this area by the North Pacific Fishery Management Council. The optimum yield there was set at 100,000 t, although MSY was not estimated because of lack of data on the Aleutian population.

Table 9.--Projections of walleye pollock abundance using population estimates by age for 1982 from the cohort analysis (Table 7) as base year data and estimates of recruitment at age 1 from survey data.

Year	Biomass estimates (million t) Total Population	Exploitable Population (Age 2 and Older)	Recruitment Age 1 (billions)	Catch (million t)	Exploitation rate
1983	10.1	9.53	24.50	0.98	0.10
1984	8.67	8.61	2.70	0.95	0.11
1985	7.90	7.35	24.80[a]	1.0	0.14

[a]Average recruitment based on results of cohort analysis.

Table 10.--Projected biomass (million t) of walleye pollock by age for the total eastern Bering Sea population. Biomass estimates for the strong 1978 year-class are underlined.

	Year		
Age	1983	1984	1985
1	0.539	0.059	0.546
2	0.057	1.098	0.121
3	0.784	0.084	1.594
4	1.574	0.839	0.088
5	<u>3.750</u>	1.427	0.744
6	1.275	<u>2.831</u>	1.054
7	0.602	1.028	<u>2.232</u>
8	0.640	0.442	0.737
9	0.320	0.445	0.301
10	0.259	0.230	0.313
11	0.271	0.185	0.160
Total	10.071	8.668	7.896

Biomass estimates for pollock in the Aleutianregion are now available, however, based on the 1980 and 1983 U.S.-Japan demersal trawl survey in that region. The estimates were 280,200 t in 1980 and 412,900 t in 1983. Yet the biomass of pollock sampled by demersal trawls may only represent one-third to one-half 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

Following the decline in CPUE 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. The continued stability of CPUE estimates through 1982 (Table 3) indicates that abundance remained at much the same level as in earlier years. This stability suggests that catches in the range of 0.9-1.2 million t have been close to an equilibrium yield (EY) since 1975. Contrary to these findings, results from combined demersal trawl-hydroacoustic surveys indicate that the overall biomass of pollock declined from 11.1 million t in 1979 to 7.8 million t in 1982.

values of CPUE based on survey and fishery data and biomass estimates from NWAFC bottom trawl surveys were much higher in 1983 and 1984 than in 1982 and other recent years, but this is believed to be the result of an increase in the average age of the population and the greater vulnerability of older pollock to survey and fishery trawls rather than to an increase in abundance of the population. This increase in average age has resulted from the strength of the 1978 year-class which still dominated survey and fishery catches in 1983 and 1984 at ages 5 and 6 and the poor recruitment of most year-classes since 1979. Cohort analysis (Table 8) and projections of abundance (Table 9) indicate that overall abundance of the eastern Bering Sea population is falling as the biomass of the 1978 year-class declines,, after reaching a maximum in 1982, and poor recruitment continues.

The condition of the eastern Bering Sea pollock is of concern. The population is primarily made up of relatively old fish, the overall population biomass is declining, and there was continued poor recruitment of young pollock through 1984. The projected exploitable biomass of pollock in the eastern Bering Sea was estimated to be 7.3 million t in 1985 (Table 9). There may be another 300,000 t or more in the eastern Aleutian area of the eastern Bering Sea management area (170°W - 165°W), based on the estimate from the 1983 U.S.-Japan cooperative bottom trawl survey in this area and assuming that catchability of pollock in bottom trawls range from 0.3 to 0.5. Thus, the exploitable biomass in the eastern Bering sea management area may be approximately 7.6 million t.

A number of factors were considered in estimating EY for 1985. The declining abundance of the population and the poor recruitment in recent years indicate that EY in 1985 will be lower than in 1984. Nevertheless, there remains a sizeable biomass of pollock in the eastern Bering Sea which is projected to be 7.6 million t in 1985. These projections also indicate that a large part of this biomass (4.8 million t) will consist of relatively old 5-8 yr fish (Table 10). Although no direct evidence is available, the abundance of these large fish may be at least partially responsible, through cannibalism, for the recent poor recruitment of young pollock as has been suggested by ecosystem models (Laevastu and Larkins 1981). Thus, there is some justificaiton for maintaining the exploitation rate at a relatively high level to reduce the potential for cannibalism and to harvest these older fish before they are lost to natural mortality.. Based on these various considerations, it is recommended that EY in 1985 be reduced 100,000 t from the level in 1984 to 1.1 million t, representing an exploitation rate of 14.5%.

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.

PACIFIC COD

by

Richard G. Bakkala and Vidar G. Wespestad

INTRODUCTION

Pacific cod, _Gadus macrocephalus_, are distributed widely over the Bering Sea continental shelf and slope and have a distributional pattern 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. At present, cod are believed to be an occasional target species of the Japanese trawl fisheries when high concentrations are detected during pollock fishing operations. They also remain a target species of the Japanese longline fishery. Recently a U.S. domestic trawl fishery and joint venture fisheries, involving U.S. catcher boats delivering catches to processing vessels from other nations, began operations in the eastern Bering Sea and Aleutian Islands areas. Catches from these two U.S. fisheries have increased to 51,700 metric tons (t) in 1983.

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 1). Catches in 1980-83 increased markedly from the level of the previous 3 yr 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. Catches by these U.S. fisheries exceeded those by fisheries from other nations in 1982 and 1983. All-nation catches of cod reached a historic high of 93,000 t in 1983.

Table 1.--Commercial catches (t) of Pacific cod by area and nation, 1964-83.[a]

	Eastern Bering Sea							Aleutian Islands Area							E.Bering Sea and Aleutians
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	Joint ventures	U.S.	Total	Comb. Total
1964	13,408	-					13,408	241	-	-				241	13,649
1965	14,719	-					14,719	451	-					451	15,170
1966	18,200	-					18,200	154	-					154	18,354
1967	32,064	-	-				32,064	293	-					293	32,357
1968	57,902	-	-				57,902	289	-	-				289	58,191
1969	50,351	-	-				50,351	220	-	-				220	50,571
1970	70,094	-	-				70,094	283	-	-				283	70,377
1971	40,568	2,486	-				43,054	425	1,653	-				2,078	45,132
1972	35,877	7,028	-				42,905	435	-	-				435	43,340
1973	40,817	12,569	-				53,386	566	411	-				977	54,363
1974	45,915	16,547	-	-			62,462	1,334	45	-				1,379	63,841
1975	33,322	18,229	-	-			51,551	2,581	257	-				2,838	54,389
1976	32,009	17,756	716	-			50,481	3,862	312	16				4,190	54,671
1977	33,141	177	-	2		15	33,335	3,162	100	-				3,262	36,597
1978	41,234	419	859	-		31	42,543	3,165	120	6			4	3,295	45,838
1979	28,532	1,956	2,446	47		780	33,761	5,171	414	6			2	5,593	39,354
1980	27,334	7	6,346	1,371	8,370	2,433	45,861	2,834	4	58	9	86	2,797	5,788	51,649
1981	27,570	0	6,147	2,481	7,410	8,388	51,996	2,426	0	476	12	1,749	5,799	10,462	62,458
1982	17,380	0	8,151	647	9,312	19,550	55,040	1,730	0	259	7	4,280	5,250	11,526	66,566
1983	29,411	0	9,792	32	9,662	34,315	83,212	1,845	0	392	34	4,700	2,984	9,955	93,167

[a]Catch data for 1964-79 as reported by fishing nations and for 1980-83 from French et al. 1981, 1982, Nelson et al., 1983, 1984.
[b]Republic of Korea.
[c]Taiwan, Poland, and Federal Republic of Germany.
[d]Joint ventures between U.S.-R.O.K. and U.S.-U.S.S.R.
[e]U.S. vessels delivering catches to domestic processors.

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 a single strong year-class spawned in 1977. The relative abundance of cod increased about sevenfold between 1976 and 1983 (Fig. 1) based on NWAFC research survey data in a comparative fishing area in the southeast Bering Sea (Fig. 2). Based on data from large-scale surveys that have sampled major portions of the eastern Bering Sea (see Fig. 1 in the section on pollock in this report), the catch per unit of effort (CPUE) of cod apparently increased approximately 9 times (from 2.7 to 24.8 kg/hectare (ha)) between 1975 and 1983. In 1984 the value declined moderately to 21.5 kg/ha. This decrease in CPUE may indicate that overall population abundance is now starting to decline and that the influence of the 1977 year-class on the overall population weight may have peaked in 1983.

Biomass Estimates

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

	Biomass (t)	
Year	mean estimate	95% confidence intervals
1978	312,000	87,300 - 536,890
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

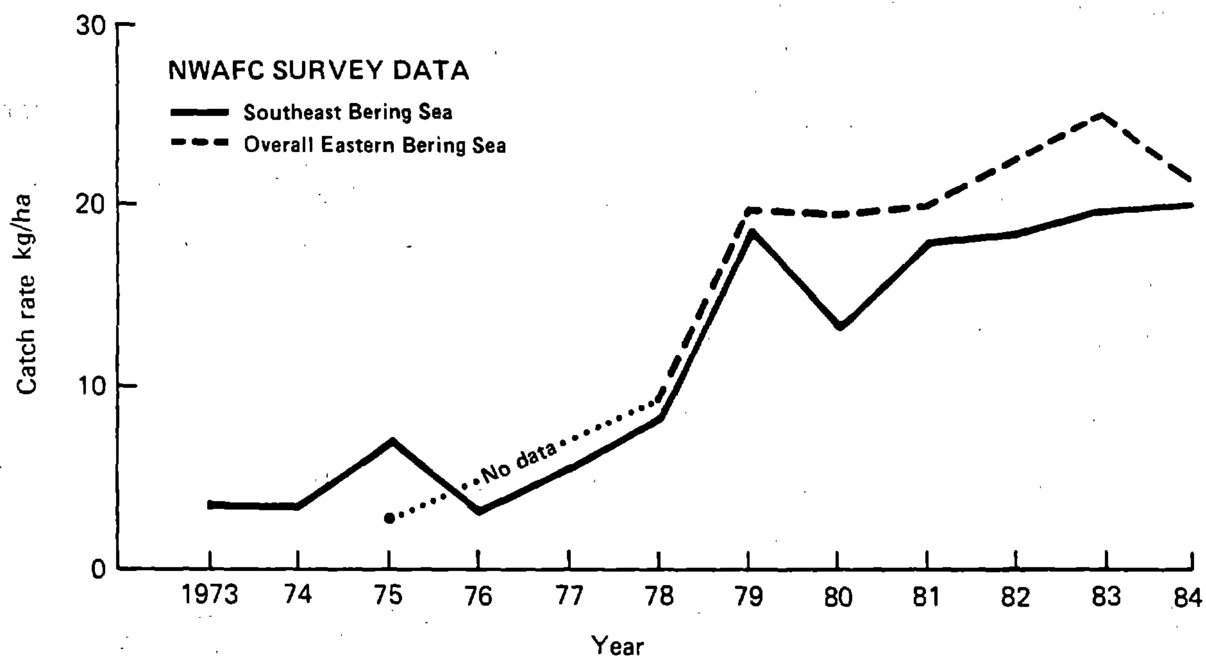

Figure 1.--Relative abundance of Pacific cod as shown by Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys.

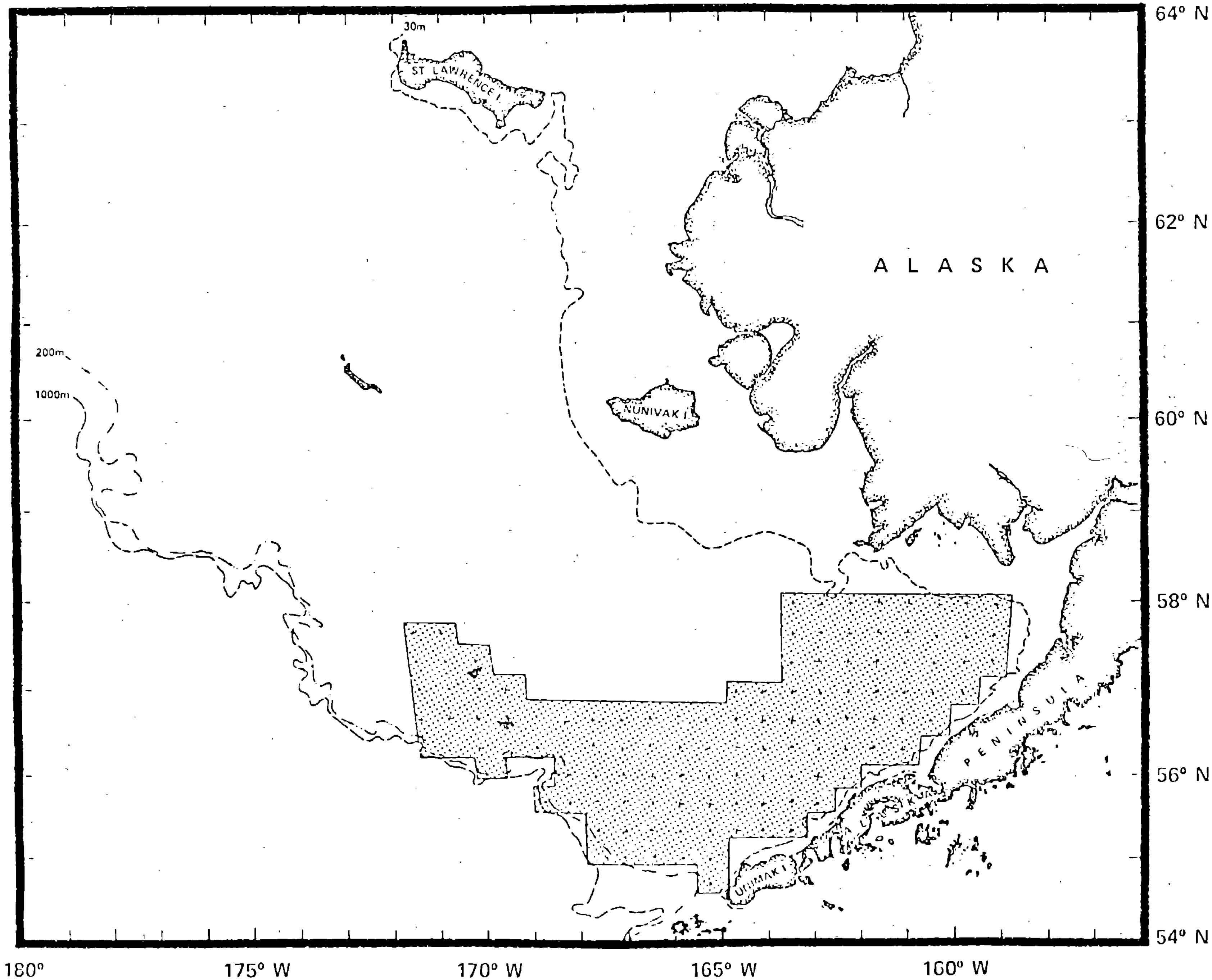

Figure 2.--Comparative fishing area sampled annually during Northwest and Alaska Fisheries Center demersal trawl surveys in 1973-84.

Estimates continued to increase through 1983 as a result of the recruitment and growth of fish from the strong 1977 year-class. The population weight may have peaked in 1983, based on the lower mean biomass estimate in 1984. The 95% confidence intervals, however, indicate that estimates have not been significantly different in recent years.

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 were as follows:

Year	Season	Area	Biomass estimate
1980	Summer	170°E-165°W	144,900
1982	Winter	170°W-165°W	283,300
1983	Summer	170°E-165°W	176,200

The estimates from the summer surveys covering the overall Aleutians showed a moderate increase (22%) 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 winter survey estimate from the eastern Aleutians 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 Islands region.

Size Composition

The increase in abundance of cod in the eastern Bering Sea has primarily been due 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 the 1977 year-class through the population has been illustrated by length-frequency distributions. Population number estimates of fish by size group illustrates the recruitment of the strong 1977 year-class to the survey area as age 1 fish in 1978 and the predominance of this year-class in the length-frequency distributions through 1981 (Fig. 3). In 1982-84, this year-class no longer formed a prominent mode in the overall size distribution of the population. To better illustrate the importance of the 1977 year-class to the overall population abundance, the length-frequency distributions were also plotted in terms of weight (Fig. 3). These weight estimates by size class demonstrate that the majority of the biomass (76% or 757,000 t), is made up of cod between 55 and 90 cm which is believed to primarily represent fish of the 1977 year-class. The 1982 year-class, which was noted last year to be stronger than the 1978 to 1981 year-classes, but not nearly-as strong as the 1977 year-class, contributed about 100,000 t to the total biomass estimate from the 1984 survey. These 2-yr-old fish are evident from the mode in the length-frequency distribution between 20 and 40 cm. The abundance of the 1983 year-class, which is represented by population number estimates of fish between 10 and 20 cm, appears to be as low, if not lower, than other year-classes observed since 1978.

PROJECTIONS OF ABUNDANCE

The abundance of Pacific cod has been projected through 1986 in previous reports (Bakkala et al. 1983; Bakkala and Wespestad 1984). The impetus for these forecasts has been the presence of the strong 1977 year-class in the population 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.

It has become increasingly apparent from comparisons of the forecasts and abundance estimates from the surveys that population characteristics of

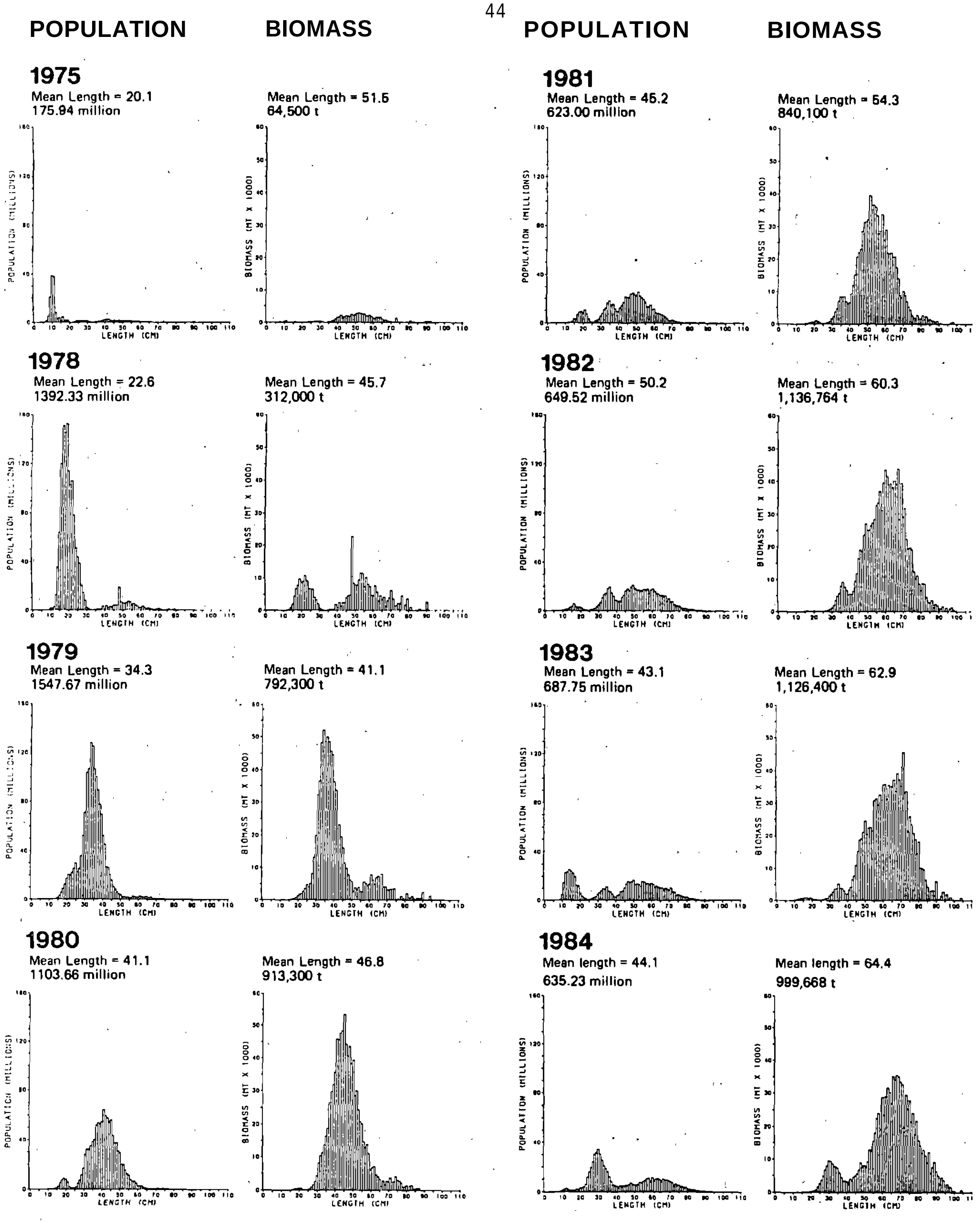

Figure 3.--Population and biomass estimates by centimeter length interval for Pacific cod as shown by Northwest and Alaska Fisheries Center bottom trawl surveys in 1975-54.

Bering Sea cod (age composition and natural mortality) are different than was assumed when making earlier forecasts. Adjustments were made to the model parameters and updated forecasts produced as new information became available,

Model parameters were again adjusted following the availability of results from the 1984 survey. The same base year data, 1979 population estimates by age, were used in the model as in the past. New information incorporated into the model included 1983 catch data, recent estimates of recruitment from survey data, an improved length-weight relationship ($W = 0.00608\ L^{3.1635}$), and two estimates of natural mortality (0.50 and 0.45). Results of the new projections in 1980-84 in terms of population numbers are shown below along with estimates from survey data:

	Survey population estimates (millions)		Projected population estimates for Ages 3+ (millions)	
Year	Total population	Ages 3+	M = 0.50	M = 0.45
1980	1,104	662	805	848
1981	623	491	732	795
1982	649	566	502	566
1983	688	492	332	429
1984	637	392	227	300

The new parameters and an M value of 0.45 resulted in better agreement between the forecasts and survey results in 1982-84.

A comparison of biomass estimates from the surveys and the forecasting model using these new parameters and an M Value of 0.45 is as follows:

Year	Survey estimates (t)	Projected estimates (t)
1980	913,000	1,230,000
1981	840,000	1,306,000
1982	1,014,000	1,231,000
1983	1,126,000	1,058,000
1984	999,700	962,000

Again, there is better agreement between survey and projected biomass estimates in 1982-84 using the new model parameters.

Knowledge gained thus far from observations of Bering Sea cod during the period the strong 1977 year-class has been in the population leads to the following conclusions:

1. It has been assumed that cod were fully recruited to the survey sampling trawls at age 2, but the higher forecasts of abundance relative to the survey estimates in 1980-81 and the similarities in the abundance estimates from the surveys in 1982-84 suggest that recruitment to the survey fishing gear may occur over a period of years.. The convergence of survey and projected abundance estimates in 1982 indicate that cod may not be fully recruited to the survey gear until about age 4. Thus, recruitment based on survey data may be underestimated and may be one of the reasons that forecasts have not agreed well with survey estimates.
2. The natural mortality rate for Bering Sea cod is much lower than the value of 0.7 originally used. A lower natural mortality rate also suggests that the maximum life span of Bering Sea cod is longer than the 10-yr estimate based on age readings from scales and otoliths.

3. An adequate method of aging cod is needed to produce accurate results from the forecasting model. In the absence of age structures that provide reliable age readings, modal analysis (MacDonald and Pitcher 1979) have been used to estimate population numbers at age from the survey data. This method may provide adequate approximations of recruitment at ages 1 and 2, but for older fish the extensive-overlap in modes prevents accurate separation of population numbers by age.

