CONDITION OF GROUNDFISH RESOURCES OF THE EASTERN BERING SEA AND ALEUTIAN ISLANDS REGION IN 1986

by

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June 1987

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ABSTRACT

This report contains assessments of the conditions of groundfish and squid in the eastern Bering Sea and Aleutian Islands region management area. The assessments are based on single species analyses of commercial fishery and research vessel survey data available through August 1986. Estimates of maximum sustainable yields and acceptable biological catches or equilibrium yields are presented to guide management of the 1987 fishery. Table A summarizes results of these assessments.

Pacific cod, Gadus macrocephalus; yellowfin sole, Limanda aspera; and other flatfish remain in excellent condition with current populations at or near observed peak levels of abundance. The abundance of walleye pollock, Theragra chalcogramma, also remains relatively high with the exploitable population consisting of older (mainly ages 5-7 year) fish than in previous years. The condition of sablefish, Anoplopoma fimbria, has improved in both the eastern Bering Sea and Aleutian Islands regions providing somewhat higher yields than in recent years. There are also indications of better recruitment of Pacific ocean perch, Sebastes alutus, the first signs of improvement in the condition of this resource in a number of years. Current assessment data is not available for Atka mackerel, Pleurogrammus monopterygius, but commercial catches remain high. The condition of Greenland turbot, Reinhardtius hippoglossoides, is of concern. There has been essentially a recruitment failure of age 1 fish since 1982 and the lack of recruitment is projected to reduce the abundance of the exploitable stock into the early 1990s.

Estimates of acceptable biological catches for the groundfish complex as a whole increased from 1.9 million metric tons (t) in 1986 to 2.2 million t in 1987. This increase results mainly from higher yield estimates for walleye pollock and Pacific cod.

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Table A.--Estimated biomass, maximum sustainable yield (MSY) and acceptable biological catch (ABC) in thousands of metric tons (t), and views on stock condition of groundfish in the eastern Bering Sea/Aleutian Islands region from assessments in 1986[a].

Species	Estimated biomass	MSY	ABC[b]	Stock condition	Abundance trend
Walleye pollock	9,800	1,600	1,300		Abundance remains high and older fish dominate
(Eastern Bering Sea)	(8,800)	(1,500)	(1,200)	Good	
(Aleutians)	(1,000)	(100)	(100)	Good	
Pacific cod	1,316	--	400	Excellent	Abundance remains at historic high
(Eastern Bering Sea)	(1,134)		(375)		
(Aleutians)	(182)		(25)		
Yellowfin sole	1,870	150-175	187	Good	Abundance declining from historic high
Turbots	781	60.9	43.0		
(Greenland turbot)	(429)	(38.5)	(15.0)	Fair	Abundance projected to decline
(Arrowtooth flounder)	(352)	(22.4)	(28.0)	Excellent	Abundance high and increasing
Other flatfish	1,981	174.7-194.7	164		
(Rock sole)	(1,014)	(50-70)	(70)	Very good	Abundance at historic peak
(Alaska plaice)	(551)	(84.5)	(50)	Very good	Abundance above average
(Flathead sole)	(369)	(40.2)	(40)	Very good	Abundance at historic peak
(Miscellaneous flatfish)	(47)	--	(4)	Fair	Abundance stable at moderate level
Sablefish	113.1	4.6-7.7	7.7		
(Eastern Bering Sea)	(44.6)	(2.2-3.7)	(3.7)	Improved	Improved but below historic levels
(Aleutians)	(68.5)	(2.4-4.0)	(4.0)	Improved	
Pacific ocean perch complex					
(Eastern Bering Sea)	46.5	>2.8-5.0	2.4		
(Pacific ocean perch)	(20.0)	(2.8-5.0)	(1.5)	Improved	Abundance low but recruitment improved
(Other species in complex)	(26.5)	(-)	(0.9)	Unknown	Unknown
(Aleutians)	213.4	>6.9-11.9	6.8		
(Pacific ocean perch)	(113.9)	(6.6-11.9)	(3.7)	Improved	Abundance low but recruitment improved
(Other species in complex)	(99.5)	(-)	(3.1)	Unknown	Unknown
Other rockfish	49.7	--	2.5		
(Eastern Bering Sea)	(11.5)	--	(0.6)	Unknown	Unknown
(Aleutians)	(38.2)	--	(1.9)	Unknown	Unknown
Atka mackerel	307	38.7	38.7	Good	Current assessment data lacking
Squid	--	>10	10	--	Unknown
Other species	605.9	59	36.7	Good	Abundance high
TOTAL GROUNDFISH	17,084	2,108-2,163	2,199		

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

[b] Estimates for most species are acceptable biological catches (ABC), but for Pacific cod, Atka mackerel, and other rockfish, the estimates represent equilibrium yields.