The abundance of cod is expected to decline in 1985 and 1986 as indicated by previous projections. However, the revised forecasts indicate higher levels of biomass than had been expected. These revised forecasts result from higher recruitment and lower rates of exploitation than anticipated and from the lower rate of natural mortality used in the latest forecasts. Projected abundance of cod in the eastern Bering Sea is as follows:

Year	Total population bibmass (t)	Fished population (ages 3+) biomass (t)	Recruitment (millions of fish)
1985	862,000	751,200	225
1986	-786,400	675,600	225

Projections of biomass can be made for the Aleutians population by assuming that trends in abundance are the same as in the eastern Bering Sea. There, the ratio of the projected, 1985 exploitable population biomass and the total 1983 biomass is 751,200 t/1,126,000 t = 0.6671. This ratio can be applied to the biomass estimate from the 1983 Aleutian Islands region survey (176,000 t) to produce an estimated biomass for the Aleutians of 117,400 t in 1985. Thus the total estimated exploitable biomass for the combined eastern Bering Sea and Aleutian regions is 868,600 t.

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 undergoing a rapid increase in abundance. Thus, observations of the population over a period of low or stable abundance are not available. It is therefore difficult to derive estimates of maximum sustainable yield (MSY) based on information from only a portion of the abundance cycle of the population. For these reasons, an estimate of MSY with present data is not considered valid.

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 population is at a high point in its natural cycle of abundance due to the strong 1977 year-class, and the abundance of this year-class is expected to decline from natural causes in the next few years. Thus, yields cannot be adjusted to maintain the stock at the present level but should be increased to take advantage of the available surplus before it is lost to natural mortality.

Based on a number of simulations of the eastern Bering Sea cod population using various exploitation rates, Wespestad et al. (1982) concluded that the exploitation strategy that appeared to provide the greatest cumulative catch in 1983-86 was to increase exploitation rates to 0.4, while the strong 1977 year-class remained relatively abundant in the population.

The 1984 survey results indicate that the biomass of cod in the eastern Bering Sea, although starting to decline, remained high at about 1 million t in 1984. Revised projections of abundance indicate that the exploitable biomass (age 3 and above) in the combined eastern Bering Sea and Aleutian regions will be about 868,600 t in 1985. Thus, the allowable catch in 1985 is estimated to be higher than previously projected. Because a large part of the population biomass in 1984 (757,000 t in the eastern Bering Sea alone) consisted of large, relatively old fish that should be utilized before they are lost to natural mortality, it is again recommended that an exploitation rate of 0.4 be used to estimate the allowable catch in 1985. This exploitation rate applied to the exploitable biomass provides an allowable catch of 347,400 t for the combined eastern Bering Sea and Aleutian Islands regions in 1985.

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YELLOWFIN SOLE

by

Richard G. Bakkala and Vidar G. Wespestad

INTRODUCTION

The yellowfin sole, Limanda aspera, resource of the eastern Bering Sea was substantially reduced in abundance 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 a third or less of pre-1960 levels. The resource began to recover in about 1972 and abundance. in recent years is estimated to be as high or higher than pre-1960 levels.

CONDITION OF STOCK

Catch Statistics

Variations in annual catches of yellowfin sole (Table 1) can be summarized as follows:

Period	Number of years	Range in annual catches (t)	Average annual catch (t)
1954-58	5	12,562 - 44,153	24,049
1959-62	4	185,321 - 553,742	403,967
1963-68	6	53,810 - 162,228	99,928
1969-71	3	133,079 - 167,134	153,537
1972-77	6	42,235 - 78,240	57,950
1978-83	6	87,391 - 138,433	104,373

Table 1.--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	USSR	ROK[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

[a]Source of catch data: 1954-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to the United States by fishing nations; 1980-82, French et al. 1981, 1982; Nelson et al. 1983, 1984.
[b]Republic of Korea.

Following the period of intense exploitation in 1959-62, catches declined to fairly low levels in 1972-77 due primarily to the absence of a directed fishery for yellowfin sole by the U.S.S.R. The U.S.S.R; reentered the yellowfin sole fishery in 1978-79 and catches increased to range from 99,000-138,400 metric tons (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. Since 1979, catches have ranged around 100,000 t annually with the highest catch in this period reaching 108,400 t in 1983. Catch quotas established by the North Pacific Fishery Management Council (NPFMC) during this period were 126,000 t in 1979 and 117,000 t in 1980-83 (see Table 4 of the Introduction section of this report). For 1984, however, the quota was increased to 230,000 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 those from 1/2° 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.

The Japanese commercial fishery for yellowfin sole operated mainly in the months of October-March from 1969 to 1976 but since then operations have shifted to summer and fall months. Catch per unit of effort (CPUE) values were originally calculated for the October-March period, 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 2; Fig. 1).

Table 2.--Catch, effort, and catch per unit of effort (CPUE) for yellowfin sole by Japanese pair trawlers in 1/2° 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
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

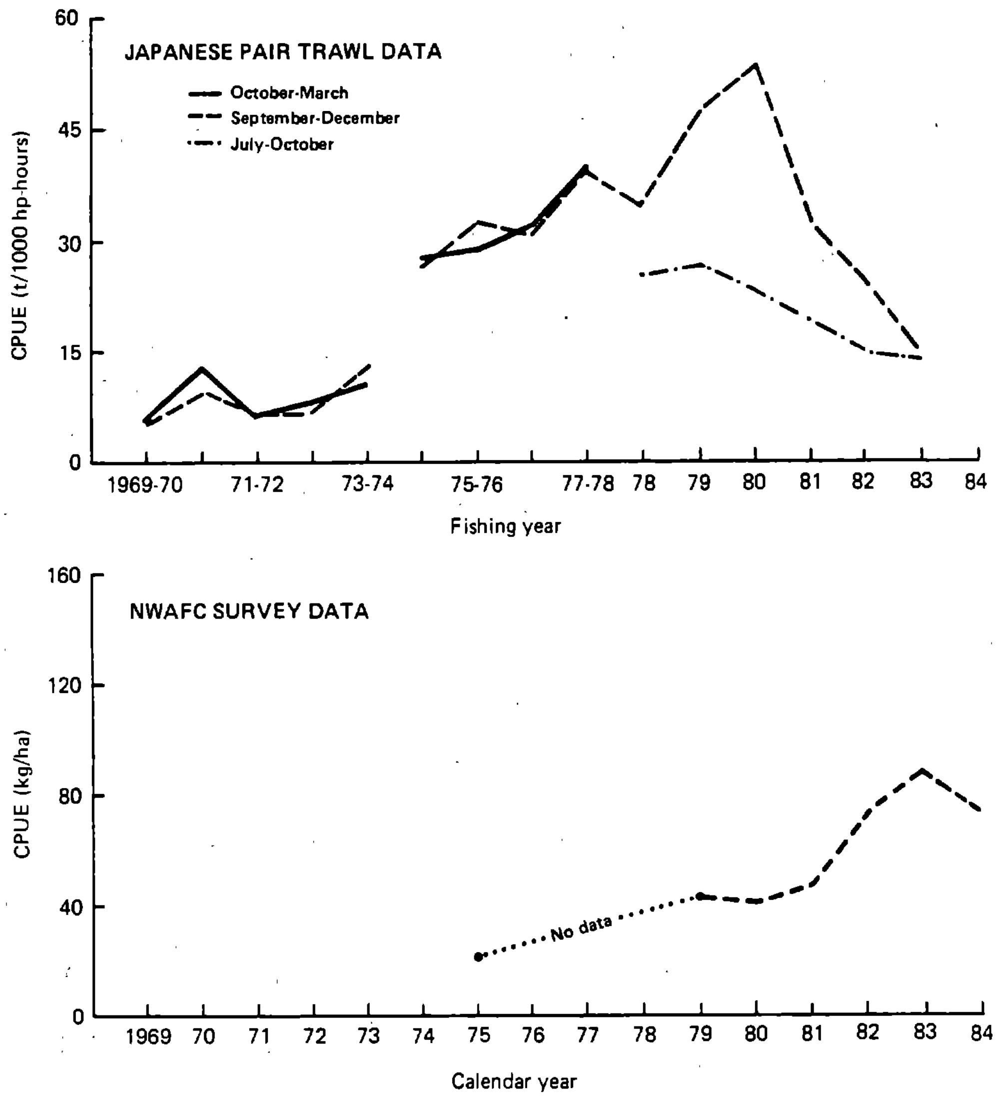

figure 1 .--Relative abundance (catch per unit of effort, CPUE) of yellowfin sole in the eastern Bering Sea as shown by Japanese pair trawl data and by data from Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys. Breaks in trend lines indicate changes in fishing gear or fishing techniques (see text).

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. 1). 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 from the Japanese pair trawl data is not believed to be representative of the actual abundance of the population in view of the results from surveys and a cohort analysis that will be discussed later in this report.

The NWAFC survey data have also shown a major increase in abundance of yellowfin sole since 1975 (Fig. 1). The CPUE values from these comprehensive surveys showed an approximate doubling of relative abundance [20-41 kg/hectare (ha)] from 1975 to 1979. There was an apparent leveling off of abundance in 1980, but CPUE values showed further substantial increases through 1983 before showing a moderate decline in 1984.

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 bottom-dwelling species. 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 of the 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 had been the standard trawl used by most survey vessels up to 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 a single 25-fathom (46 m) section branching into two 15-fathom (27 m) bridles for an overall length of 40-fathom (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.

High CPUE estimates from the survey again in 1983 and 1984 provide evidence that the new rigging has in fact increased the efficiency of the trawls for bottom-tending species such as flatfish. The CPUE rose rather markedly from 70.3 kg/ha in 1982 to 86.5 kg/ha in 1983 but declined to 72.4 kg/ha in 1984.

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. 2). These year-classes are now relatively old, ranging from 13 to 17 yr in 1983. They still contribute substantially to commercial catches (45% in 1982), however, and may continue to contribute substantially to the commercial fishery for a few more years.

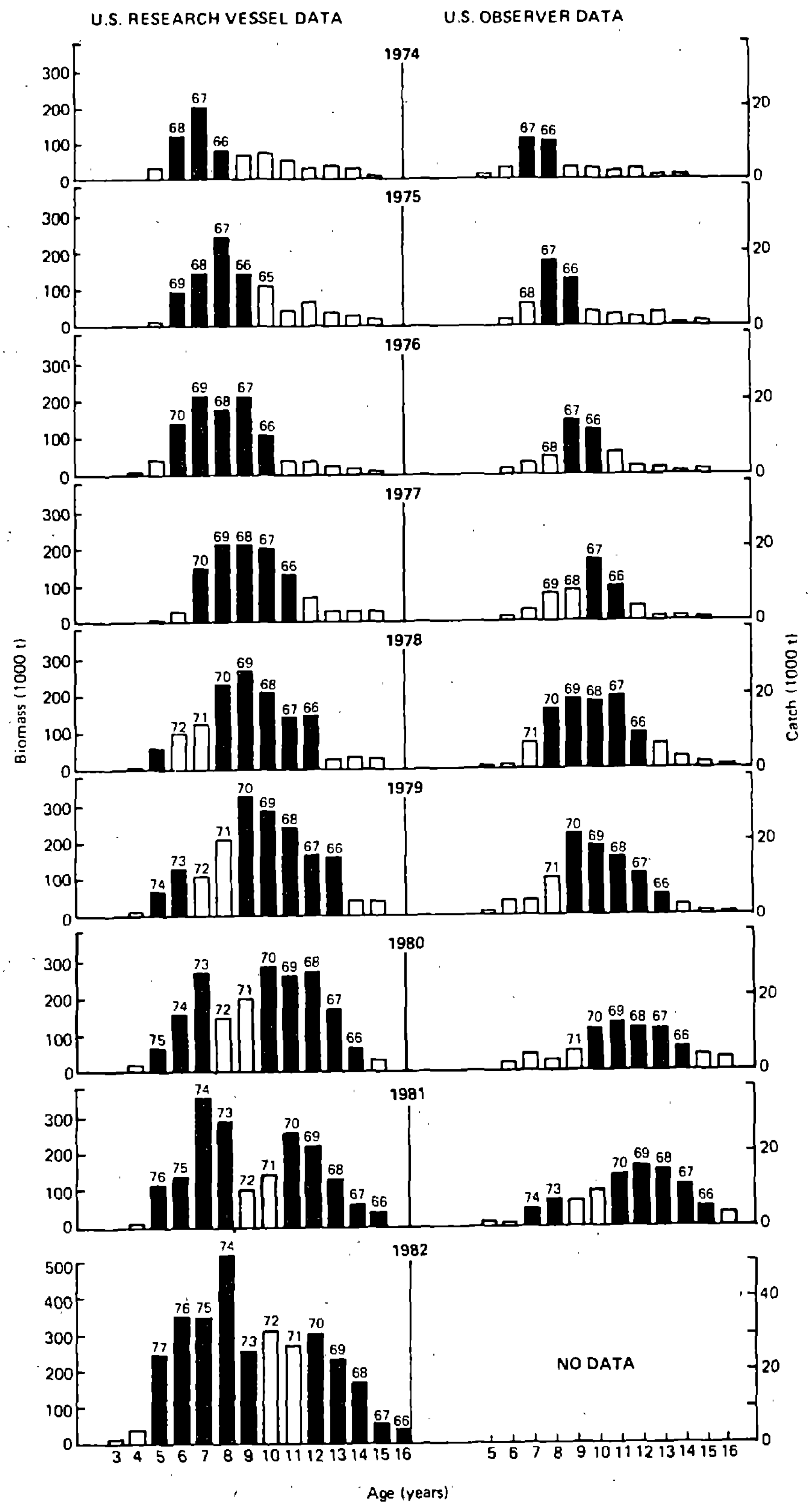

Figure 2.--Age composition of yellowfin sole of the eastern Bering Sea as shown by data from trawl surveys of the Northwest and Alaska Fisheries Center and by U.S. observer data from the commercial fishery. Year-classes for more abundant ages are shown with the appropriate bars, and darkened bars represent stronger than average year-classes.

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. This new series of strong year-classes are mainly responsible for the more recent increases in abundance of the population in 1981-83. 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

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 1979-81 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 1 in the section on walleye pollock in this report) not surveyed in 1981 yielded 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, approximating the 1982 estimate. 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.

Biomass Estimates from Cohort Analysis

Cohort analyses have previously been carried out foreastern 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 3 in terms of numbers and in Table 4 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 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 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

Table 3.-- 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
	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
	11.130	13.177	16.571	20.276	20.856	20.659	23.885	27.751	29.743

[a] Differences in totals due to rounding.

Table 3.--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
	33.524	32.063	27.932	24.359	21.232

[a] Differences in totals due to rounding.

Table 4.-- 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]Differences in totals due to rounding.

Table 4.-- 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.

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.

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 (19691, 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).

Wakabayashi (1982) estimated MSY based on results of a yield-per-recruit analysis. His estimates and input data were as follows:

M	F_{MSY}[a]	Yield/recruit (g)	Recruitment at age 3 (billions of fish)		MSY (t)	
			Low	High	Low	High
0.25	0.30	34.1	3.84	8.27	131,000	282,000
0.20	0.25	46.8	2.30	5.78	108,000	271,000
0.12	0.22	86.0	1.11	3.30	95,000	284,000

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--similar in magnitude to the above estimates by Wakabayashi (1982) for low recruitment levels.

The actual MSY probably falls somewhere in the middle of the estimates, which vary from 78,000 to 284,000 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

[a]F values producing MSY.

(175,000 t) estimated from an ecosystem model (Low 1984). Thus MSY is probably near 150,000-175,000 t.

EQUILIBRIUM YIELD

Evidence from survey data indicates that the yellowfin sole population is in excellent condition., The biomass of the population is extremely high and averaged 3.1 million t during 1981-83. The 1984 estimate (3.4 million t) was similar to the 1981-83 mean value. Moreover, the age composition of the population is well balanced with the strong 1966-70 year-classes still providing a substantial share of commercial catches and a new series of strong year-classes entering the exploitable population. Equilibrium yield in 1985 should therefore be maintained at the 310,000 t level estimated in 1984, which represents an exploitation rate of approximately 10%.

GREENLAND TURBOT AND ARROWTOOTH FLOUNDER

by

Richard G. Bakkala

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: adults are usually found in waters of the continental slope and juveniles in shelf waters. 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. Catch records 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, though their abundance there is lower than in the eastern Bering-Sea. Because small juveniles of the two species have not been found in the Aleutians, these turbots are assumed to be from the same stocks as those in the Bering Sea.

The target fishery on turbot by the Japanese land-based trawl fleet 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 half of the catch of turbot (Table 1), presumably as

Table 15.--All nation catches (t) of arrowtooth flounder and Greenland turbot, 1960-83.[a]

	Eastern Bering Sea (east of long. 180°)							Aleutian Island 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

Table 1.--(Continued)

Year	Eastern Bering Sea (east of long. 180°): Japan MS-LG-NPT[b]	Japan LBD[c]	USSR	ROK[d]	Other nations[e]	Joint ventures[f]	Total	Aleutian Island area: Japan MS-LG-NPT	Japan LBD	USSR	ROK	Joint ventures	Total	E. Bering Sea and Aleutian comb. 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
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

[a]Sources of data: 1960-76, Wakabayashi and Bakkala 1978, 1977-79, data submitted to United States by fishing nations, 1980-82, French et al. 1981, 1982; Nelson et al. 1983; 1984.
[b]Mothership, North Pacific longline and North Pacific trawl fisheries combined. [c]Land-based dragnet trawl fishery.
[d]Republic of Korea. [e]Taiwan, Poland, and Federal Republic of Germany (F.R.G.). [f]Joint ventures between U.S. fishing vessels and Japanese, Polish, R.O.K., F. R. G., and U.S.S.R. processing vessels.

an incidentalpart of the target fishery for 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 metric tons (t) in 1974 (Table 1). Catches then declined to less than 60,000 t in 1977-79 but again increased to range above 60,000 t in 1980-83.

CONDITION OF STOCKS

Relative Abundance

Two sources of data are used to examine trends in relative abundance of Greenland turbot and arrowtooth flounder: commercial catch and effort data from the Japanese land-based dragnet fishery and data from Northwest and Alaska Fisheries Center (NWAFC) research vessel surveys. The Japanese land-based stern trawlers have targeted Greenland turbot, and data from these vessels 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 NWAFC research vessel surveys have been limited to continental shelf waters in most years and have 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.

Greenland turbot catch and effort data from the land-based fishery were analyzed by 1/2° latitude and 1°, longitude statistical blocks and by month 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 1 shows that following relatively high annual catch rates in 1972 and 1973 at approximately 48 t/100 h trawled, catch per unit of effort (CPUE) declined to range from 27 to 33 t/100 h trawled in 1976-79. In 1980, CPUE values increased to 41 t/100 h, but they have since declined sharply to 18 t/100 h in 1983.

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. There followed a marked decline, with CPUE falling from 3.7 kg/hectare (ha) in 1980 to 0.4 kg/ha in 1984. This low recruitment of juvenile fish has apparently resulted in the decrease in abundance of the adult stock in 1982 and 1983. Following the overall trend seen in the fishery, CPUE values from the sampling of adults on the slope during joint U.S.-Japan trawl surveys remained stable from 1979 to 1981 at about 27 kg/ha and then declined to 24 kg/ha in 1982.

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. 1), shows a decline in CPUE between 1976 and 1978 and then moderate increases through 1983. Results from joint U.S.-Japan surveys on the slope show similar CPUE values in 1979 and 1981 at around 9 kg/ha trawled and then a decrease to about 7 kg/ha during 1982.

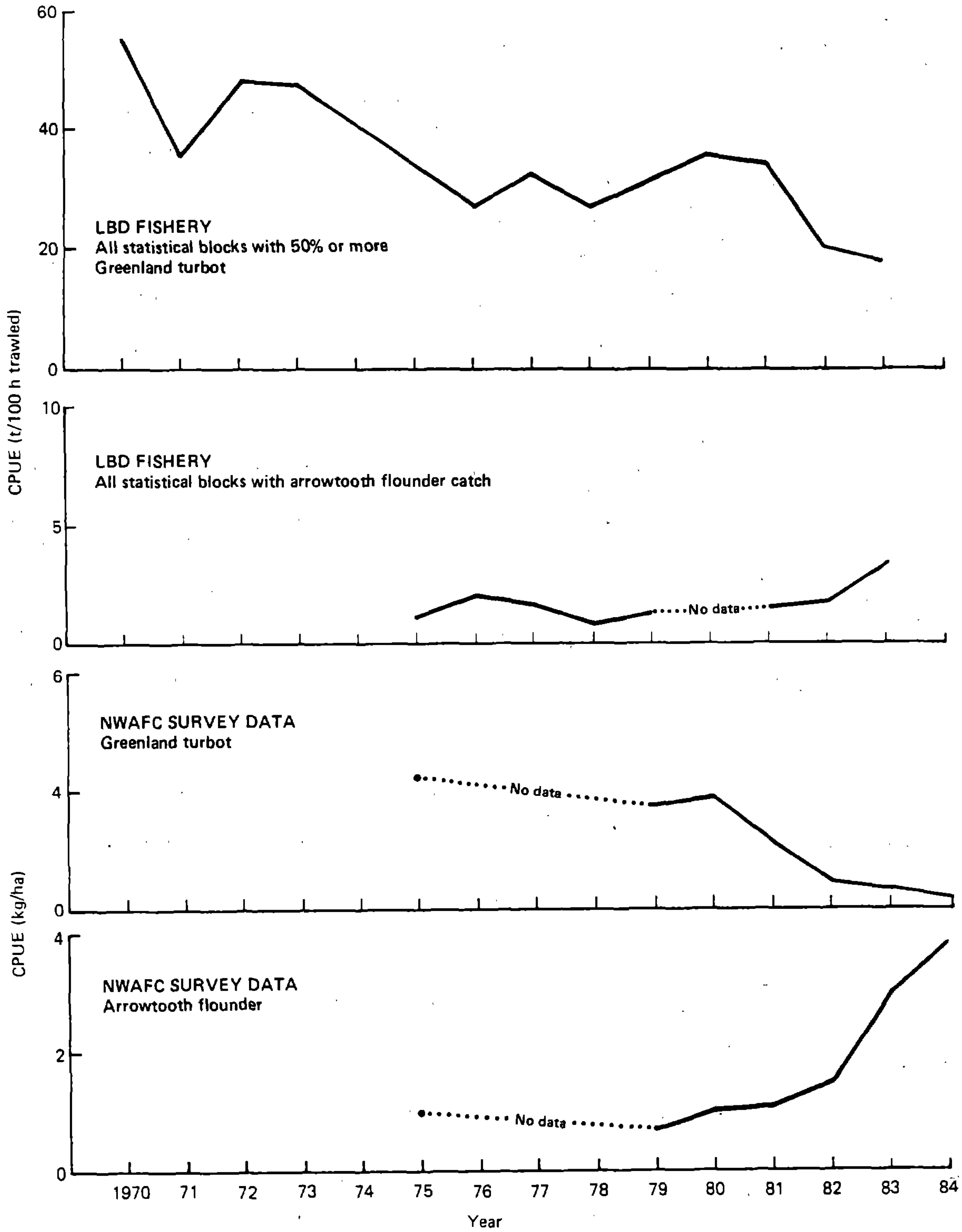

Figure 1 .--Relative abundance (catch per unit of effort, CPUE) of Greenland turbot and arrowtooth flounder as shown by data from the Japanese land-based dragnet (LBD) fishery and by large-scale surveys of the Northwest and Alaska Fisheries Center (NWAFC) that have sampled major portions of the eastern Bering Sea continental shelf.

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 (Fig. 1).

Biomass Estimates

Biomass estimates (t) from large-scale NWAFC surveys in 1975 and 1979-84 (for comparable areas sampled on the continental shelf) were as follows:

Species	1975	1979	1980	1981	1982	1983	1984
	t						
Arrowtooth flounder	28,000	42,000	47,800	53,400	70,200	149,300	182,900
Greenland turbot	126,700	146,900	172,200	81,900	41,800	35,100	17,900
Total	154,700	188,900	220,000	135,300	112,000	184,400	200,800

These estimates primarily represent the biomass of only the juvenile portion of the population. They indicate an increase in the abundance of juveniles through 1980, a sharp decrease in 1981 and 1982, and then an increase to the 1980 level in 1984. Although the abundance of the juveniles for the combined species has returned to the level of 1980, the increase is entirely due to higher abundance of arrowtooth flounder; the abundance of juveniles of the commercially more valuable Greenland turbot has declined to about 10% of their abundance in 1980. The continued poor recruitment of juvenile Greenland turbot through 1984 would suggest that the abundance of adults will also continue to decline.

Data from the Japanese and U.S. cooperative surveys in 1979 and 1981-82 from the eastern Bering Sea (including sampling of continental slope waters) and in 1980 and 1983 from the Aleutian Islands region provide the most comprehensive and latest abundance estimates for the overall juvenile and adult populations:

Species	Eastern Bering Sea 1979	1981	1982	Aleutian region 1980	1983
	----------	----------	t	----------	----------
Arrowtooth flounder	58,100	85,500	89,000	40,400	34,200
Greenland turbot	304,300	185,800	124,900	48,700	42,400
Total	362,400	271,300	213,900	89,100	76,600

The 1979 and 1982 survey data are believed to be more representative of the overall population abundance in the eastern Bering Sea because waters north of St. Matthew Island, where Greenland turbot are relatively abundant, were sampled. The combined sampled biomass of turbots from the 1979 eastern Bering Sea and 1980 Aleutian surveys was approximately 451,500 t. The estimate from the 1982 eastern Bering Sea and 1983 Aleutian surveys was 290,500 t. This decline was due entirely to the decrease in abundance of Greenland turbot.

Size and Age Composition

Age data for arrowtooth flounder and Greenland turbot have been collected during U.S. research vessel surveys and by U.S. observers from the commercial fishery. Arrowtooth flounder taken during NWAFC surveys on the continental shelf are mainly 2- to 4-yr-olds (Fig. 2). Age information collected during these surveys in 1978-82 indicated that the 1975-77 year-classes were relatively strong with the 1977 year-class the strongest of this series. The 1979-80 year-classes also appear to be relatively strong. Age data for arrowtooth flounder from Japanese large trawlers in 1977 and Japanese small trawlers (mainly land-based) in 1978 indicated that arrowtooth flounder are 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. 3). Age data collected from catches by small

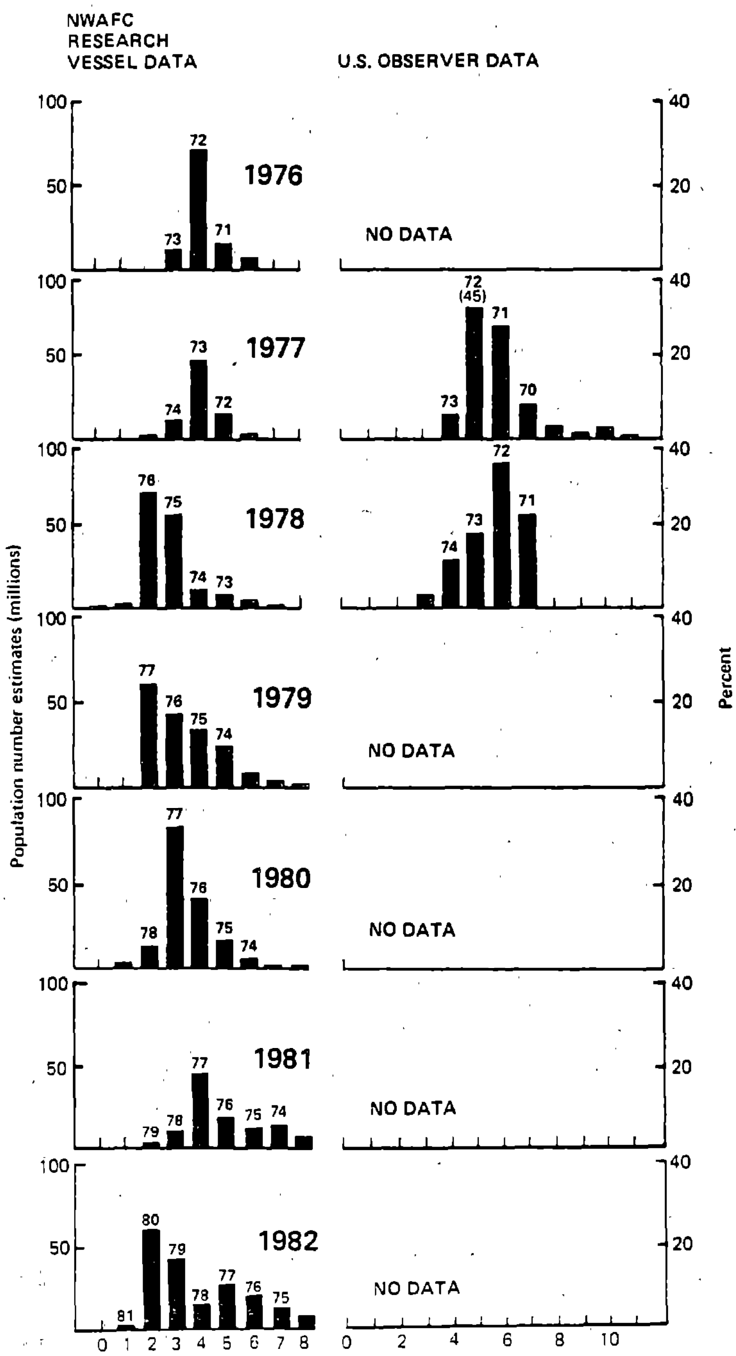

Figure 2 .--Age composition of arrowtooth flounder as shown by data from Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by data collected in the commercial fishery by U.S. observers.

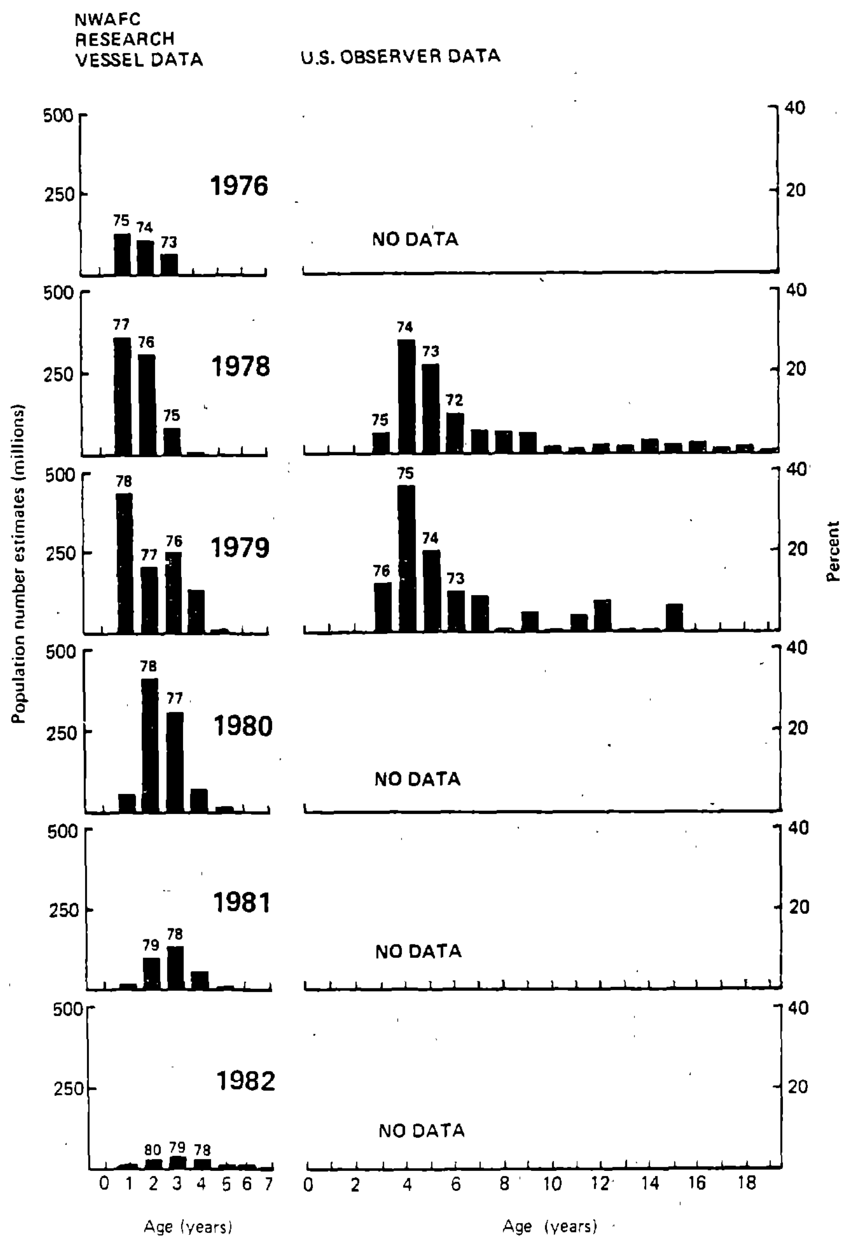

Figure 3 .--Age composition of Greenland turbot as shown by data from Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by data collected in the commercial fisheries by U.S. observers.

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.

The recruitment of age 1 Greenland turbot in 1980-82 was low (Fig. 3), 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 1984 and a major decline in population numbers of juveniles in continental shelf waters (Fig. 4). Population estimates decreased from approximately 289 million fish in 1981 to 22 million in 1984.

Size 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. 4). 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 (Fig. 5). 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.

Population numbers of adult arrowtooth flounder decreased on the continental slope from about 41 million in 1979 to 25 million by 1982. However, estimates of abundance by weight were rather stable during this period, probably due to a concurrent increase in average size.

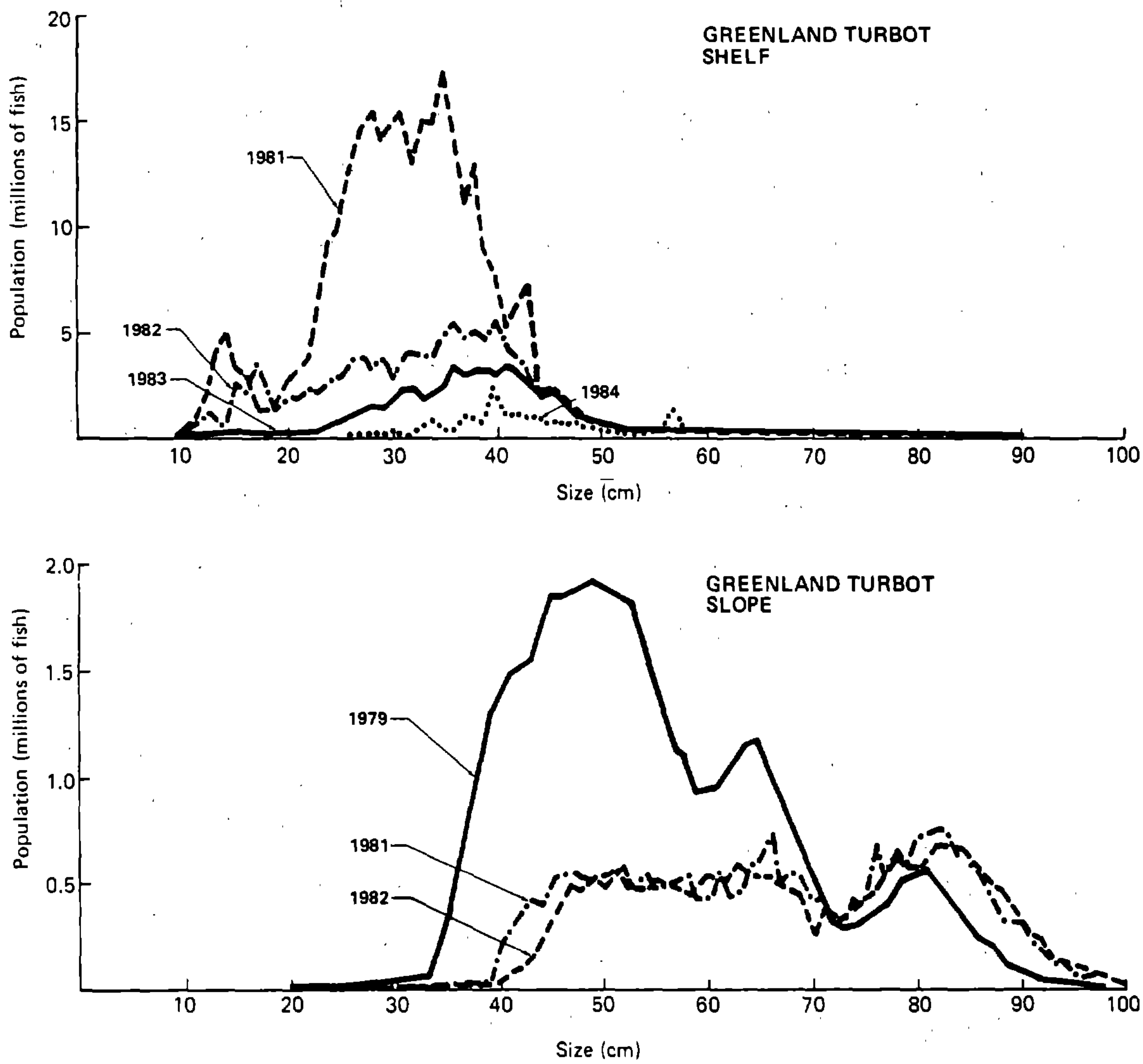

Figure 4.--Size composition of Greenland turbot on the eastern Bering Sea continental shelf and slope during research vessel surveys, 1979-84.

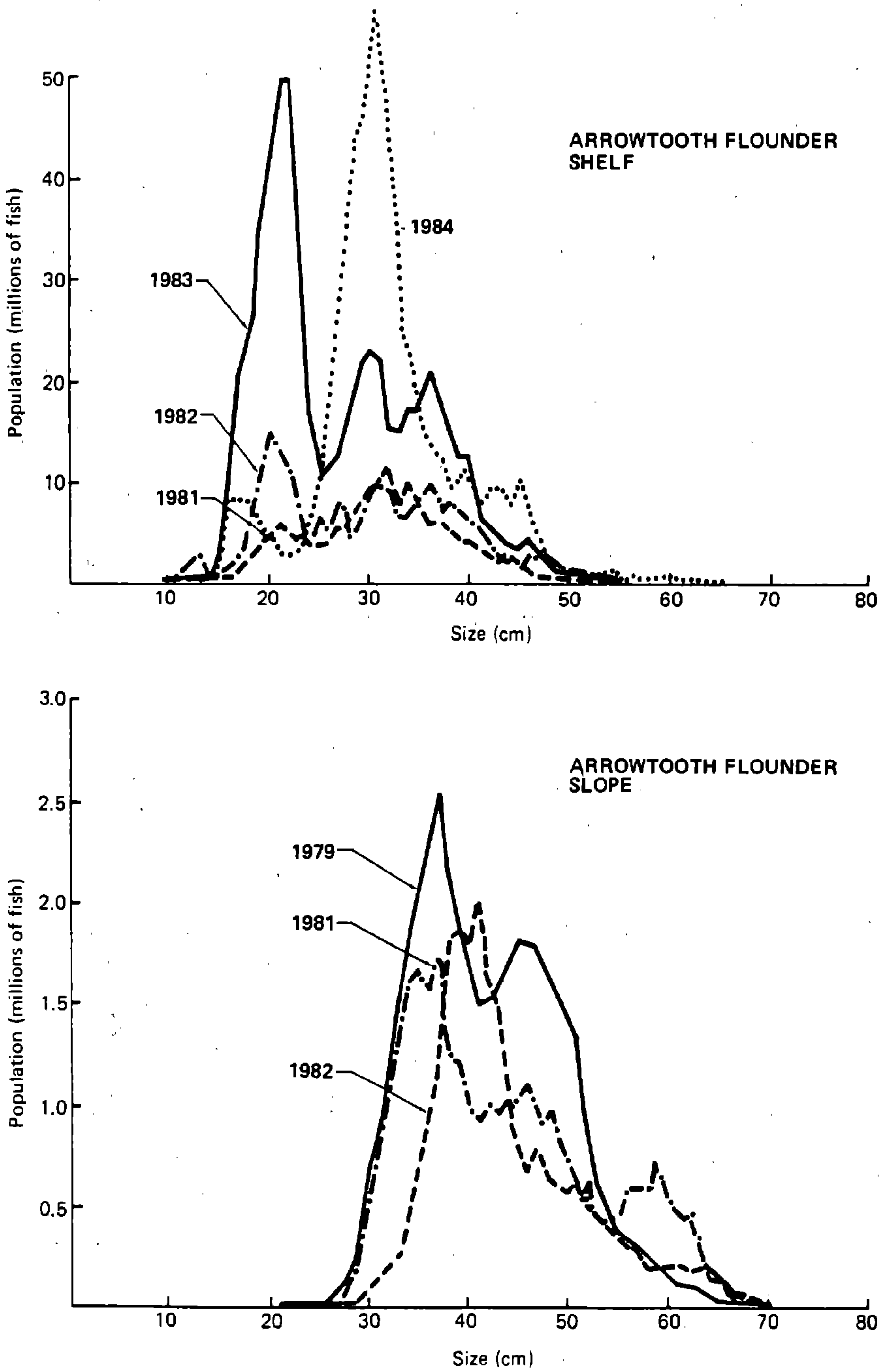

Figure 5.--Size composition of arrowtooth flounder on the eastern Bering Sea continental shelf and slope during research vessel surveys, 1979-84.

MAXIMUM SUSTAINABLE YIELD

Data from cooperative Japanese-U.S. surveys are now available for both the eastern Bering Sea and, Aleutian Islands region, from which an estimate of maximum sustainable yield (MSY) can be made for the complete Bering Sea management area. Using estimates from the 1979 survey in the eastern Bering Sea (304,300 t) and the 1980 survey in the Aleutians (48,700 t) as being most representative of the total population, the overall biomass for Greenland turbot in that period was estimated at 353,000 t. Assuming that Greenland turbot have 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 is estimated at 706,000 t. Based on the Alverson and Pereyra (1969) yield equation and a natural mortality coefficient of 0.19 (Okada et al. 1980), MSY is estimated as 0.5 x 0.19 x 706,000 t or 67,000 t.

Based on the above survey data, the overall biomass of arrowtooth flounder from the eastern Bering Sea and Aleutians was estimated to be 98,500 t. Using the same assumptions as those for Greenland turbot, except that a value of 0.2 was used for natural mortality (Okada et al. 1980), MSY is 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 from the overall management area is then 86,700 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 1984. 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 apparent in a decline in CPUE from the fishery in 1982 and 1983 and in reductions in CPUE and biomass estimates from research surveys on the slope. Based on the assumption that the stock was producing at the MSY level in 1979 and that the CPUE from the fishery in 1983 (18 t/l00 h) was 56% of the 1979 value (32 t/100 h), equilibrium yield in 1985 is estimated to be 56% of the MSY estimate (67,000 t) or 37,500 t.

The CPUE and biomass estimates for juvenile arrowtooth flounder have increased in 1979-82 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 last year or 20,000 t.

For the combined turbot complex, the estimate of equilibrium yield for the eastern Bering Sea and Aleutians is 57,500 t.

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OTHER FLATFISH

by Richard G. Bakkala

INTRODUCTION

This species complex is made up of the following small flatfish which have distributions that are mainly restricted to waters of the continental shelf: flathead sole, Hippoglossoides elassodon; rock sole, Lepidopsetta bilineata; Alaska plaice, Pleuronectes quadrituberculatus; and small amounts of miscell - aneous flatfish including rex sole, Glyptocephalus zachirus; Dover sole, Microstomus pacificus; starry flounder, Platichthys stellatus; longhead dab, Limanda proboscidea; and butter sole, Isopsetta isolepis. Catches of these species are almost entirely from the eastern Bering Sea, with only small amounts taken in the Aleutian Islands region. All-nation catches of these species in- reased from around 30,000 metric tons (t) in the 1960s to a range of 65,000 to 92,000 t in 1970-72 (Table 1). At least part of this increase was due to better species identification and reporting of catches in the 1970s. After 1971, reported catches declined to about 20,000 t in 1975 but increased to 43,000 t in 1978 and 35,600 t in 1979. The higher catches in 1978 and 1979 may be due to two causes--the renewal of the U.S.S.R. flounder fishery in those years and the first reporting (starting in 1977) of catches of miscellaneous species of flatfish. These latter catches are believed to contain some amounts of Greenland turbot, Reinhardtius hippoglossoides, and arrowtooth flounder, Atheresthes stomias, because some fisheries may have categorized part of their turbot catch as miscellaneous flatfish. This categorization would have arti- ficially inflated these "miscellaneous" catches and, subsequently, the total catches of other flatfish in 1977-79. Catches in 1980 and 1981, based on U.S. observer data, were much lower (20,500-23,400 t) but they increased to

Table 1 .--All-nation catches of- other flatfishes in the eastern Bering Sea and Aleutian Islands region in metric tons (t)(l980-83 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	5,319	7,586	3,119	7,578	23,602
1978	7,038	14,603	9,468	11,838	42,947
1979	5,874	6,777	15,572	7,376	35,599
1980	7,601	5,011	6,908	937	20,457
1981	9,021	5,193	8,653	561	23,428
1982	14,450	8,183	8,612	1,421	32,666
1983	15,402	6,262	12,416	1,159	35,239

[a]Sources of data: 1963-76, Wakabayashi and Bakkala 1978;
1977-79, data submitted to United States by fishing nations;
1980-83, French et al. 1981; 1982; Nelson et al. 1983; 1984.

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

32,700 t in 1982 and 35,200 t in 1983. These higher catches in 1982 and 1983 were mainly the result of the new joint, venture fisheries.

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. Increases in catch per unit of effort (CPUE) were particularly large for rock sole increasing from 6.9 to 13.4 kg/hectare (ha) and Alaska plaice, from 10.6 to 14.5 kg/ha. The increase for flathead sole (3.6 to 4.6 kg/ha) was moderate. As discussed previously, these higher 1982 estimates may have been due in part to better bottom contact 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 in fact increased the efficiency of the trawls for flatfish.

The CPUE values from surveys that have sampled major portions of the eastern Bering Sea since 1975 are illustrated in Figure 1. These trends indicate that the abundance of rock sole and Alaska plaice may have increased from 1975 to 1978-79 and showed further increases in 1980-83. The abundance of flathead sole was relatively stable from 1975 to 1979 and then increased moderately each year in 1980-84. In 1984, CPUE values for rock sole and Alaska plaice leveled off or declined slightly from 1983 values, suggesting that abundance may now be peaking for these species.

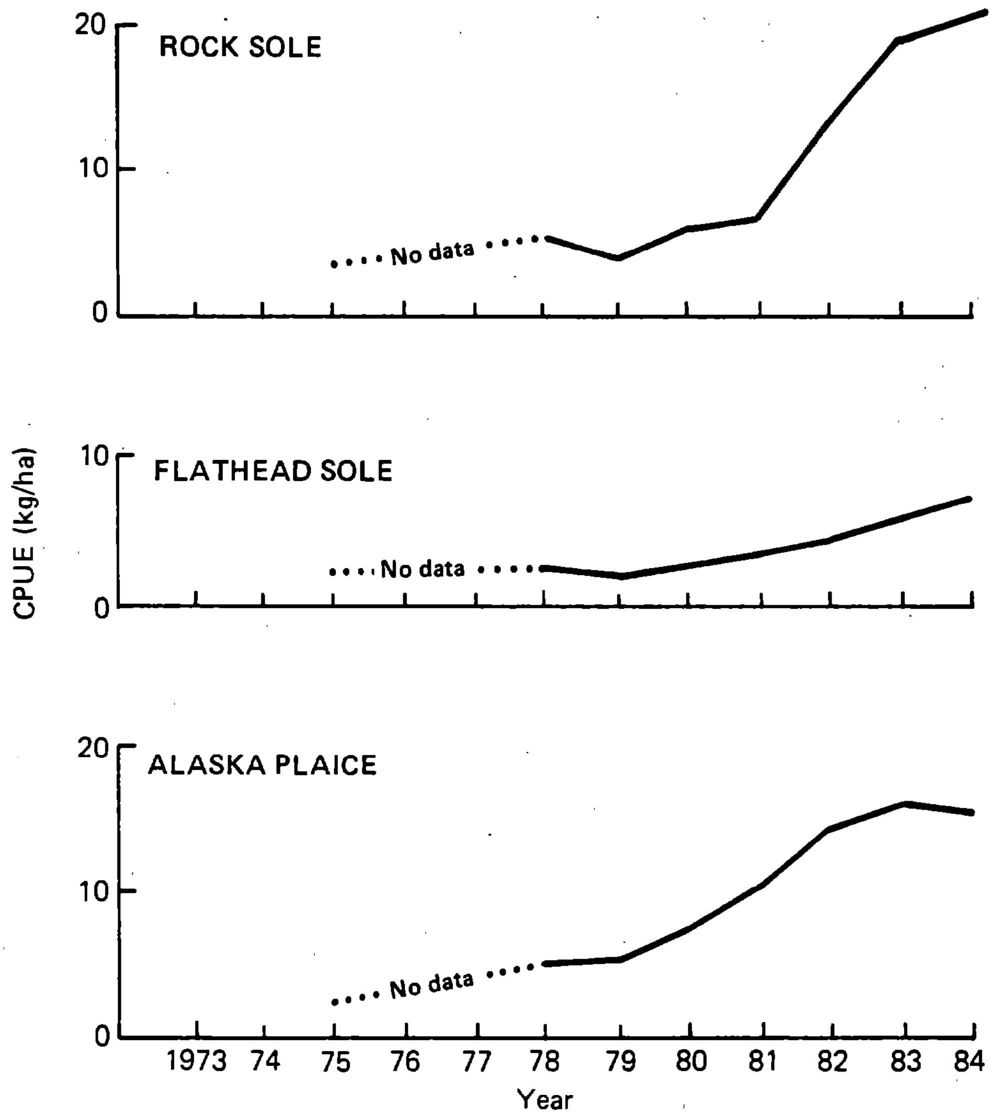

Figure 1 .--Relative abundance (catch per unit of effort, CPUE) of rock sole, flathead sole, and Alaska plaice as obtained by large-scale bottom trawl surveys of the Northwest and Alaska Fisheries Center.

Biomass Estimates

Estimates from large-scale NWAFC surveys (Table 2) indicate that the biomass of Alaska plaice had steadily increased from 127,100 t in 1975 to 745,400 t in 1983 before decreasing slightly to 726,800 t in 1984. For the other two major species in the other flatfish group, estimates were relatively stable through 1979, but then increased- substantially for rock sole from 182,800 t in 1979 to 967,500 t in 1984, and for flathead sole from 101,800 t in 1979 to 340,900 t in 1984. The biomass of the miscellaneous species of flatfish increased through 1982, but then 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 1982 trawls for flatfish over the trawls used in 1981. Sampling of waters in the vicinity of Nunivak Island in 1982, but not in 1981, also accounted for part of these increases for some species. The additional area sampled in 1982 (see Fig. 1 of the section on walleye pollock in this report) 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. None of the 1982 biomass estimate for flathead sole was accounted for by 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 the species.

Although the actual magnitude of changes in abundance of other flatfish over the past several years is difficult to judge because of the changes in fishing gear and areas sampled, real increases are believed to have taken place. These higher levels of abundance are probably due to good recruitment in recent years as will be discussed later.

Table 2.--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 1978-83.

		Species					
Year	Area	Rock sole	Flathead sole	Alaska plaice	Others	Total all species excluding Alaska plaice	Total all species
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	2,400	34,200	34,200
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.	10,000	600	0	2,500	13,100	13,100
1984	EBS	967,500	340,900	726,800	52,000	1,360,400	2,087,200

[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 34,200 t and 13,100 t respectively, most of which was rock sole.

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. 2). These year-classes also formed the major part of commercial catches of rock sole in 1975-79 (Fig. 2). 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.

Age data for the flathead sole, collected during research vessel surveys since 1976 and from the commercial fishery in 1977-79 (Fig. 3), show that the, 1965-69 year-classes formed the bulk of the population sampled by research vessels in 1976 and were a major component of catches by the commercial fishery, along with the 1970 year-class, in 1977. In more recent years, there appears to be good recruitment from the 1974-79 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

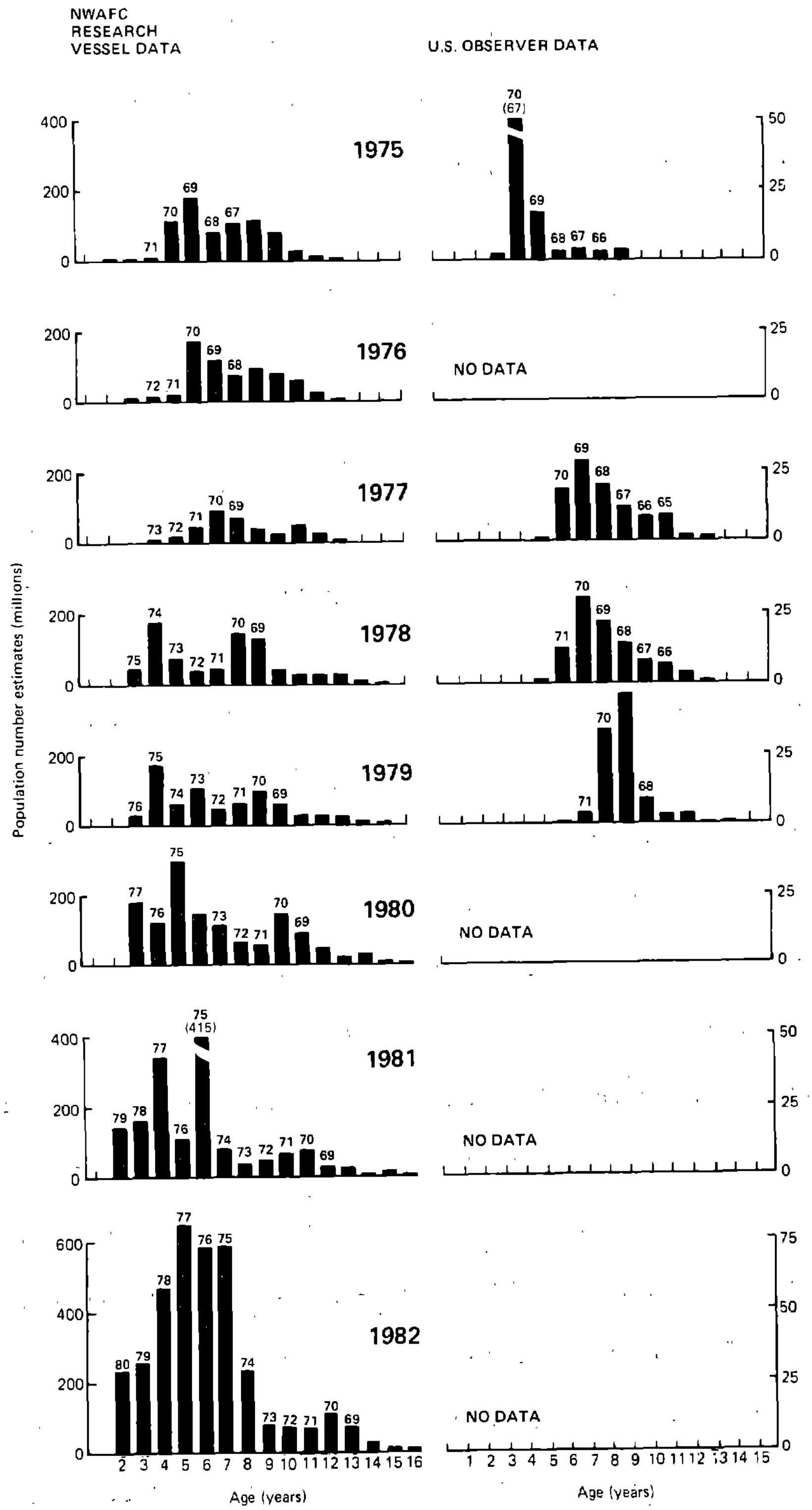

Figure 2. --Age composition of rock sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

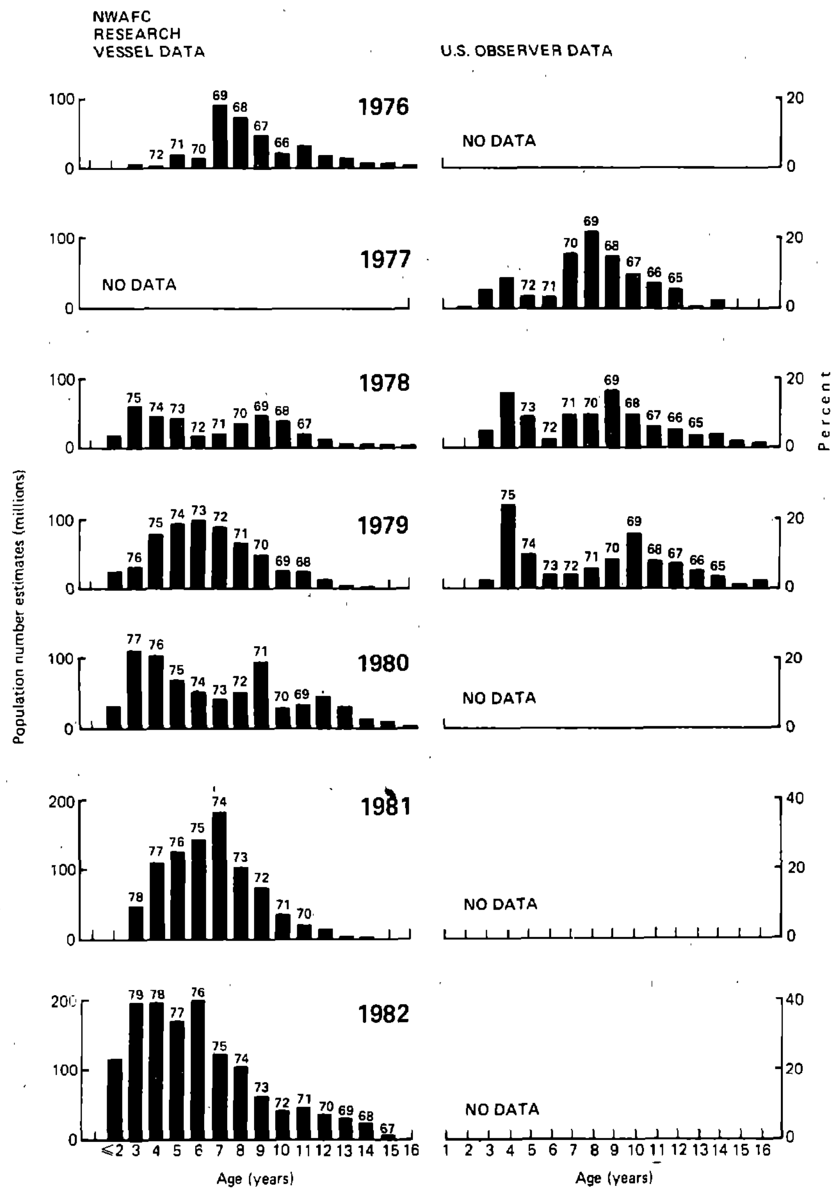

Figure 3. --Age composition of flathead sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

and continued to predominate in the population through 1982 at the relative old ages of 11-15 yr (Fig. 4). Some later year-classes also appear to be abundant, particularly the 1974 and 1975 year-classes.

MAXIMUM SUSTAINABLE YIELD

Intially, 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 a natural mortality coefficient (M) of 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.

The mean estimated biomass from the 1980 eastern Bering Sea and Aleutian surveys (504,600 t) and the 1981 eastern Bering Sea survey (538,900) falls within the estimated virgin population biomass derived from the 1975 data.

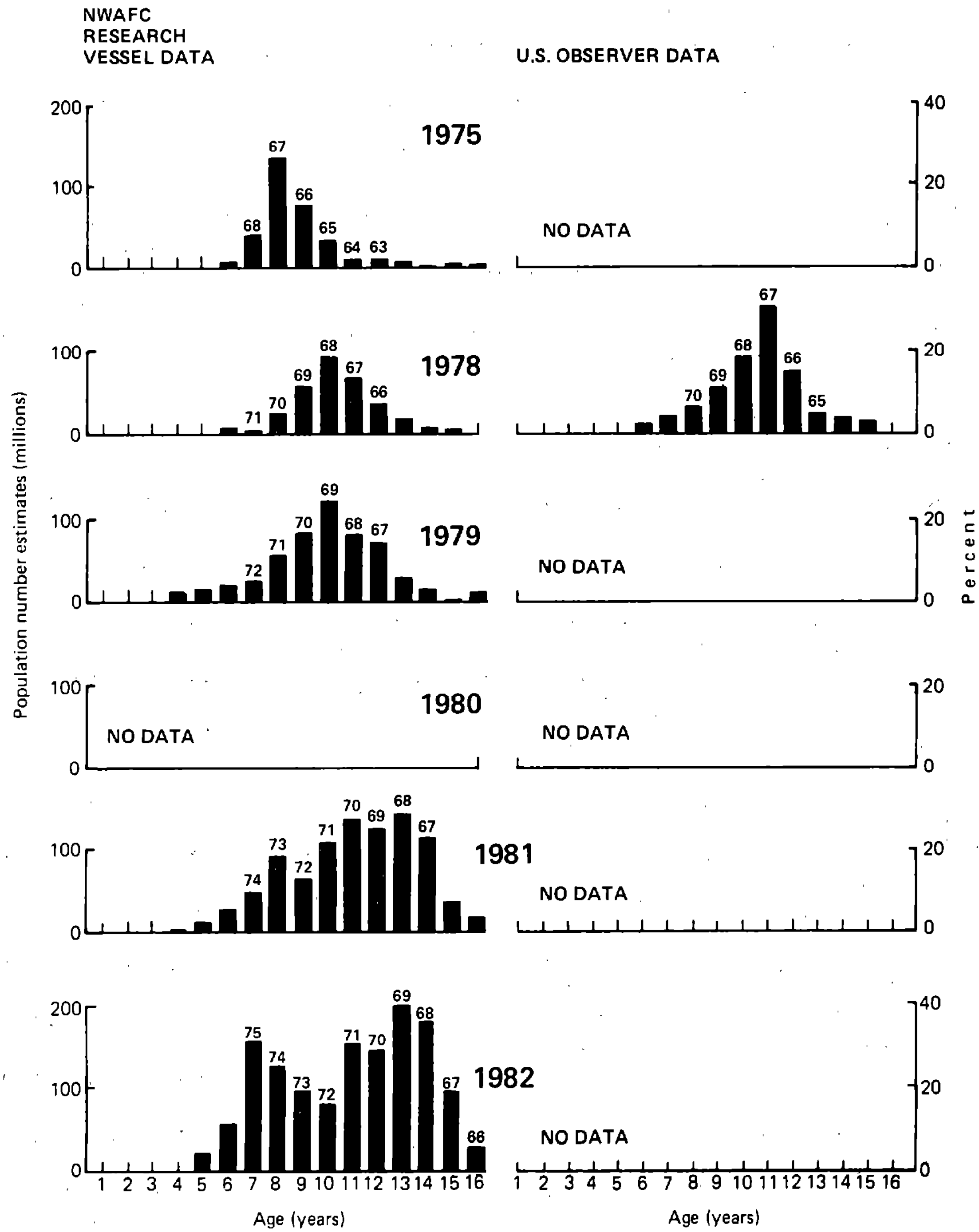

Figure 4.--Age composition of Alaska plaice as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

The 1982 (968,100 t), 1983 (1,218,600 t), and 1984 (1,360,400 t), estimates exceeded 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 exploited at the same rate as rock sole and flathead sole until recent years. Alaska plaice have probably not been exploited because of their more inshore distribution, which is removed from the main fishing areas. 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, possibly leading 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 small decline to 726,800 t in 1984. The MSY for Alaska plaice was estimated in 1980 based on the 95% confidence interval around the 1979 mean estimate, and assuming that, because this species has only been lightly exploited throughout the history of the fishery and because the biomass more than doubled between 1975 and 1979, the 1979 biomass may have approximated the abundance of the virgin population. Later, the higher 1981 estimate was considered to more nearly approximate the virgin biomass. 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

Recent estimates from large-scale NWAFC research vessel surveys show that the abundances of rock sole, flathead sole, and miscellaneous species of flatfish are currently very high at about 1.4 million t. In view of the present high abundance of these species, the resources should be capable of producing catches at the upper end of the MSY range. Therefore, EY is estimated to be at least as high as 80,200 t.

The abundance of Alaska plaice is also extremely high relative to past years with an estimated biomass of 726,800 t in 1984. The population should be capable of producing catches at the high end of the MSY range, or 70,000 t.

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SABLEFISH

by

Renold E. Narita

INTRODUCTION

Sablefish are widely distributed along the continental shelf and slope of the North Pacific Ocean (including the Bering Sea). Longline vessels and (occasionally) trawlers fish for sablefish in relatively deep waters of 400-900 m. The-fishery in the eastern Bering Sea grew rapidly during the early 1960s and catches increased to a peak of 28,520 metric tons (t) in 1962 (Table 1). As fishing grounds used by longliners in the eastern Bering Sea became preempted by expanding trawl fisheries, new longlining areas were established in the Aleutian Islands region. Catches peaked in the Aleutians at 3,580 t in 1972.

Catches declined after 1968 in the eastern Bering Sea and after 1972 in the Aleutian region, largely due to declining stock abundance. Since 1978, catches have remained at relatively stable and reduced levels because of low abundance of the stocks and catch restrictions placed on the fishery. In 1983, the all-nation catch of sablefish was 2,603 t in the eastern Bering Sea and 574 t in the Aleutian Islands region, with Japan responsible for 86% and 92% of the respective regional catches.

The sablefish resource is managed by discrete regions to distribute exploitation throughout its wide geographical area. In the Bering Sea, the two management units are the eastern Bering Sea and the Aleutian Islands region.

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, and management regulations which have influenced fishing patterns. With these

Table 1.--Historical catches of sablefish in metric tons by area and nation, in the Bering Sea/Aleutians, 1958-83.[a]

	Eastern Bering Sea				Aleutian Region				
Year	Japan[b]	U.S.S.R.	Others[c]	Total	Japan[b]	R.O.K.[d]	U.S.S.R.	Others[e]	TOTAL
1958	32	--	--	32	f	--	--	--	f
1959	393	--	--	393	f	--	--	--	f
1960	1,861	--	--	1,861	f	--	--	--	f
1961	26,182	--	--	26,182	f	--	--	--	f
1962	28,521	--	--	28,521	f	--	--	--	f
1963	18,404	--	--	18,404	f	--	--	--	f
1964	8,262	--	--	8,262	975	--	--	--	975
1965	8,240	--	--	8,240	360	--	--	--	360
1966	11,981	--	--	11,981	1,107	--	--	--	1,107
1967	13,457	274	--	13,731	1,383	--	--	--	1,383
1968	14,597	4,256	--	18,853	1,661	--	--	--	1,661
1969	17,009	1,579	--	18,588	1,804	--	--	--	1,804
1970	9,627	2,874	--	12,501	1,277	--	--	--	1,277
1971	12,410	2,830	--	15,240	2,571	--	170	--	2,741
1972	13,231	2,137	--	15,368	3,307	--	269	--	3,576
1973	6,395	1,220	--	7,615	2,875	--	134	--	3,009
1974	5,081	77	--	5,158	2,506	--	14	--	2,520
1975	3,384	38	--	3,422	1,538	--	79	--	1,617
1976	3,267	29	--	3,296	1,573	--	61	--	1,634
1977	2,109	--	--	2,109	1,631	86	--	--	1,717
1978	1,007	--	132	1,139	798	23	--	--	821
1979	1,071	49	269	1,389	617	164	--	--	781
1980	1,649	--	522	2,171	233	26	--	8	267
1981	2,091	--	487	2,578	320	56	--	1	377
1982	2,315	--	715	3,030	715	92	--	1	808
1983	2,231	--	373	2,604	527	45	--	3	575

[a]Japanese catch data for 1958-77 from Sasaki (1976) and pers. commun., T. Sasaki, Par Seas Fishery Research Lab., Shimizu, Japan; U.S.S.R. data for 1967-77 provided through U.S.-U.S.S.R. bilateral agreements; 1976 data for Republic of Korea (R.O.K.) and 1978-83 data for all nations from U. S. foreign fisheries observer program.
[b]For years prior to 1977, Japanese catch data are reported by fishing year (Nov.-Dec.); later Japanese catches are reported by calendar year.
[c]Includes Republic of Korea (R.O.K.), Taiwan, Poland, and Federal Republic of Germany.
[d]Republic of Korea.
[e]Includes Taiwan, Poland, and Federal Republic of Germany.
[f]Included in the Bering Sea catches.

limitations, CPUE data from commercial fisheries may only provide general indications of abundance trends.

A considerable decline in CPUE is apparent from Japanese longline and stern trawl data since 1970 for both the eastern Bering Sea and Aleutian areas (Table 2). To more clearly illustrate this trend, Japanese estimates of longline CPUE in units of kg/l0 hachi from Table 2 are standardized below by setting the 1970 CPUE values to 100 units:

	Eastern Bering Sea		Aleutian Region	
Year	All-nation catch (t)	Standardized CPUE	All-nation catch (t)	Standardized CPUE
1970	12,500	100	1,300	100
1971	12,200	77	2,700	83
1972	15,400	49	3,600	86
1973	7,600	61	3,000	85
1974	5,200	68	2,500	86
1975	3,400	54	1,600	70
1976	3,300	61	1,600	47
1977	2,100	56	1,700	45
1978	1,100	22	800	17
1979	1,400	20	800	16
1980	2,200	27	300	27
1981	2,600	31	400	40
1982	3,000	Not Available	800	Not Available
1983	2,600	Not Available	600	Not Available

The data show a general decline in CPUE through 1976 or 1977. In 1976 the CPUE value in the eastern Bering Sea was 61% of the 1970 level, while that for the Aleutians was 47% of the 1970 level. The CPUE values for 1978-81 may not be comparable to those from previous years due to changes in fishing patterns brought about by fishing regulations following enactment of the U.S. Fishery Conservation and Management Act. However, it should be noted that CPUE levels continued to drop reaching lows of 20 and 16% of 1970

Table 2.--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	131	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			47	2			76		<1
1983			49	1			86		<1

[a] Okada et al. (1982)
[b] Far Seas Fisheries Research Laboratory (1978)
[c] Method of Low et al. (1977).
Hachi is a unit of longline gear 100 m long.

values in 1979 for the eastern Bering Sea and Aleutians, respectively. In 1981, rates increased to 31% of 1970 values in the eastern Bering Sea and to 40% in the Aleutians, still well below values of 1975 and earlier years.

Sablefish catch and effort data collected by U.S. observers on foreign vessels are given in Table 3. The catch rates of the trawlers show no consistent trend. The CPUE values for Japanese small trawlers reached all-time low levels, while those of Japanese large trawlers markedly improved in 1983 over 1982 catch rates. Since sablefish are caught incidentally by trawlers, these catch rates may not accurately reflect trends in abundance.

The longline fishery, however, may target effort on sablefish and provide more useful information on stock abundance. Between 1980 and 1982 CPUE for sablefish improved on Japanese longliners and remained at these improved levels in 1983 (Table 3). The Korean longline CPUE values were similar to those of the Japanese longliners in 1982 and 1983 (Table 3). The greatest increase in longline CPUE occurred on Japanese longliners in the Aleutian region (76%), increasing from 1961 kg/day in 1982 to 3444 kg/day in 1983. Whether these data accurately reflect changes in sablefish abundance is difficult to evaluate because depth and time periods fished varied between years. The average depth fished was 160 m greater in 1983 than in 1982, and fishing occurred in December for the first time in 1983; the December catch (126 t) and catch rate (582 kg/1000 hooks) that year was the highest recorded in any month during the five yr period of 1977-79 and 1982-83 (Table 4).

Abundance Estimates from Surveys

Eastern Bering Sea

Increased commercial catches and longline CPUE reflect the recruitment of the unusually strong 1977 year-class into the fishery. This year-class was

Table 3.--Catch rate information on sablefish and the dominant species taken in foreign fisheries as collected by U.S. observers in the eastern Bering Sea and Aleutian Region, 1977-83.

Country	Vessel[a]	Area[b]	Yr	Ave. depth (m)	Rk[c]	kg/day	kg/h[d]	First three species: order of abundance[e]
Japan	Small trawl	I	77	461	4	462	30	Tur, Pol, Cod
			78	481	7	146	10	Tur, Pol, Ap
			79	495	7	230	15	Tur, Cod, Pol
			80	291	9	162	14	Tur, Ysol, Rat
			81	-	7	275	21	Tur, Pol, Pop
			82	452	8	82	6	Ysol, Tur, Pol
			83	359	16	46	3	Tur, Ysol, Cod
		II	77	373	9	35	3	Pol, Tur, Her
			78	409	11	111	5	Tur, Pol, Ap
			79	450	15	73	5	Tur, Pol, Af
			80	475	7	180	8	Tur, Pol, Af
			81	-	7	285	18	Tur, Pol, Af
			82	473	8	68	4	Tur, Pol, Cod
			83	459	13	33	2	Tur, Pol, Cod
		V	77	224	25	1	-	Pop, Am, Nroc
			78	387	13	181	13	Pol, Tur, Squ
			79	372	16	61	5	Tur, Pop, Af
			80	279	18	45	6	Pol, Squ, Pop
			81	-	8	230	24	Pol, Tur, Pop
			82	445	12	43	3	Rat, Pol, Tur
			83	469	16	24	2	Rat, Pol, Tur
	Large trawl	I	77	243	20	2	-	Pol, Cod, Squ
			78	189	21	45	3	Pol, Cod, Ysol
			79	170	4	208	17	Pol, Cod, Af
			80	206	7	50	4	Pol, Cod, Her
			81	-	9	24	2	Pol, Cod, Squ
			82	207	10	44	3	Pol, Jel, Cod
			83	256	8	110	8	Pol, Cod, Her
		II	77	196	-	-	-	Pol, Her, Cod
			78	213	40	1	-	Pol, Squ, Cod
			79	223	22	15	1	Pol, Cod, Squ
			80	254	32	2	<1	Pol, Cod, Tur
			81	-	12	14	1	Pol, Cod, Squ
			82	248	16	10	1	Pol, Her, Squ
			83	230	6	103	9	Pol, Cod, Squ
	Long-liner	I	78	317	5	119	7	Cod, Tur, Pol
			79	459	4	447	31	Cod, Tur, Rat
			80	552	3	95	61	Tur, Cod, Sab
			81	538	3	1553	96	Cod, Tur, Sab
			82	517	3	2067	146	Tur, Cod, Sab
			83	487	3	1734	126	Cod, Tur, Sab

Table 3.--Continued.

Country	Vessel[a]	Area[b]	Yr	Ave. depth (m)	Rk[c]	kg/day	kg/h[d]	First three species: order of abundance[e]
		II	80	567	5	327	18	Tur, Cod, Rat
			81	499	4	1173	73	Tur, Cod, Rat
			82	437	3	1344	88	Tur, Cod, Sab
			83	379	3	1235	85	Cod, Tur, Sab
Japan	Long-liner	V	77	593	2	1114	89	Tur, Sab, Str
			78	508	2	1186	92	Tur, Sab, Rat
			79	596	3	1084	72	Tur, Rat, Sab
			82	349	1	1961	209	Sab, Cod, Tur
			83	510	1	3444	315	Sab, Cod, Rat
U.S.S.R.	Large trawl	I	77	154	-	-	-	Pol, Squ, Scul
			78	67	52	1	0	Ysol, Ap, Pol
			79	67	-	-	-	Ysol, Pol, Cod
		II	77	162	-	-	-	Pol, Her, Skate
			78	204	-	-	-	Pol, Her, Cod
			79	178	12	76	8	Pol, Scul, Ysol
			80	233	-	-	-	Pol, Sal, Tur
		V	77	110	-	-	-	Am, Nroc, Pop
			78	175	40	0	0	Am, Pol, Cod
			79	162	-	-	-	Am, Cod, Pol
			80	152	-	-	-	Am, Yil, Cod
R.O.K.	Large trawl	I	77	268	27	2	0	Pol, Tur, Squ
			78	226	13	22	2	Pol, Cod, Squ
			79	201	6	274	20	Pol, Cod, Am
			80	149	11	153	13	Pol, Ysol, Cod
			81	-	10	136	13	Pol, Ysol, Cod
			82	155	10	164	16	Pol, Cod, Ysol
			83	141	15	111	9	Pol, Ysol, Cod
		II	77	281	-	-	-	Pol, Lum, Squ
			78	168	10	24	3	Pol, Tur, Squ
			79	249	12	30	3	Pol, Squ, Cod
			80	430	9	42	4	Pol, Cod, Squ
			81	-	5	117	12	Pol, Cod, Squ
			82	242	6	28	4	Pol, Cod, Squ
			83	275	-	-	-	Pol, Lum, Squ
		V	80	156	5	255	92	Am, Pol, Cod
			81	-	8	59	24	Pol, Am, Cod
			82	178	10	90	21	Pol, Am, Cod
			83	200	13	45	11	Pol, Am, Pop

Table 3.--Continued.

Country	Vessel[a]	Area[b]	Yr	Ave. depth (m)	Rk[c]	kg/day	kg/h[d]	First three species: order of abundance[e]
R.O.K. (cont'd)	Long-liner	I	82	332	1	1964	105	Sab, Cod, Tur
			83	319	2	1638	115	Skate, Sab, Cod
		II	82	308	2	1976	115	Cod, Sab, Tur
			83	333	2	2639	148	Cod, Tur, Sab
		V	82	650	1	1462	229	Sab, Rat, Skate
			83	569	1	2013	185	Sab, Tur, Skate

[a] Small trawler (<1,500 GRT), large trawler (>1,500 GRT).
[b] Area I (Bering Sea east of 170° w), Area II (Bering Sea 170° W to 180°), Area V (Aleutian region).
[c] Rank of species in catches by weight.
[d] In the case of longliners, CPUE is in kg per 1000 hooks.
[e] Tur-Greenland turbot, Pol-Pollock, Cod-Pacific Cod, Her-Herring, Ap-Alaska. plaice, Pop-Pacific ocean perch, Am-Atka mackerel, Nroc-Northern rockfish, Squ-Squid, Ysol-yellowfin sole, Sab-Sablefish, Rat-Rattail, Scul-Sculpin, Lum-Lumpsucker, Af-Arrowtooth flounder, Str-Shortspine thornyhead rockfish, Yil-Yellow Irish lord, Sal-Salmon, Jel-Jellyfish.

Table 4.--Japanese longline CPUE data on sablefish, collected by U.S. observers in the Aleutians during 1977-79 and 1982-83.

Year	Area	Month	Days	Sets	Hooks	Ave. depth (m)	Sable-fish (t)	Percent of total catch	Catch per 1000 hooks[a]
1983	Aleutians	2	2	1	11,400	140	-	-	-
1983	Aleutians	3	2	1	8,400	180	-	-	-
1983	Aleutians	4	18	10	126,730	324	14.710	12	116
1983	Aleutians	5	2	2	31,392	465	13.699	77	436
1983	Aleutians	6	4	3	42,800	715	11.590	54	271
1983	Aleutians	7	7	5	95,000	344	11.037	26	116
1983	Aleutians	8	10	7	117,040	524	24.910	28	213
1983	Aleutians	9	5	3	46,000	617	8.947	51	195
1983	Aleutians	10	5	4	69,958	670	26.368	63	377
1983	Aleutians	11	5	3	55,640	667	21.074	61	379
1983	Aleutians	12	15	13	216,600	612	125.991	63	582
1982	Aleutians	3	22	15	131,428	117	5.685	9	43
1982	Aleutians	4	12	6	104,150	543	16.440	29	158
1982	Aleutians	5	9	5	91,200	615	23.883	45	262
1982	Aleutians	6	9	9	105,848	414	37.663	51	356
1982	Aleutians	7	10	10	132,056	473	27.644	40	209
1982	Aleutians	8	6	6	81,354	443	15.132	42	186
1982	Aleutians	9	5	5	50,632	355	16.379	63	323
1982	Aleutians	10	7	2	27,750	150	2.301	20	83
1982	Aleutians	11	5	5	73,310	485	21.541	46	294
1979	Aleutians	1	2	2	21,000	152	.004	<1	<1
1979	Aleutians	2	1	1	20,000	750	3.373	32	169
1979	Aleutians	3	25	21	342,780	707	20.500	17	60
1979	Aleutians	4	26	21	345,313	518	27.834	17	81
1979	Aleutians	5	27	22	394,290	581	31.181	22	79
1979	Aleutians	6	27	25	499,795	603	34.697	19	69
1979	Aleutians	9	5	4	79,287	637	4.760	16	60
1978	Aleutians	6	19	20	293,036	466	18.275	20	62
1978	Aleutians	7	3	2	15,540	369	.013	<1	<1
1978	Aleutians	8	5	4	68,880	617	11.761	28	171
1978	Aleutians	9	7	4	68,880	552	10.801	28	157
1977	Aleutians	9	14	13	172,900	592	15.325	29	89

[a]kg per 1000 hooks

first observed as age 1 juveniles In 1978 during the annual U.S. trawl survey of the eastern Bering Sea (Fig. 1). Sablefish have rarely been observed on the shelf since the survey was initiated in 1971, but appeared in abundance in 1978. More recent surveys indicated that the 1977 year-class persisted in continental shelf waters of the eastern Bering Sea in 1979-80. In 1981, however, the survey showed that the abundance of this year-class on the shelf had dramatically decreased.

The cooperative U.S.-Japan trawl survey along the continental slope also confirmed strong recruitment of the 1977 year-class to the adult population. Population estimates by length interval (Fig. 2) from the 1979, 1981, and 1982 surveys show that population numbers tripled between 1979 (5.3 million) and 1981 (18.0 million). Estimated biomass on the slope (201-1,000 m) increased from 12,200 t in 1979 to 39,400 t in 1981 (Table 5). In 1982, the population number (22.7 million) and biomass (42,700 t) were slightly higher than in 1981. For the combined shelf and slope areas of the eastern Bering Sea, trawl survey results show a 4% increase in population biomass between 1981 (47,100 t) and 1982 (52,300 t). On the other hand, the Japan-U.S. longline survey indicated a 12% decline in relative biomass from 1981 to 1982 (Sasaki 1984, Table 5).

Joint U.S.-Japan trawl surveys of the Aleutian Islands region were conducted in 1980 and 1983. These surveys were the first comprehensive assessments of Aleutian groundfish resources in which the United States has participated and encompassed areas north and south of the Aleutian chain between Attu Island and Unimak Pass. The estimated biomasses of sablefish from these surveys are shown in Table 5. These trawl survey data indicate a 331% increase in the Aleutian region, International North Pacific Fisheries Commission (INPFC) area 5. Most of the Aleutian region increase occurred between 170°W and 180° longitude and especially north of the chain, where biomass increased nearly five times from 10,100 t in 1980 to 47,000 in 1983 (Fig. 3). Only moderate increases were

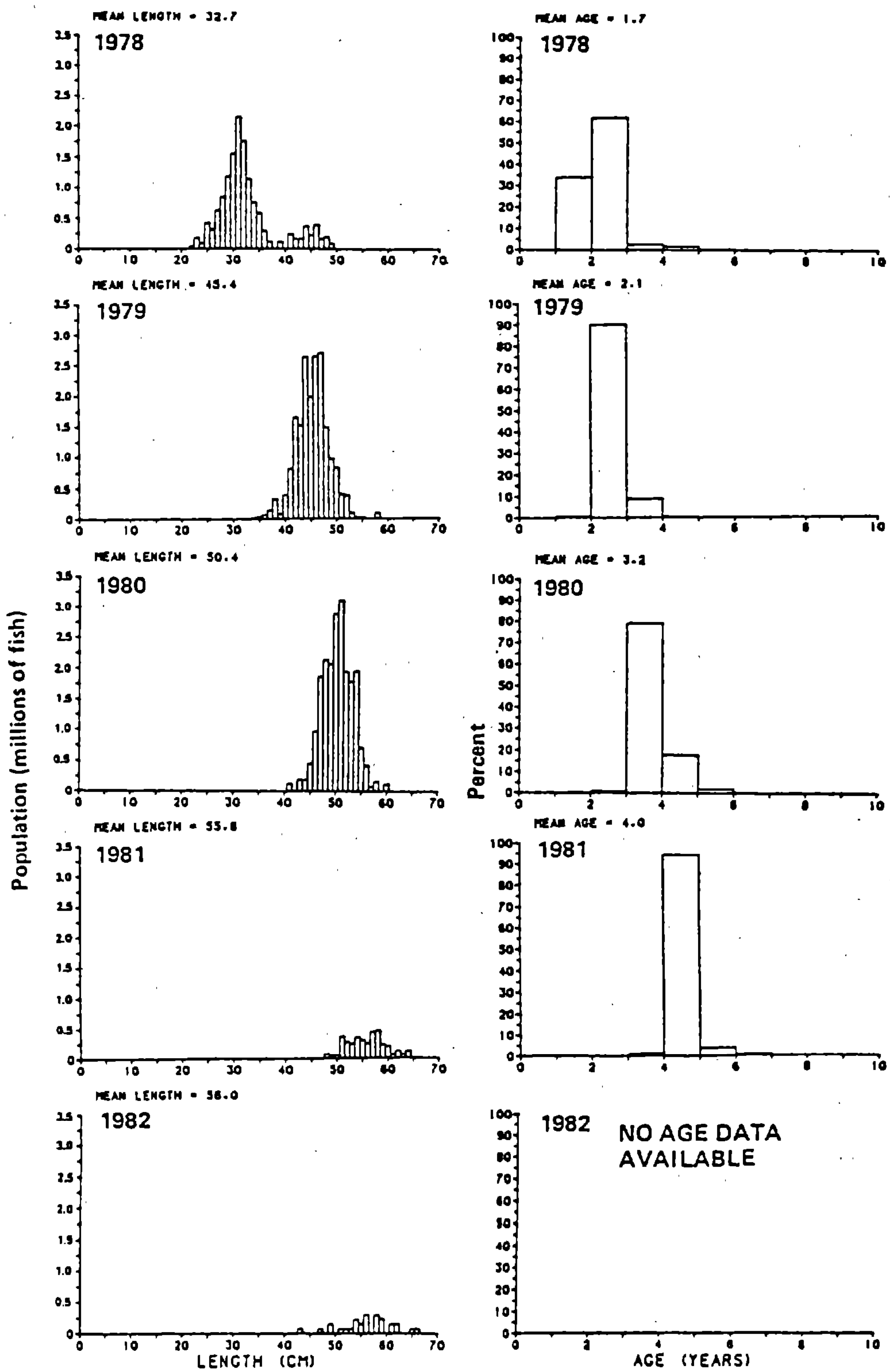

Figure 1 .--Size and age composition of sablefish within the continental shelf comparative fishing area surveyed by U.S. research vessels, 1978-82. Age determinations for 1978 may be inaccurate due to differences in aging structures; scales were used in 1978, and otoliths were used in subsequent years (Umeda et al. 1983)

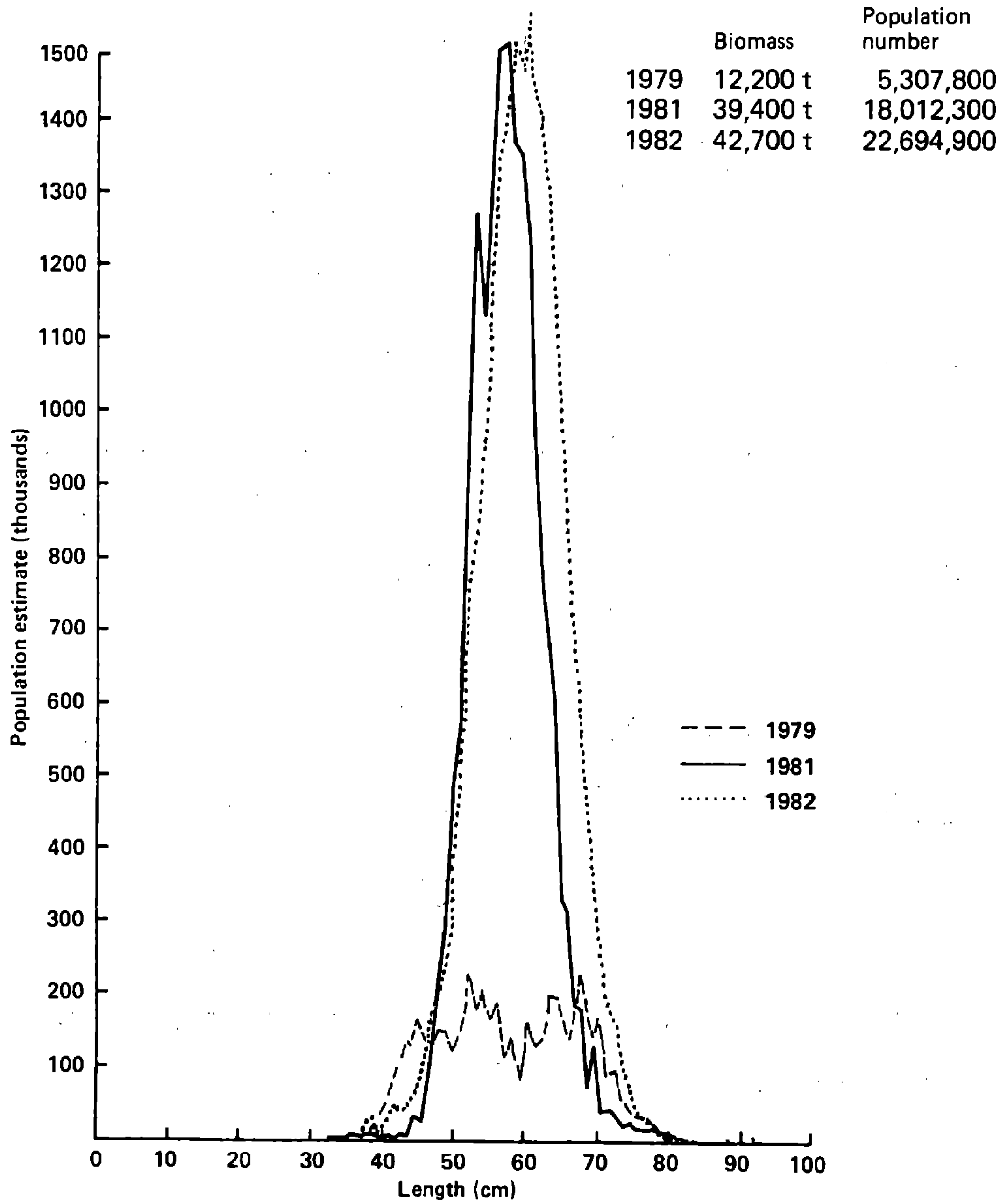

Figure 2.--Population estimates of sablefish by centimeter size interval on the continental slope of the eastern Bering Sea as shown by data from cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, 1982. Total estimated biomass and population number for the slope areas surveyed are also given.

Table 5.--Estimated biomass or relative biomass in metric tons (t) of sablefish from U.S.-Japan cooperative trawl and longline surveys.

Depth (m) or Area		1979	1980	1981	1982	1983
Trawl Surveys (Biomass in t)		--	--	t	--	--
Eastern Bering Sea	201-1,000	12,200	--	39,400	42,700	--
Aleutian Region	101-1,000	--	20,300	--	--	67,200
Eastern Bering Sea	Area 1	--	8,500	--	--	9,600
Longline Survey (Relative Population Weight, RPW)						
Eastern Bering Sea		--	--	--	5,885	5,180
Aleutian Region		--	11,138	11,357	10,312	13,514

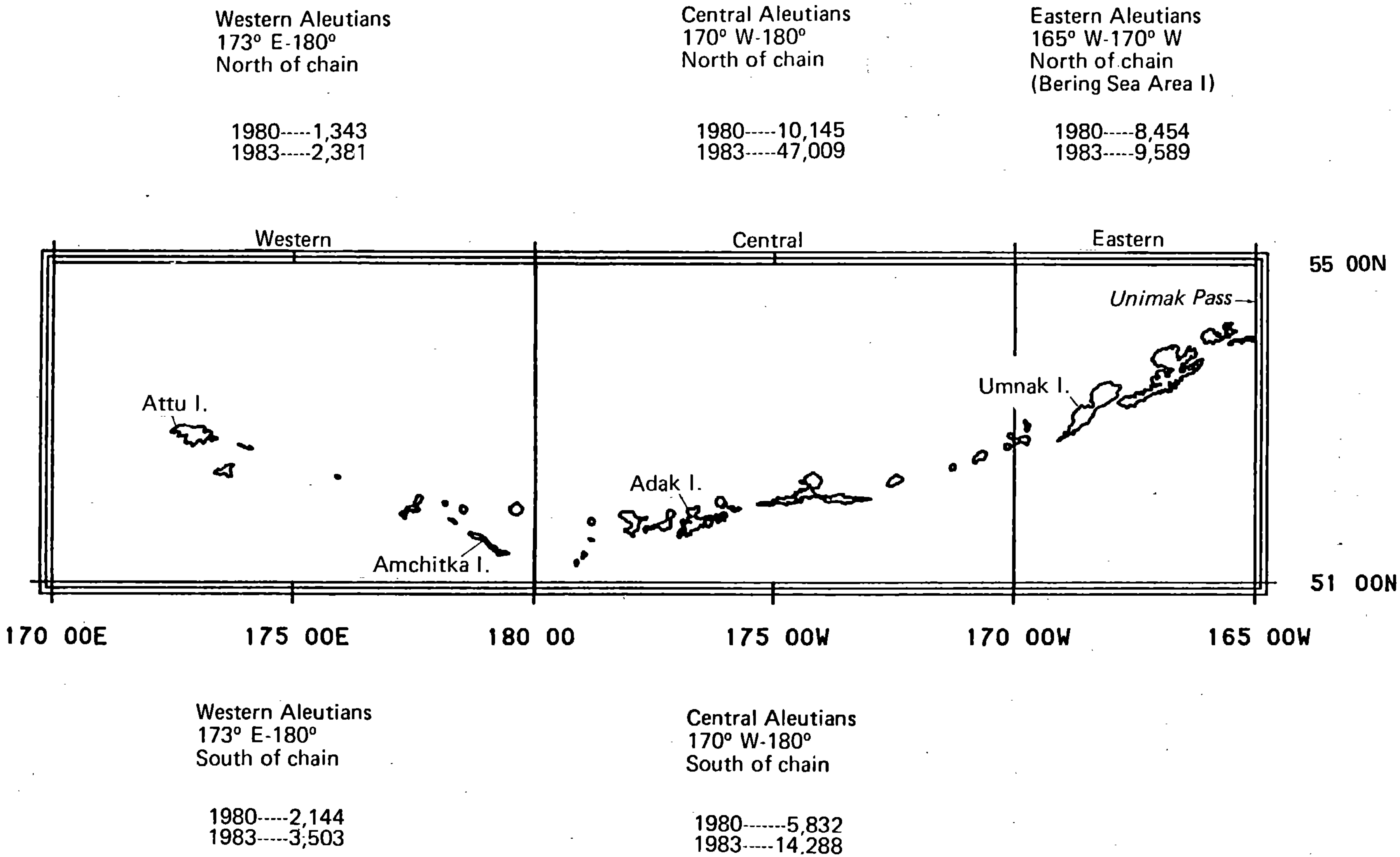

Figure 3.--Biomass estimates of sablefish in metric tons (t) in the Aleutian Islands region, by area, as shown by 1980 and 1983 U.S.-Japan cooperative trawl survey data.

indicated in the western Aleutians (170°E - 180°) and the eastern Aleutian portion of INPFC area 1.

Evidence of improving sablefish abundance in the Aleutian region, coincident with the recruitment of the 1977 year-class, has also been collected by the Japan-U.S. joint longline surveys during the summers of 1979-83 (Sasaki 1983, 1984). These surveys show a 21% increase in relative population weight in the Aleutian region between 1986 and 1983 (Table 5).

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) as 50,300 t for the Bering Sea to California region. The 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 is estimated at 13,000 t in the eastern Bering Sea and 2,100 t in the Aleutian area. The eastern Bering Sea and Aleutian estimates should be combined because CPUE and biomass trends indicate that MSY is probably overestimated in the eastern Bering Sea and underestimated in the Aleutian region.

Japanese scientists have 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.

EQUILIBRIUM YIELD

Estimated equilibrium yield (EY) levels in 1981 were 2,000 t for the eastern Bering Sea and 900 t for the Aleutians 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 52,300 t in the eastern Bering Sea (in 1982) and 67,200 t in the Aleutians region (in 1983). Based on these EY and biomass estimates, the exploitation rates at the 1981 EY levels would be 0.038 and 0.013 in the eastern Bering Sea and Aleutians region, respectively.

The stock condition in both regions appears to have improved during 1982-83 from the low levels of abundance during 1977-80. However, CPUE values are still substantially below historical levels. Exploitation rates of 1.3 to 3.8% appear very conservative for sablefish. Sasaki (1984) has suggested a sustainable exploitation rate of 5%. Applying this rate to the latest biomass estimate of 52,300 in 1982 in the eastern Bering Sea and 67,200 t in 1983 in the Aleutians, the EY for sablefish would be 2,600 t in the eastern Bering Sea and 3,360 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. 1). Commercial catch records (Table 1) indicate that the Aleutian region population is the larger of the two stocks.

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 1). Catches since then have declined substantially. In 1983, harvests were but a small fraction of peak levels: 235 t from the eastern Bering Sea slope region and 611 t from the Aleutian Islands region.

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 2, 3). However, CPUE data from these fisheries

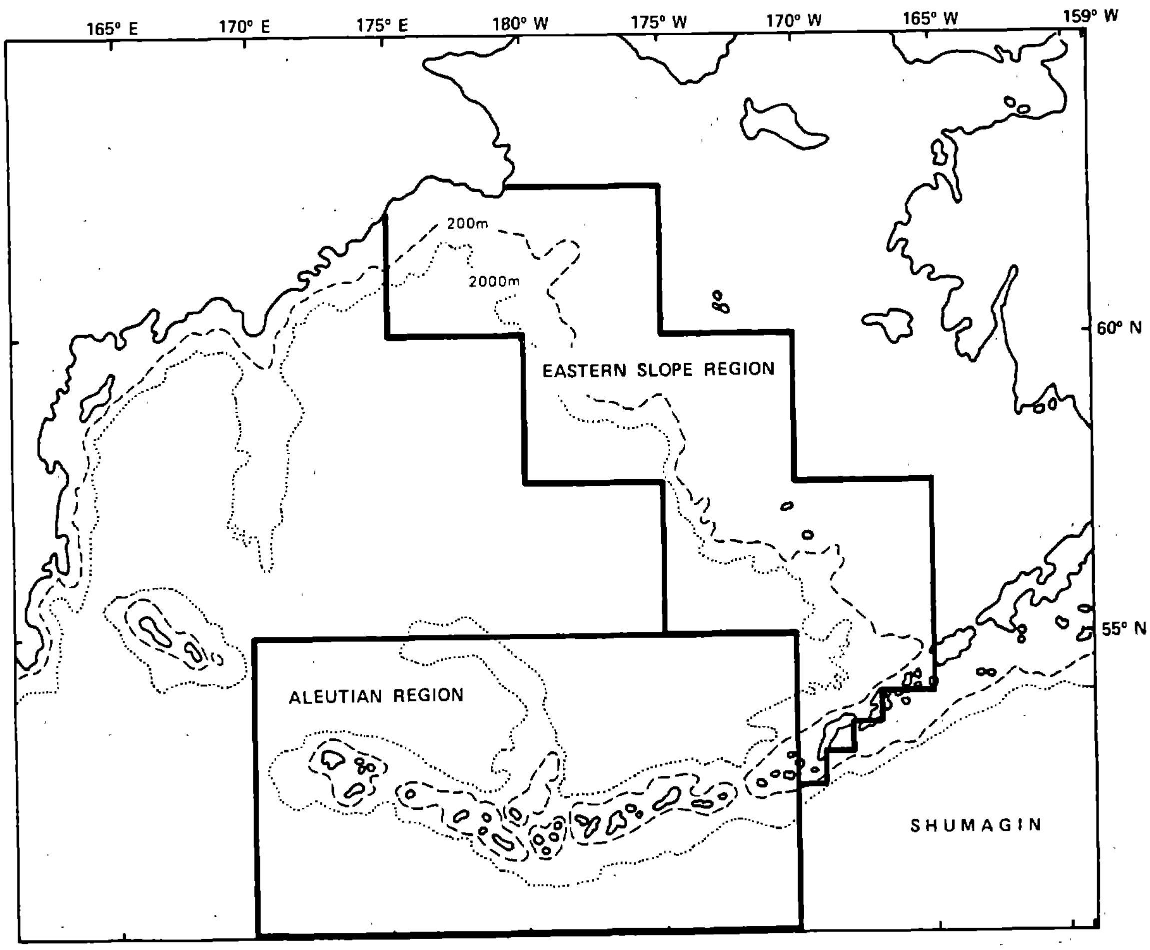

Figure 1. --The Bering Sea with the two proposed stock areas (regions) for Pacific ocean perch delineated.

Table 1.--Annual catch of Pacific ocean perch 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	0.4	0.0	0.4	0.8	3.3	0.0	0.4	3.7	3.7	0.0	0.8	4.5
1981	0.8	0.0	0.4	1.2	3.3	0.0	0.2	3.5	4.1	0.0	0.6	4.7
1982	0.4	0.0	0.2	0.6	1.3	0.0	0.2	1.5	1.7	0.0	0.4	2.1
1983	0.2	0.0	Tr[e]	0.2	0.6	0.0	Tr[e]	0.6	0.8	0.0	Tr[e]	0.9

[a]Source: Bakkala et al. (1980) for catches through 1979: catches for 1980-83 are from foreign reported statistics on file, Northwest and Alaska Fisheries Center, Seattle, Washington.
[b]Catches from mothership-longline, North Pacific trawl, and land-based dragnet fisheries.
[c]May include some amounts of rockfishes, Sebastes spp., other than Pacific ocean perch.
[d]Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.
[e]Tr: Trace less than 50 t.

Table 2.--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, 1968-83[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

[a] 1973-83 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 3.--Pacific ocean perch (POP) catch and effort data from stern trawlers of the Japanese land-based dragnet fishery in the eastern Bering Sea region, 1969-83.

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

[a]CPUE = catch per unit of effort.

may not be a good 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. 2). Subarea P generally accounted for most of the Pacific ocean perch harvest: catches peaked in both areas in 1968 but declined rapidly thereafter (Table 4). 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 4). 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 11 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

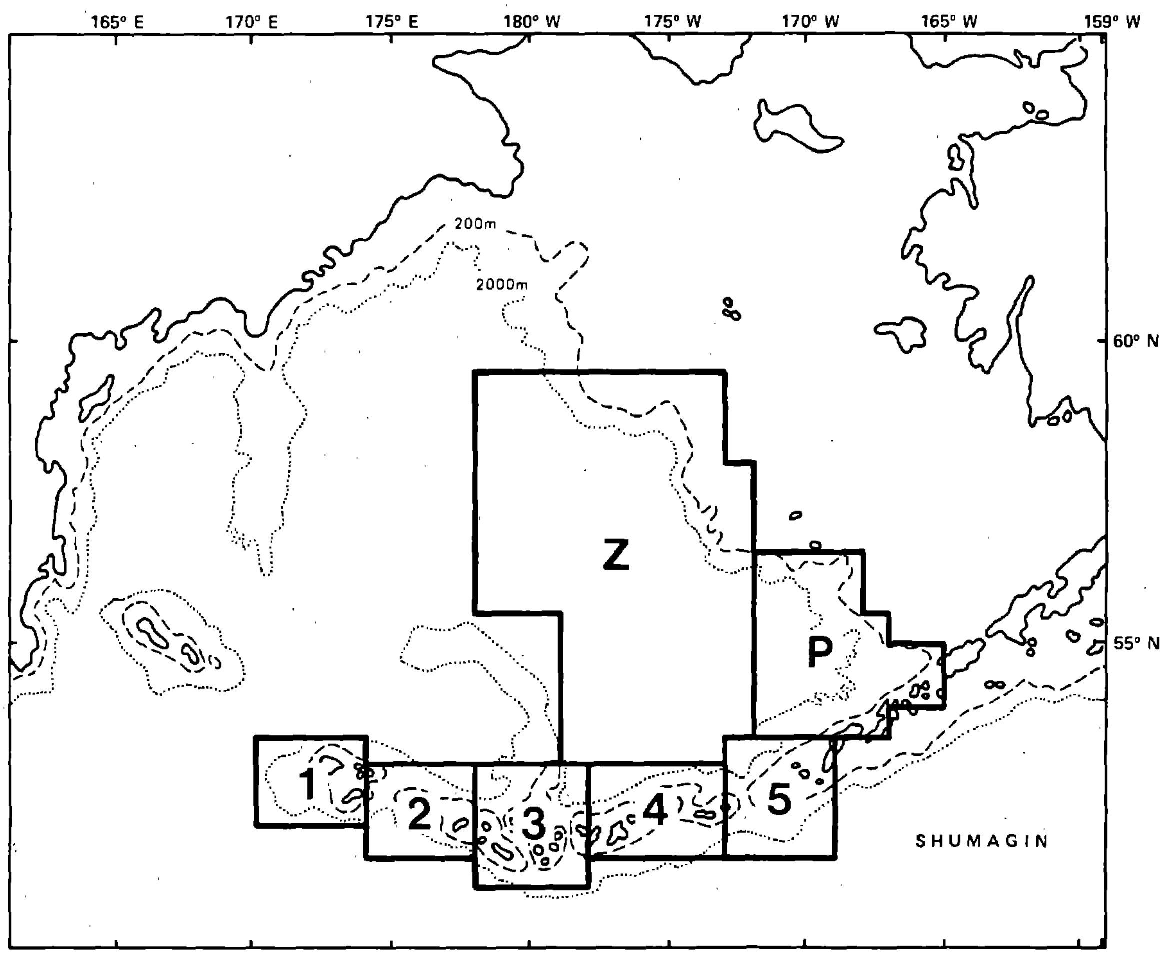

Figure 2. --Subdivisions of the eastern Bering Sea and Aleutian Islands region used to examine trends of catch and catch per unit of effort (CPUE) for Pacific ocean perch.

Table 4.--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) 1963-83.

	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

greater than 200 m. For this reason, only data collected by Japanese vessels were employed to calculate Pacific ocean perch abundance estimates.

More recent information from 1983 and 1984 NWAFC surveys is of limited value in assessing population changes of Pacific ocean perch. All of the effort during these surveys was directed toward fish assemblages of the continental shelf; the bulk of Pacific ocean perch population is associated with the outer continental shelf and upper slope areas. For this reason, these data are not used in the following assessment.

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 5); 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 (165° W to 170° W) portion of the eastern Bering Sea management area. This area, however, was sampled during the 1980 U.S.-Japan trawl survey of the Aleutian Islands which provided a biomass estimate of about 7,000 t. A, biomass estimate for the entire eastern Bering Sea region (13,600 t) was calculated by averaging the 1979-82 estimates and adding the 1980 point estimate from the Aleutian Islands segment.

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

Table 5.--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.

Depth strata	Year	Mean Estimates[a] 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.

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 5). 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. Unfortunately, that portion of the population unavailable to the trawl gear cannot be determined at this time.

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. The technique employed was 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. 3). 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).

During the 1983 U.S.-Japan bilateral meetings, the Japanese scientific delegation stated its belief that the F(t) values used in Ito's (1982) cohort

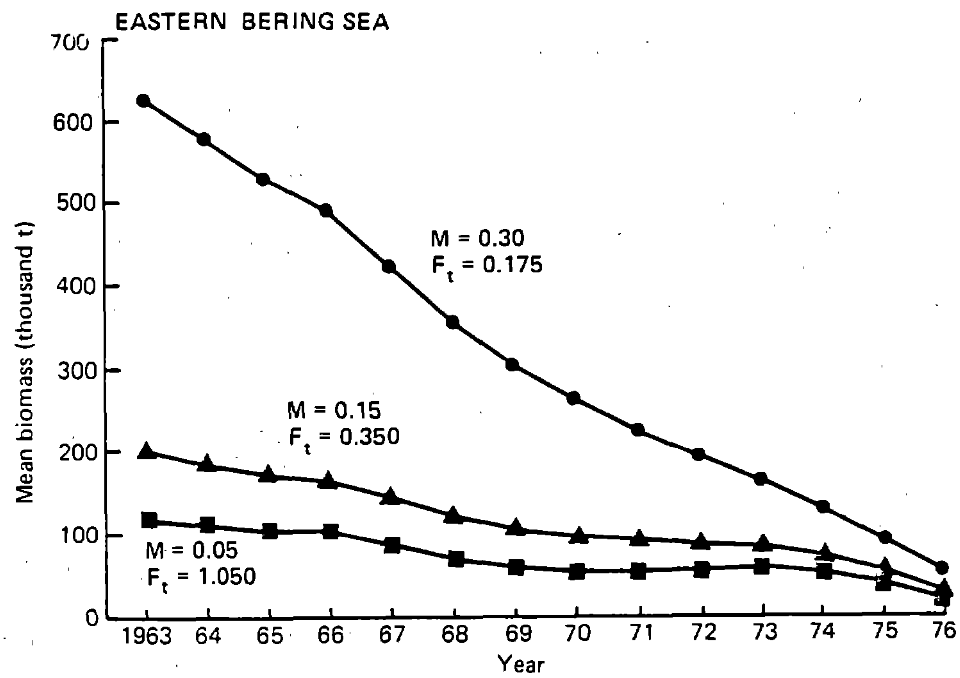

Figure 3.--Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by cohort analyses using various estimates of natural (M) and terminal fishing mortalities (F_t).

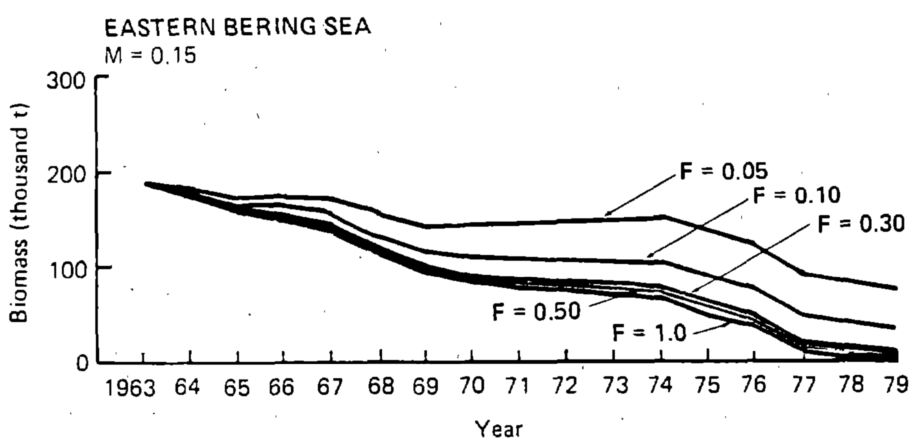

Figure 4.--Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by virtual population analyses using various estimates of fishing mortalities (F).

analysis were too high. However, these values do not appear high if one considers that recent removals were probably taken from a depleted stock. Such a condition would justify high F(t) values since Pacific ocean perch catches, although mostly incidental in nature, represent relatively significant removals from the stock.

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 25-30 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. 4). 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. Assuming knife-edge recruitment at 9 yr, the B_o estimate was calculated by 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.

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 change in biomass due to catches), and R (recruitment biomass) that is 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 and 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.

The SRA results indicate that the virgin fishable biomass in the eastern Bering Sea is between 210,000 and 270,000 t. This is not a statistical confidence interval, but an interval consistent with P = 0.2 and various levels of recruitment.

A range of maximum sustainable yield (MSY) was calculated using the formulas described by Kimura et al. (1984). The-upper end of the range (4,984 t) was obtained by assuming a P value of about 0.25 with constant recruitment (i.e., r = 0.0--the variable r describes the strength of the stock-recruitment relationship). The lower estimate (2,840 t) was calculated by assuming P at about 0.20 with moderate recruitment (i.e., r = 0.5). One property of SRA which is relevant here is that if r = 1.0 (i.e., recruitment is directly proportional to stock biomass), 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 relative strong year-class (Fig. 5). 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 years other than in 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 6). Vessels of classes 4 and 7, which

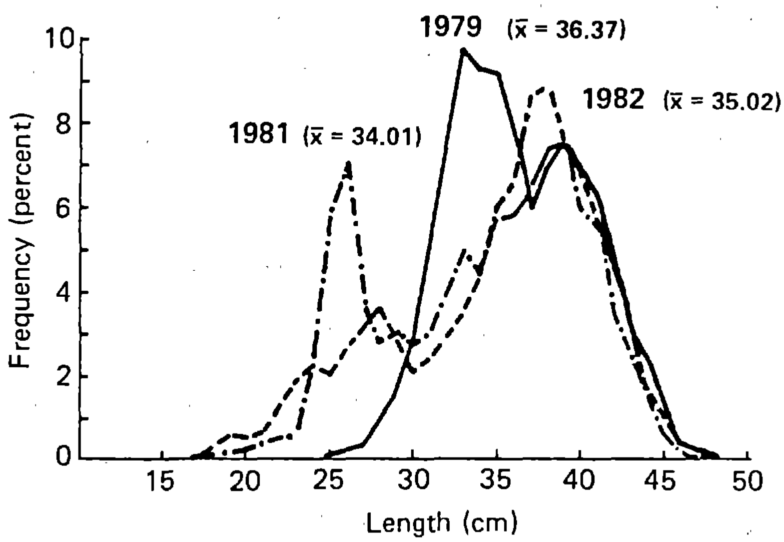

Figure 5. --Size composition of pacific ocean perch in the eastern Bering Sea as shown by data collected on Japanese trawlers during the cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, and 1982.

Table 6.--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, 1968-83.

	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
(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

Table 6.--Continued.

Year	Vessel class[a] 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]

[a]1973-82 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.

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 5 yr. Vessel class 7 CPUE reached its lowest level in 1983, falling 96.8% from its peak level in 1968.

Catch and effort data from the land-based dragnet fishery also indicate decreasing stock abundance. Catch per unit of effort fell from 322.7 kg/hour (h) in 1969 to 0.7 kg/h in 1983 (Table 7). The CPUE data from 1977 to 1983, however, may not be a reliable index of population size because the proportion of Pacific ocean perch in catches were 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 8). The CPUE in units of kg/day (d) and kg/hour (h) fell 99.4 and 99.7%, respectively, from 1977 to 1983. With the exception of 1978, 1982 and 1983, Pacific ocean perch ranked among the top three species in the catch by small trawlers. For years other than 1978, 1982 and 1983, CPUE should be a fairly good index of stock size.

The Aleutian region was subdivided into five areas (Fig. 2) 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-North Pacific trawl fishery; these indices were then plotted for each subarea (fig. 6). 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.

Table 7.--Pacific ocean perch (POP) catch and effort data from stern trawlers of the Japanese land-based dragnet fishery in the Aleutian region, 1.969-83.

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

[a]CPUE = catch per unit of effort.

Table 8.--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, 1977-83.

	Pacific ocean perch			First three species caught in order of abundance
Year	Rank	kg/d	kg/h	
77	1	4,665	642	Pacific ocean perch Atka mackerel Northern rockfish
78	6	580	50	Greenland turbot Walleye pollock Pacific cod
79	2	1,319	106	Greenland turbot Pacific ocean perch Arrowtooth flounder
80	3	1,256	171	Walleye pollock Squid Pacific ocean perch
81	3	978	102	Walleye pollock Greenland turbot Pacific ocean perch
82	7	129	10	Rattail - unidentified Walleye pollock Greenland turbot
83	15	27	2	Rattail - unidentified Walleye pollock Pectoral rattail

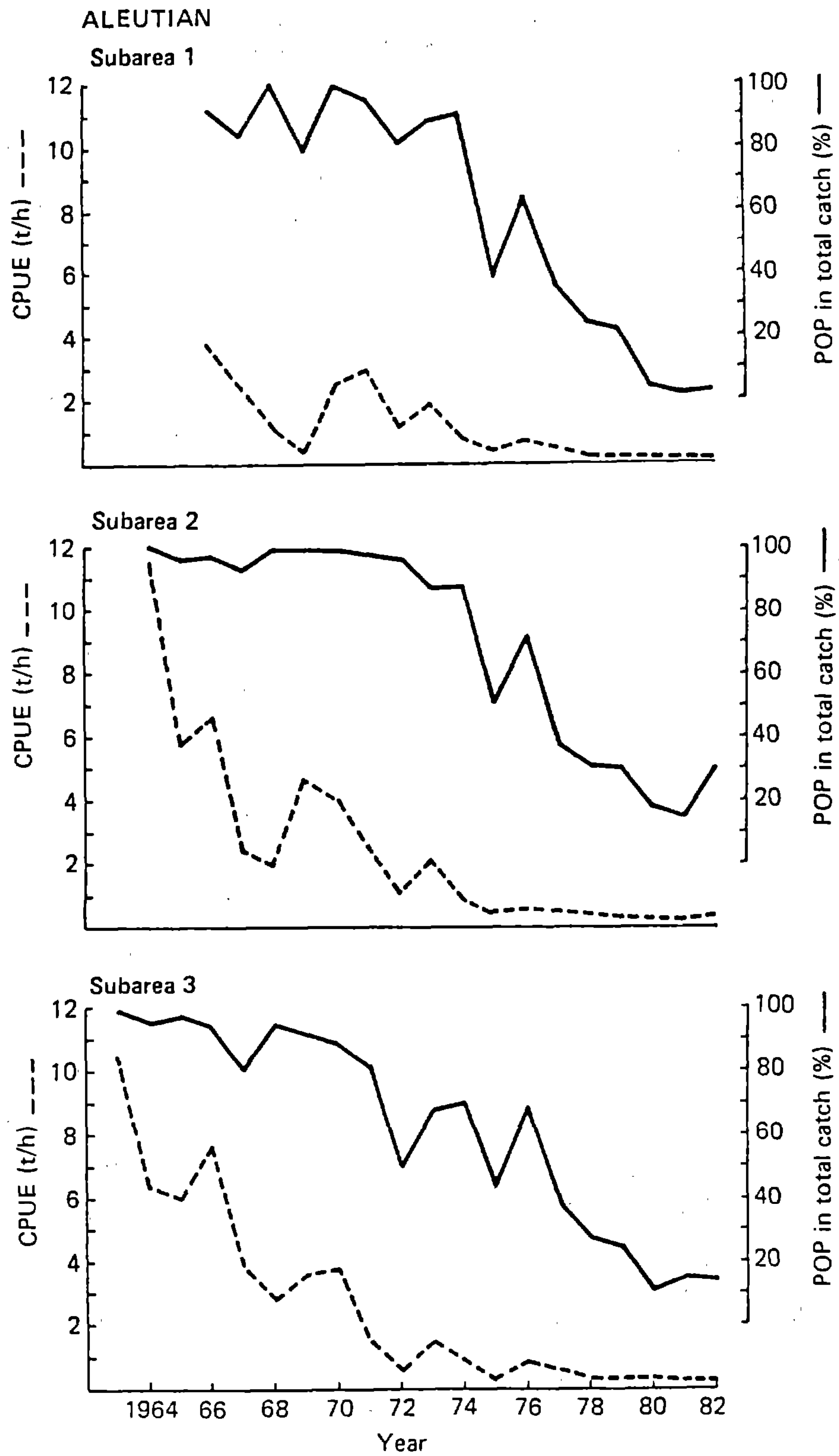

Figure 6.--Annual changes in the percentage of Pacific ocean perch (POP) in the total groundfish catch and POP catch per unit of effort (CPUE) in the subareas of the Aleutian Islands.

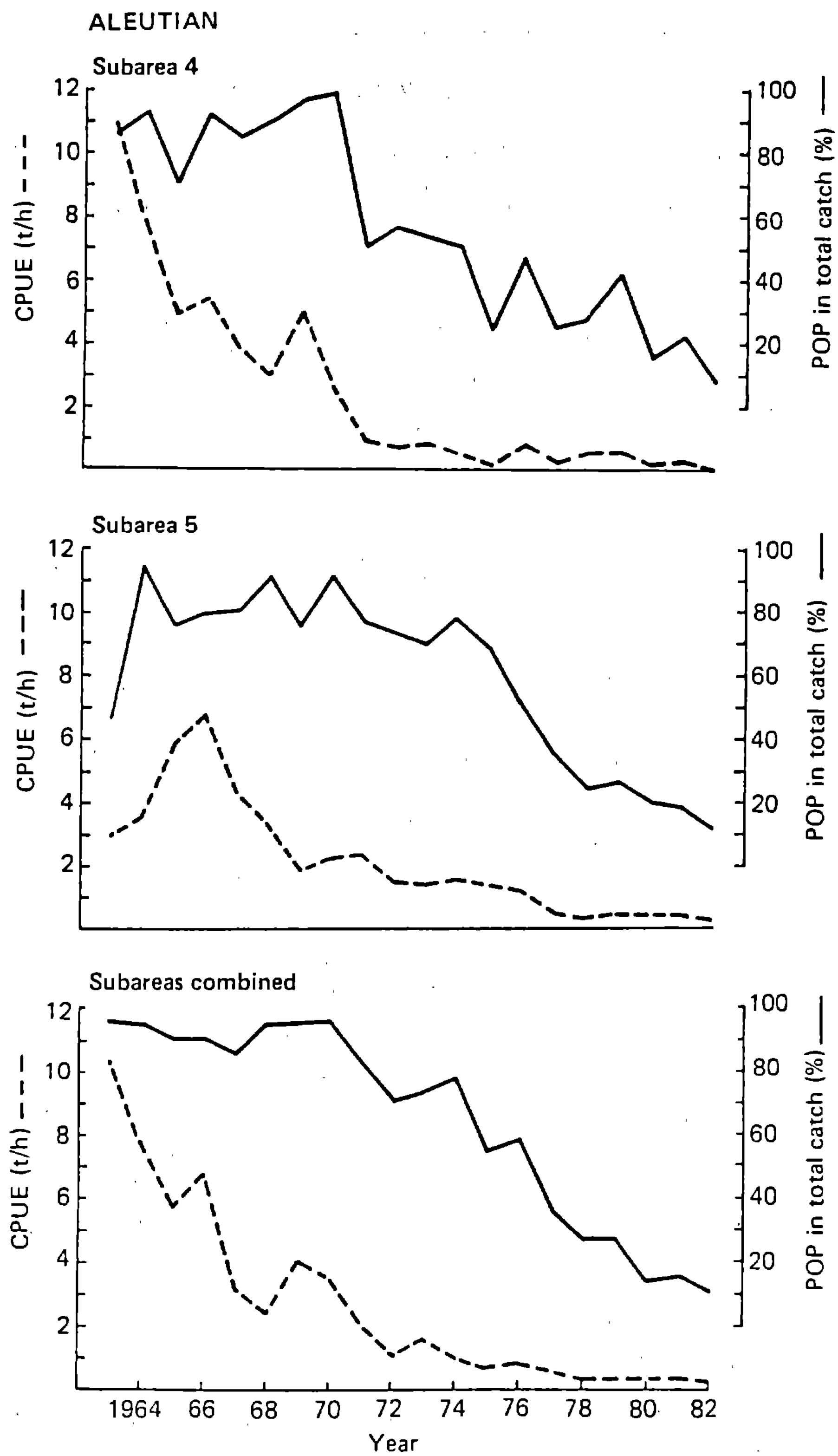

Figure 6. --Continued.

The greatest reductions in CPUE occurred in subareas 2, 3, and 4 (Fig. 6). 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 5 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 never exceeded 80% after 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 (170° E to 170° W long.) 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 (165° W to 170° W long.) 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 7,000 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 Islands 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 Aleutian Islands 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).

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. 7). 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).

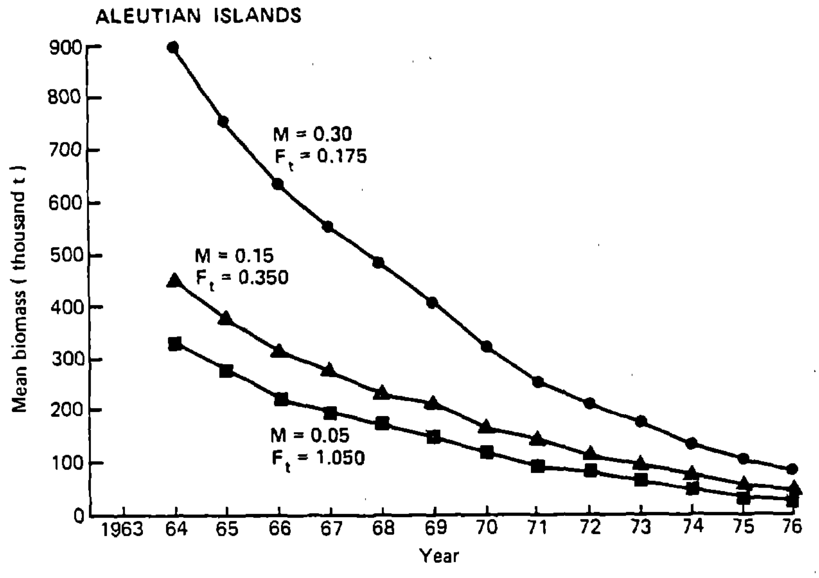

Figure 7.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by cohort analyses using various estimates of natural (M) and fishing mortalities (F_t).

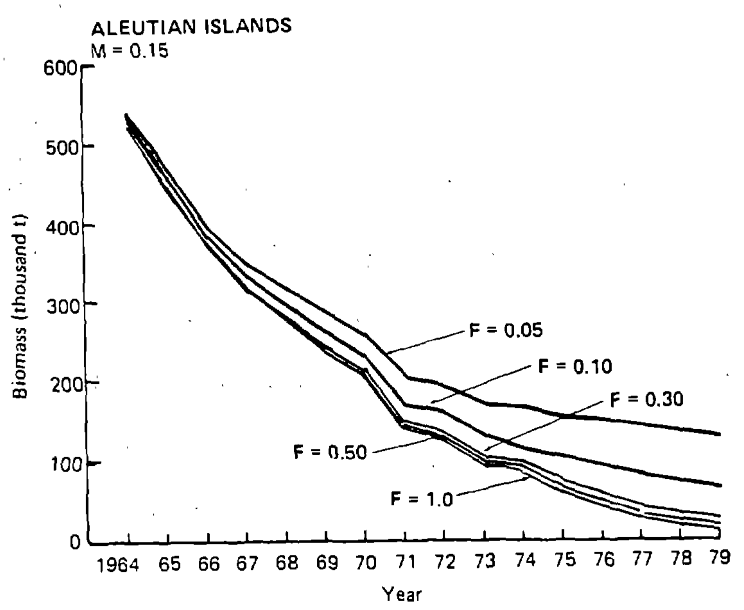

Figure 8.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by virtual population analyses using various estimates of fishing mortalities (F).

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. 8). 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 was 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. These parameter values are consistent with the greater age range derived from sectioned and break/burned otoliths.

Estimates of virgin biomass from SRA ranged from 500,000 to 620,000 t. The SRA results indicated a range of MSY values from 6,627 to 11,864 t. It should again be noted 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 extends 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. 9). 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.

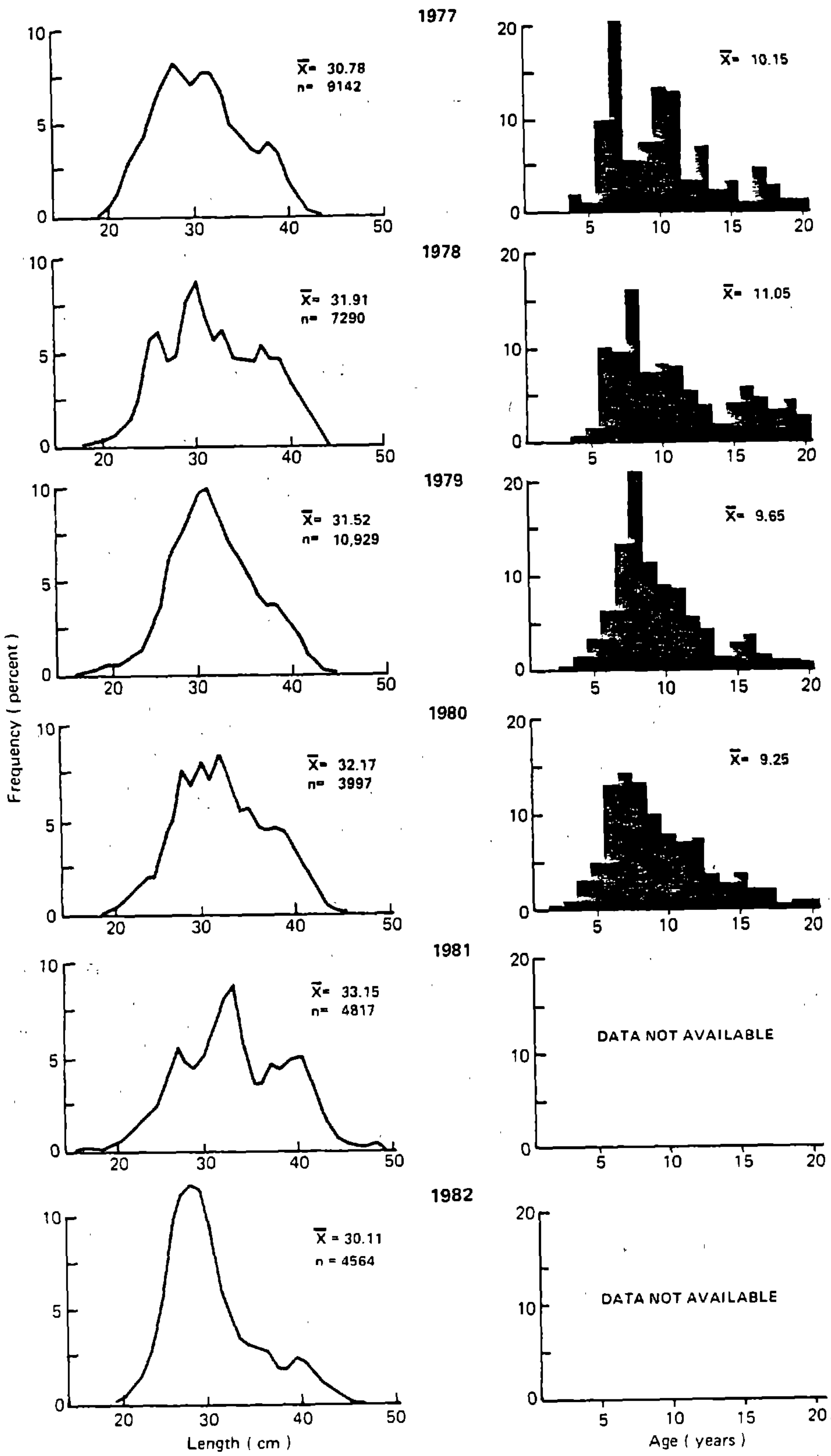

Figure 9. --Length and age composition of Pacific ocean perch, in the Aleutian region as shown by data taken by U.S. observers from catches aboard Japanese small stern trawlers, 1977-82.

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 1). 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 9).

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 SPA of 9,467-16,848 t for the eastern Bering Sea and Aleutian Islands regions compare well with Low's estimates (1974). of 12,000-17,000 t (Table 9).

EQUILIBRIUM YIELD

Results from recent eastern Bering Sea trawl surveys suggest that the sampled biomass of Pacific ocean perch in the region has stabilized at a low level of about 13,600 t. This figure is based on combined estimates from the 1980 Aleutian Islands survey in INPFC statistical area 1 and the mean of the

Table 9.--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 (This study)
	2,840-4,984	SRA (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)

VPA = Virtual population analysis
SRA = Stock reduction analysis

1979-82 eastern Bering Sea survey estimates. Similarly, estimates from the 1980 and 1983 Aleutian surveys suggest a stable but low sampled biomass level of about 113,860 t. Assuming that a 5% exploitation rate is sustainable for the two stocks and that biomasses from survey data may be underestimated by as much as 50%, we estimate the equilibrium yield (EY) to be about 1,360 t in the eastern Bering Sea and 11,400 t in the Aleutian region.

Recent information suggests that both stocks are in poor but stable condition. 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 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 600-2,200 t in the eastern Bering Sea and 1,500-5,500 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 at or below 50% of EY. Catch levels should therefore not exceed 680 t in the eastern Bering Sea and 5,700 t in the Aleutian region.

OTHER ROCKFISH

by

Daniel H. Ito

INTRODUCTION

Other rockfish, which include all species of _Sebastes_ and _Sebastolobus_ other than Pacific ocean perch, _Sebastes alutus_, have traditionally been grouped together in commercial catch statistics. As a result, commercial catch and effort data have not been available for individual species of other rockfish. Since 1977, however, species of rockfish have been identified in commercial catches by U.S. observers, which 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 1977-83.

COMMERCIAL CATCHES

The methods of sampling and estimating commercial catches of rockfish from U.S. observer data have been described by Nelson et al. (1980, 1981a, 1981b, 1982, 1983). U.S. observers have identified 15 species of rockfish of known occurrence in groundfish catches from the eastern Bering Sea and Aleutian Islands region and 14 others that have not been verified (Table 1).

The 1977-83 catches of other rockfish from the eastern Bering Sea and Aleutian Islands regions are listed in Tables 2 and 3, respectively. Catches of other rockfish from the eastern Bering Sea region increased from 1,678 metric tons (t) in 1977 to 12,222 t in 1978 and then decreased to 10,098 t in 1979.

Table 1.--The common and scientific names of rockfish (Sebastes and Sebastolobus spp.) identified in the Bering Sea-Aleutian Islands groundfish fisheries in 1977-81 by U.S. observers.

Common name	Scientific name
Species of known occurrence	
Black rockfish	*Sebastes melanops*
Blue rockfish	*Sebastes mystinus*
Darkblotched rockfish	*Sebastes crameri*
Dusky rockfish	*Sebastes ciliatus*
Harlequin rockfish	*Sebastes variegatus*
Longspine thornyhead	*Sebastolobus altivelis*
Northern rockfish	*Sebastes polyspinis*
Pacific ocean perch	*Sebastes alutus*
Redbanded rockfish	*Sebastes babcocki*
Redstripe rockfish	*Sebastes proriger*
Rougheye rockfish	*Sebastes aleutianus*
Sharpchin rockfish	*Sebastes zacentrus*
Shortraker rockfish	*Sebastes borealis*
Shortspine thornyhead	*Sebastolobus alascanus*
Silvergray rockfish	*Sebastes brevispinis*
Species of questionable identification[a]	
Aurora rockfish	*Sebastes aurora*
Blackgill rockfish	*Sebastes melanostomus*
Bocaccio	*Sebastes paucispinis*
Canary rockfish	*Sebastes pinniger*
Chilipepper rockfish	*Sebastes goodei*
Rosethorn rockfish	*Sebastes helvomaculatus*
Rosy rockfish	*Sebastes rosaceus*
Splitnose rockfish	*Sebastes diploproa*
Tiger rockfish	*Sebastes nigrocinctus*
Vermilion rockfish	*Sebastes miniatus*
Widow rockfish	*Sebastes entomelas*
Yelloweye rockfish	*Sebastes ruberrimus*
Yellowmouth rockfish	*Sebastes reedi*
Yellowtail rockfish	*Sebastes flavidus*

[a]The occurrence of these 14 species in the eastern Bering Sea and Aleutian Islands region has not been documented in the literature.

Table 2.--Catches in metric tons (t) of rockfish (Sebastes and Sebastolobus spp.) other than Pacific ocean perch (Sebastes alutus) in the eastern Bering Sea groundfish fishery, 1977-83.

Common Name	Foreign Fishery							Joint Venture Fishery			
	1977	1978	1979	1980	1981	1982	1983	1980	1981	1982	1983
Black rockfish		0.7	12.2	0.1							
Blackgill rockfish					0.4	0.9	1.6				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				
Dusky rockfish	3.1	56.5	92.4	18.9	13.7	13.9	4.8	1.2	Tr	1.3	6.6
Harlequin rockfish		2.2		10.1	50.0	2.4					
Longspined thornyhead		0.4	16.2	0.3	3.3	1.0	0.4				
Northern rockfish	321.7	147.6	125.7	57.8	30.8	67.8	10.4	11.0	Tr	1.7	24.1
Redbanded rockfish		1.8	12.8	3.3	1.3						
Redstripe rockfish		65.6	78.9	0.2	8.5	8.5	3.0			4.6	
Rougheye rockfish	1,043.6	660.2	5,131.2	183.2	300.0	150.1	58.3	0.3		Tr	0.1
Sharpchin rockfish			5.7	3.1	4.0	3.7	0.2	1.4			
Shortraker rockfish	1.4	8,800.2	2,726.5	651.6	444.3	354.4	147.6			12.0	0.1
Shortspine thornyhead	292.2	2,288.8	1,585.6	389.2	195.9	219.4	178.4			4.9	0.3
Silvergray rockfish		0.8									
Splitnose rockfish						4.8	10.6				
Other rockfish	12.0	149.3	247.3	1.3	3.1	3.7	3.9	1.4		Tr	0.5
TOTAL	1,677.6	12,222.4	10,097.5	1,352.1	1,110.4	837.8	428.5	15.3	Tr	24.5	32.7

Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983, 1984.
The "other rockfish" category includes those species listed in Table 1 that are not named in this table.
tr = trace amounts.

Table 3.--Catches in metric tons (t) of rockfish (Sebastes and Sebastolobus spp.) other than Pacific ocean perch (Sebastes alutus) in the Aleutian Islands groundfish fishery, 1977-83.

Common Name	Foreign Fishery							Joint Venture Fishery			
	1977	1978	1979	1980	1981	1982	1983	1980	1981	1982	1983
Black rockfish		1.6	2.3								
Blackgill rockfish						4.8	3.8				
Darkblotched rockfish	0.4	42.2	1,641.8	86.3	7.0	7.6	1.7				
Dusky rockfish	2,932.9	11.3	54.8	2.8	10.6	3.8	1.0		Tr		0.9
Harlequin rockfish	1.0	8.1	51.6	60.8	8.4	0.4					
Longspined thornyhead		0.2	2.2			2.1	0.7				
Northern rockfish	5,311.2	3,781.9	996.9	374.0	137.6	193.1	28.3		2.0	0.1	
Redbanded rockfish		81.8	40.0	6.8	Tr						
Redstripe rockfish		127.0	997.1	51.3	5.1	2.2	2.2				3.4
Rougheye rockfish	1,127.6	2,938.4	4,538.1	468.8	477.1	158.8	21.6	Tr	0.6		1.5
Sharpchin rockfish	3.2	1.4	73.0	0.2	0.1	14.5	0.8				
Shortraker rockfish	102.9	1,094.6	4,418.4	102.4	450.8	312.1	47.8				0.8
Shortspine thornyhead	89.1	546.8	1,709.6	210.7	276.3	2,089.1	982.6	Tr			
Silvergray rockfish			1.0								
Splitnose rockfish						3.3	44.0				
Other rockfish	19.1	102.0	16.2	2.0	20.8	0.7	5.0		Tr		
TOTAL	9,587.4	8,737.3	14,543.0	1,366.1	1,393.8	2,792.5	1,139.5	Tr	2.6	0.1	6.6

Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983, 1984.
The "other rockfish" category includes those species listed in Table 1 that are not named in this table.
tr = trace amounts.

The low estimate in 1977 was primarily due to the estimate being based on catch rates of rockfish observed in all fisheries, while in 1978 and 1979 only rates from vessels taking rockfish were used., The 1978 and 1979 estimates are probably more representative of the actual catches taken in this region. Since 1979 catches have decreased and reached an all time low of 428 t in 1983.

with the exception of 1978, the Aleutian region has accounted for the largest portion of the Bering Sea-Aleutian Islands catch of other rockfish. Catches in the Aleutian region averaged about 11,000 t, during the 3-yr period from 1977 to 1979. Catches have since declined and averaged 1,673 t from 1980 to 1983. There is no single species which has consistently dominated the catch from year to year. Northern, rougheye, shortraker, dusky, dark-blotched, and shortspine thornyhead rockfish have all made up significant portions of the other rockfish catch during the past 7 yr.

The large reductions in catch observed in both regions from 1979 to 1980-83 were the result of placing the category of "other rockfish" under a specific rockfish TALFF (total allowable level of foreign fishing)--a management action by the North Pacific Fishery Management Council (NPFMC). Prior to 1980, only the catch of Pacific ocean perch was restricted by a specific TALFF, whereas all other species of rockfish were placed under a large TALFF of "other groundfish."

BIOMASS ESTIMATES

Estimates of biomass and maximum sustainable yields (MSY) for other rockfish have been calculated based on Japanese research vessel data (Ikeda 1979). These estimates were as follows:

Area	Estimated biomass (t)	Estimated range in MSY (t)
Eastern Bering Sea	55,000	7,000-15,000
Aleutians	167,000	23,000-45,000

The range in MSY estimates were derived using the yield equation with the virgin biomass for the lower MSY value and one-half virgin biomass for the upper MSY value. Because Ikeda (1979) had limited survey data and used a number of assumptions which need verification, these estimates have been used only as first approximations.

Data from the 1979, 1981, and 1982 cooperative U.S.-Japan trawl surveys provide biomass estimates for other rockfish in the eastern Bering Sea. These surveys 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 abundance estimates.

Survey results indicate that the biomass of other rockfish in the eastern Bering Sea increased from 5,646 t in 1979 to 9,385 t in 1981 and 10,180 t in 1982. These abundance estimates should be viewed with caution, however, because of their relatively low degree of precision. The 1980 cooperative U.S.-Japan survey of the Aleutian region indicated another 2,800 t of other rockfish in the Aleutian Islands portion of International North Pacific Fisheries Commission (INPFC) area 1 (north side of Aleutians from long. 165° W to 170° W). Thus, an overall estimate for the eastern Bering Sea region, based on the 1980 Aleutian survey data and the mean of the 1979-82 eastern Bering Sea survey data, is 11,204 t. These survey results are assumed to have substantially underestimated the true abundance of these species. The commercial catch alone in 1979 was about 10,000 t.

Biomass estimates of other rockfish from the 1980 and 1983 U.S.-Japan cooperative trawl surveys of the Aleutian Islands region indicate an increase from 62,000 t in 1980 to 94,600 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 two estimates (78,300 t) indicates a much larger stock size than that found in the eastern Bering Sea region.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) estimates for other rockfish given by Ikeda (1979) were expressed as a range of values: 7,000-15,000 t for the eastern Bering Sea and 23,000-45,000 t for the Aleutians.

EQUILIBRIUM YIELD

Equilibrium yield (EY) for other rockfish was estimated at 11,000 t for both the eastern Bering Sea and Aleutian region in 1981 based on the estimated catches in 1977-79. This same EY for each region does not now appear reasonable given that the biomass in the Aleutian region appears to be several times greater than that found in the eastern Bering Sea.

Assuming that biomass is underestimated by 50% and an exploitation rate of 5% is sustainable, then EY is estimated at 1,120 t in the eastern Bering sea and 7,830 t in the Aleutian region.

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ATKA MACKEREL

by

Daniel K. Kimura and Lael L. Ronholt

INTRODUCTION

Atka mackerel, Pleurogrammus monopterygius, are found throughout the Aleutian and Komandorskiye Islands, westward to the east coast of the Kamchatka Peninsula, north to the Pribilof Islands, and eastward throughout the Gulf of Alaska to southeastern Alaska. Commercial catches in the Bering Sea occur in both the eastern Bering Sea and Aleutians, but the largest landings have come from the Aleutians, region which, from 1978 to 1983, produced over 90% of the total Bering Sea landings (Table 1). Based on the 1983 cooperative U.S.-Japanese groundfish resource assessment survey, Atka mackerel is the third most abundant species in the Aleutian Islands region after grenadiers (rattails, family Macrouridae) and walleye pollock, Theragra chalcogramma.

Levada (1979a) compared 21 morphological and meristic characters in a study of the stock structure of Atka mackerel from the Aleutian Islands region and the Gulf of Alaska. Although the author felt 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 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

Table 1.--Atka mackerel catches in metric tons by INPFC[a] 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

[a]INPFC = International North Pacific Fisheries Commission.

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 from the eastern Bering Sea and Aleutian regions increased throughout the 1970s peaking in 1978 at 24,250 metric tons (t); subsequently, they declined to 11,726 t in 1983 (Table 2). From 1979 to 1981, landings increased in the eastern Bering Sea but declined slightly in the Aleutians region (Table 1). Landings have since declined further in both regions. However, this decline in catches apparently does not indicate a decline in stock abundance, but was caused by the withdrawal of the U.S.S.R. fleet in 1980. The U.S. joint venture fisheries also began in 1980 (Table 2). Japan (1978-81) and the Republic of Korea (R.O.K.) (1979-82) were the only other foreign nations catching significant quantities of Atka mackerel, but by 1983 their catches had declined to insignificant levels. By 1983, U.S. joint venture fisheries accounted for nearly 90% of the eastern Bering Sea and Aleutian Islands landings of Atka mackerel.

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. Nevertheless, surveys probably provide the best available information on current stock condition. Survey data (Table 3) show a marked building of stocks from 1974-75 through 1983, but whether this increase is

Table 2.--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

[a]Republic of Korea.
[b]U.S. joint venture.

Table 3.--Surveyed 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

real or the result of changes or improvements in survey techniques is difficult to ascertain. Recent survey results indicate that Atka mackerel stocks in the Aleutians region are presently healthy, if not at a historically high biomass level. The biomass estimate from the 1983 U.S.-Japan survey, which was 304,132 t for the Aleutians region, is a key statistic from which we shall estimate maximum sustainable yield (MSY) values.

BIOLOGICAL STATISTICS

Biological statistics for Atka mackerel in the Aleutians region are available from Levada (1979b), the U.S. Observer Program's sampling of commercial catches (1977-83),U.S.-Japan cooperative trawl surveys in 1980 and 1983, and a Soviet trawl survey in 1982. Because catches were small in other regions, the statistics we present are from only the Aleutians region.

Because the Atka mackerel population in the Aleutians 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. 1) were 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 R.O.K. were also used. Generally, sample sizes appear to be large enough, and the length-frequencies consistent enough, to be meaningful. These length-frequency data show a dramatic, but gradual, increase in the size of fish taken in the commercial fishery (Fig. 1). In 1975, nearly all sampled fish

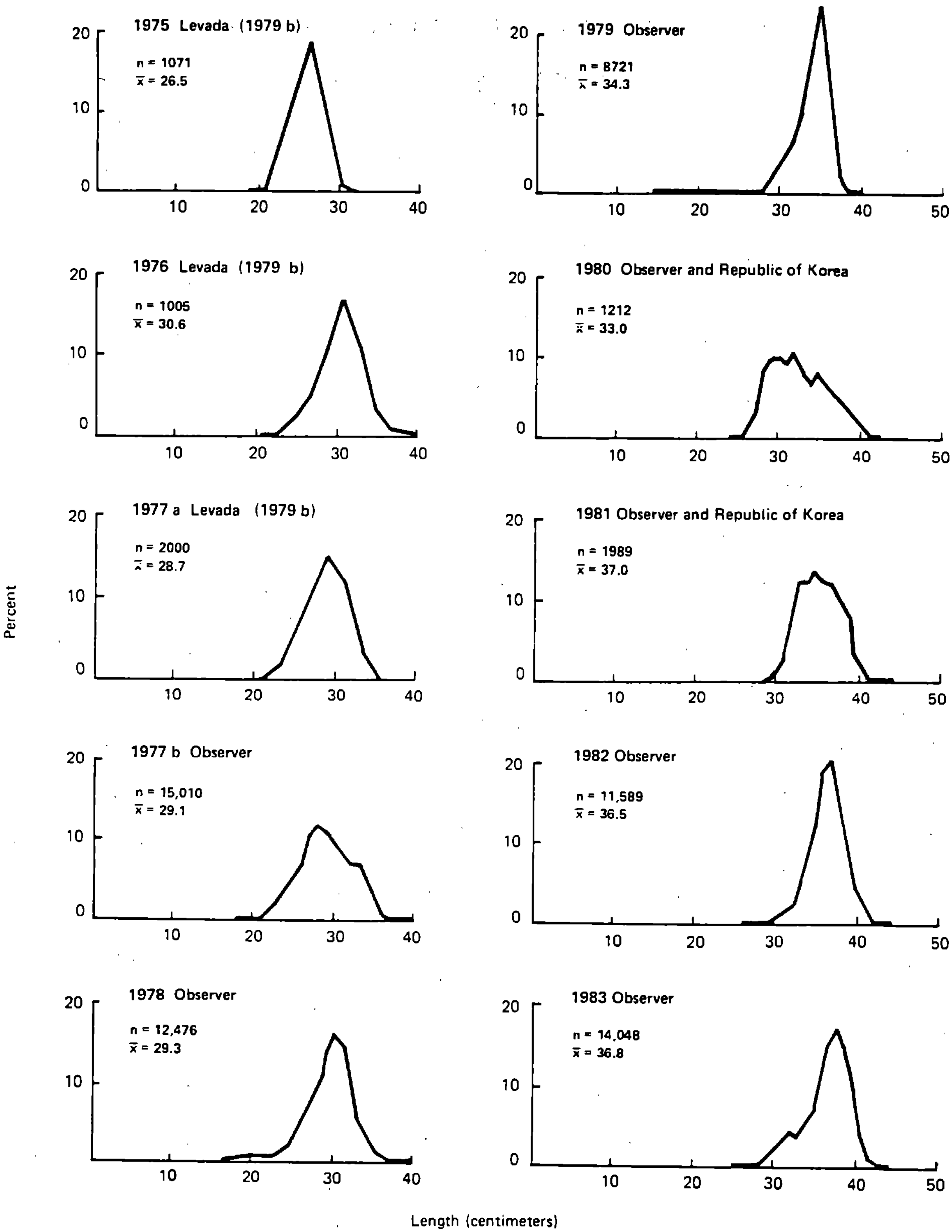

Figure 1. Length-frequency data from Levada (1979b) and the U.S. Observer Program for Atka mackerel in the Aleutian Islands region.

were under 30 cm, but by 1979, nearly all were over 30 cm. 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.

Age Distributions

Age determination methods for Atka mackerel have not been fully investigated. Levada (1979b), using scales and tail ossicles, 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 Aleutians 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 Aleutians region from both observer (1977-79) and survey (1980, 1982, and 1983) data (Fig. 2). 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.

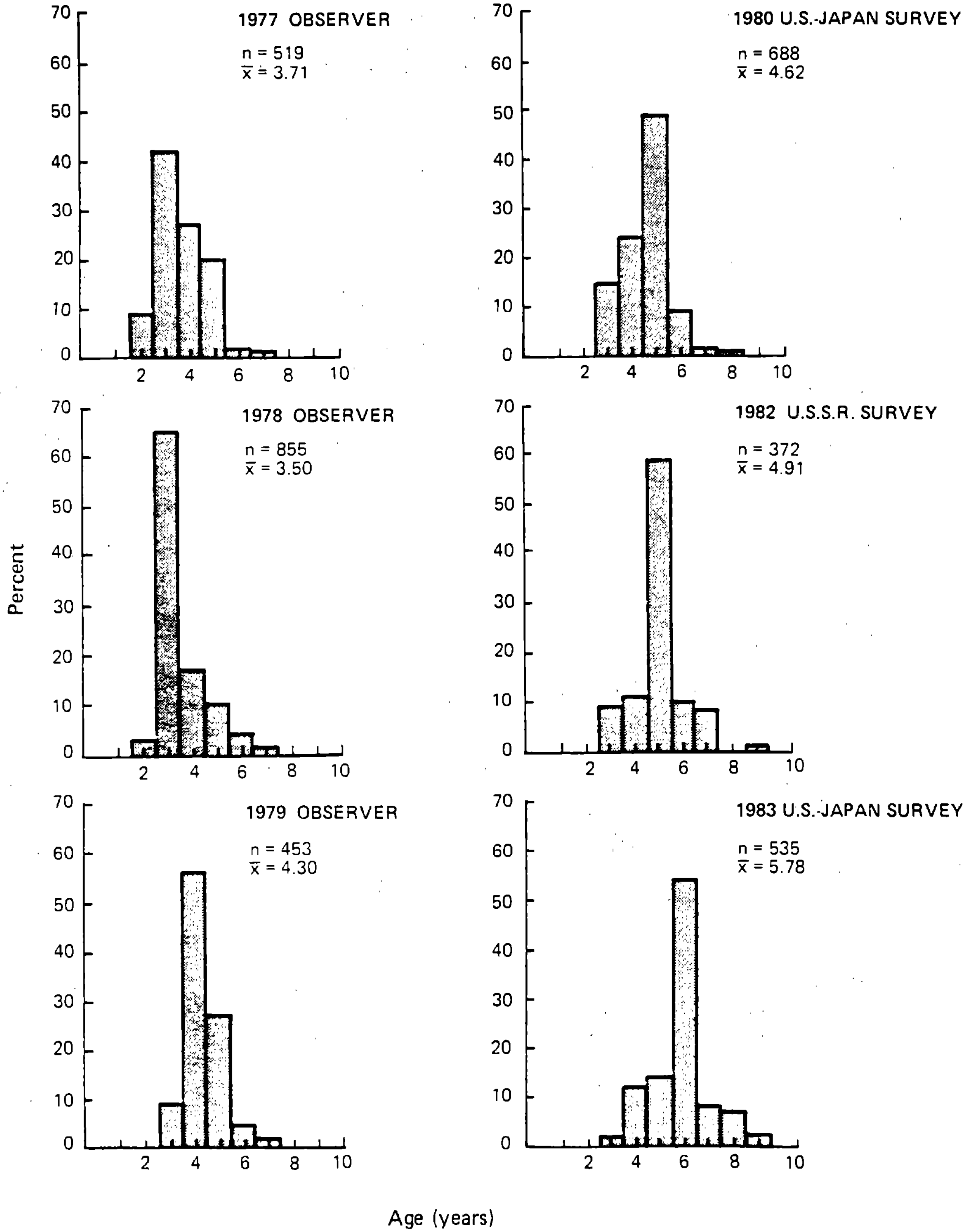

Figure 2. Estimated age frequency of commercial catches of Atka mackerel in the Aleutian Islands region sampled by the U.S. Observer Program (1977-79) and bottom trawl surveys (1980, 1982, 1983). Ages were determined by the NWAFC Ageing Unit.

Besides these two exceptional year-classes, it may be 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. 1). This phenomenon is important because the abundance of Atka mackerel in the Aleutians region may decline sharply as the strong, old, 1975 and 1977 year-classes pass 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-Carney (1975) estimate of the instantaneous natural mortality rate (M). An estimate of the natural mortality rate 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 6-yr-of-age data (Fig. 2). The resulting parameter estimates were:

males: L_{oo} = 36.80 K = 0.72 t_o = 0.73

females: L_{oo} = 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_{00} = 37.06 K = 0.66 t_o = 0.64

provides an adequate description of growth for Atka mackerel in the Aleutians region (Fig. 3).

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 Aleutians region. The resulting parameter estimates were:

males: a = 0.000144 b = 3.581

females: a = 0.000471 b = 3.227.

Using a likelihood ratio test, these curves were found to be significantly different (a = 0.001), with a chi-square value of 41.919, with df = 2. Nevertheless, the fitted curves (Fig. 4) were quite similar, and the combined curve:

sexes combined: a = 0.000270 b = 3.393

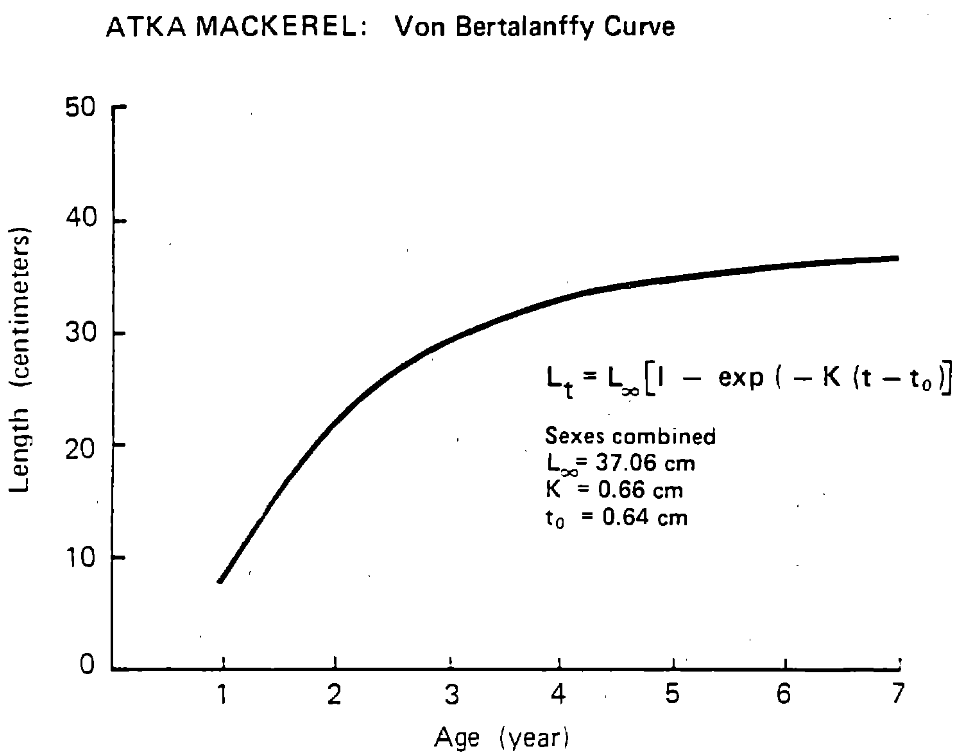

Figure 3. --Estimated von Bertalanffy growth curve (sexes combined) for Atka mackerel in the Aleutian Islands region.

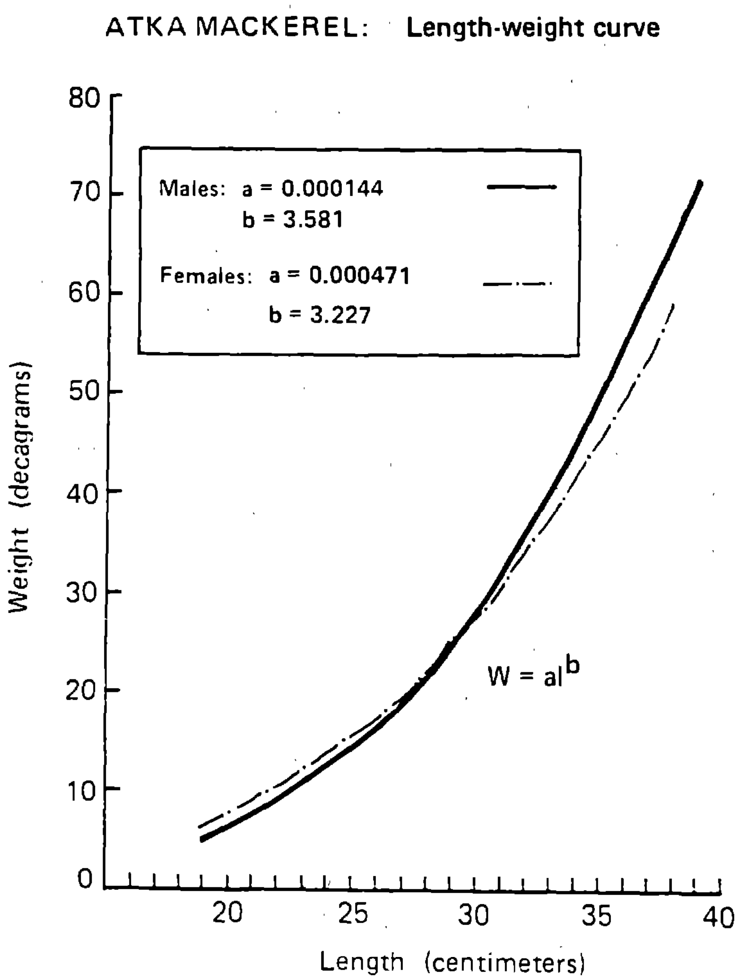

Figure 4.--Estimated lengthweight relationship for male and female Atka mackerel in the Aleutian Islands region.

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

Natural Mortality Rate 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 the instantaneous natural mortality rate 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_{mb} 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-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 Aleutians data for the exploited 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 4). 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 Aleutians stock. Using our Aleutians 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.

ESTIMATES OF MAXIMUM SUSTAINABLE YIELD

Maximum Sustainable Yield (MSY) was estimated for Atka mackerel stocks in the Aleutians 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 the natural mortality rate. Catch data

Table 4.--Estimates of the instantaneous natural mortality rate (M) for Atka mackerel in the Aleutian Islands region baaed 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

were used from the years 1974-82 (Tables 1 and 21, and all catches from the years 1974-77 were assumed to be from the Aleutians region.

Given the commercial catches, an estimate of the natural mortality rate (Table 4), and an initial population biomass at the beginning of 1974 of 100,000 t (Table 31, the average recruitment biomass level required to obtain a given final population biomass (at the beginning of 1983) 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 5 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 3).

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 Aleutians 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

Table 5.--Estimates of recruitment, equilibrium biomass (assuming F f= 0 and F = M) and MSY for Atka mackerel in the Aleutian Islands region. All biomass estimates are in metric tons.

Presumed natural mortality rate (M)	Presumed initial 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
		100,000 low	1	25,678	269,833	141,657	0.091	12,891
M = 0.10	100,000	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
		100,000 low	1	34,000	187,566	103,130	0.165	17,000
M = 0.20	100,000	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
		100,000 low	1	41,283	159,282	91,498	0.226	20,641
M = 0.30	100,000	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
		100,000 low	1	58,397	129,429	83,567	0.349	29,199
M = 0.60	100,000	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 equals zero in the SRA model, "recruitment" includes both growth in the fishable biomass and the recruitment biomass of new fish.

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 6). 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, MSY for the extreme long-term may have been overestimated.

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. 1) and age-frequency (Fig. 2) data. These data show large 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.

Table 6.--Intervals around the estimated MSY of Atka mackerel in the Aleutian Islands region (summarized from Table 5).

	Estimated MSY (t)		
	Varying 1983[1/] survey biomass (M = 0.2)	Varying[2/] estimates of M (1983 Biomass = 300,000 t)	Varying both[3/] 1983 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

[1]/ Low, medium, and high estimates of 1983 biomass are 100,000 t, 300,000 t, and 500,000 t (Table 3).

[2]/ Low, medium, and high estimates of M are 0.10, 0.20, and 0.30 (Table 4).

[3]/ Parameters were selected as in footnotes 1 and 2, to provide the greatest range possible.

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 Islands 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 0. *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 4,000 t in 1983 (Table 1). The distribution of catches show that the major fishing ground is on the continental slope of the eastern Bering Sea where squid are mainly taken by the land-based 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 1984) have shown some fluctuations but have generally been relatively stable as shown below:

Year	1976	1977	1978	1979	1980	1981	1982
CPUE	.025	.026	.044	.027	.022	.024	.024

Table 1.--Catches of squid in metric tons (t) by nation in the Aleutian Islands region and eastern Bering Sea 1977-83[a].

	Aleutian Islands Region				Eastern Bering Sea				
Year	Japan	R.O.K.[b]	Others[c]	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

[a]Catches in 1977-79 from data submitted to the United States by fishing nations; 1980-83 from French et al. 1981, 1982; Nelson el al. 1983, 1984.

[b]Republic of Korea.

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

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.

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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 eastern Bering Sea and Aleutians with 34 identified during a cooperative U.S.-Japan survey of the eastern Bering Sea in 1979 (Bakkala et al. 1983). Species of smelt occurring in the regions are capelin, *Mallotus villosus*; rainbow smelt, *Osmerus mordax dentex*; 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 of the "other fish" category reached a peak of 133,340 metric tons (t) in 1972, but have since substantially declined and were only 14,000 t in 1983 (Table 1). 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 of the introduction section of this report for species included in this latter category).

Data from large-scale surveys of the eastern Bering Sea in 1975 and 1979-84 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 2). 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 the 1979-80 level in 1984.

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 6 to 13% as abundant in the Aleutian Islands region as they are in the eastern Bering Sea (Table 2).

MAXIMUM SUSTAINABLE YIELD

In view of the apparent major increase in abundance of the "other species" category in the eastern Bering Sea (Table 2), this aggregation of stocks in 1981 may have been somewhere between a level that produces maximum sustainable

Table 1.--All-nation catches of other fish, 1964-83 In metric tons.[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

[a]Data for 1964-80 from catches reported to the United States by fishing nations; 1981-83 data from French et al. 1982 and Nelson et al. 1983, 1984.

Table 2.--Biomass estimates (in metric tons) of other species from large-scale demersal trawl surveys in 1975 and 1979-84.[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
Aleutian Islands Region	1980	39,300	15,500	0	800	2,300	57,900
	1983	18,800	10,600	0	0	200	29,600

[a]The biomass estimates for the eastern Bering Sea are from the approximate area shown in Figure 1 of the section on walleye pollock in this report. The 1979, 1981, and 1982 data include estimates from continental slope waters (200-1,000 m), but the 1975, 1980, 1983, and 1984 data do not.

yield (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 Aleutians 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 672,200 t) is 67,200 t.

EQUILIBRIUM YIELD

Based on the combined biomass estimates (467,100 t) from the 1984 eastern Bering Sea and 1983 Aleutian Islands surveys, the MSY of 67,200 t would represent an exploitation rate of 14%. Due to the uncertainties of the data base for this species group, it is recommended that the equilibrium yield (EY) for the "other species" category be set at 10% of the current biomass estimate or 46,700 t.

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