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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 resource assessment surveys. Estimates of maximum sustainable yields (MSY) and acceptable biological catches (ABC) or equilibrium yields (EY) are presented to guide management of the 1987 fishery. This introduction to the report presents background information on the fishery and management which may be useful in evaluating the species assessments that follow.

Management Area

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

Species of Concern

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

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

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

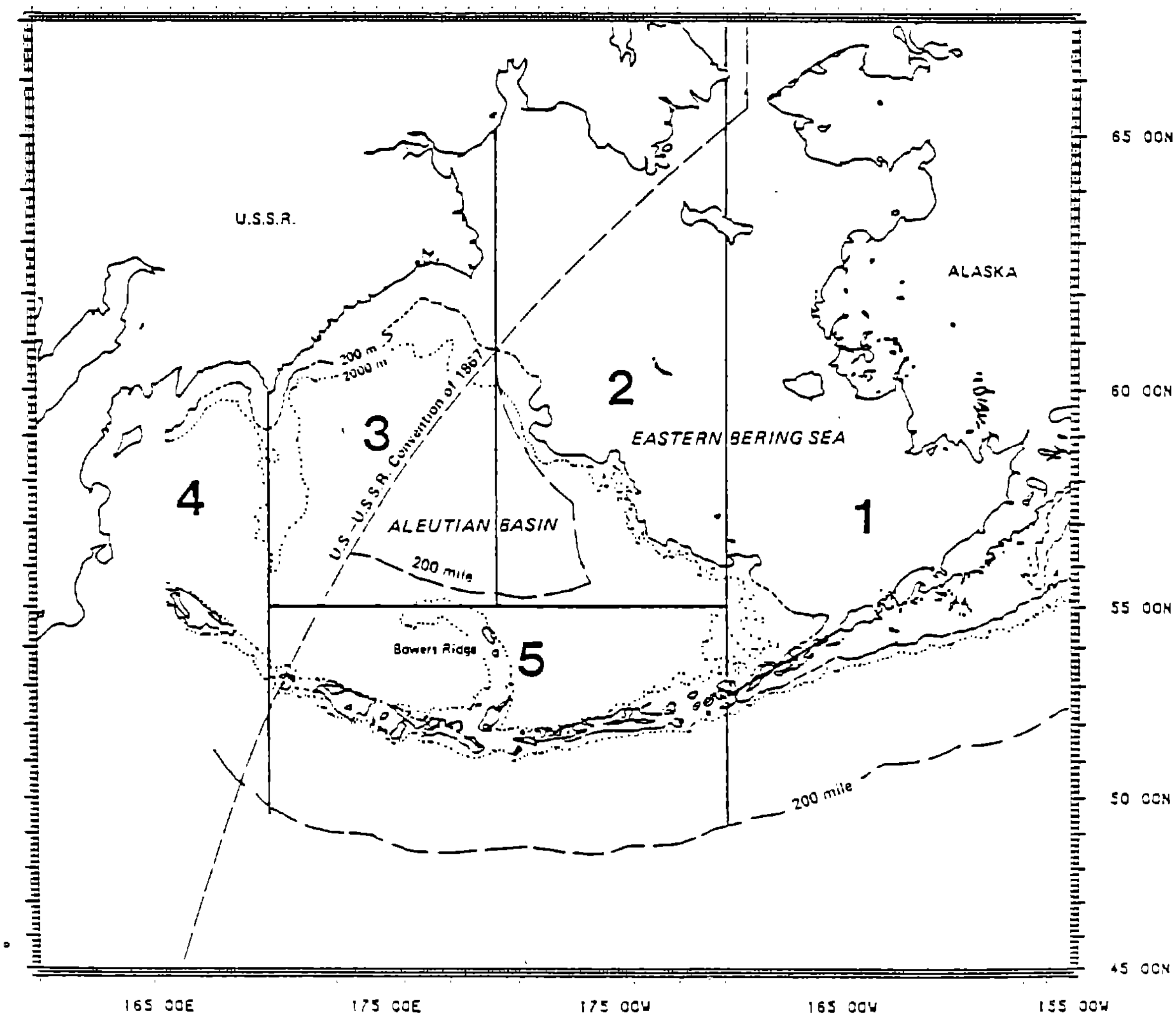

Figure 1. --Bering Sea showing U.S. 200-mile fishery conservation zone and eastern Bering Sea (areas 1 and 2) and Aleutian Islands region (area 5) management areas. Areas 1-5 are International North Pacific Fisheries Commission statistical areas.

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

Prohibited species[a]	Target species[b]	Other species[c]	Nonspecified species[d]	
FINFISHES				
Salmonids	Walleye pollock	Sculpins	Eelpouts (Zoarcidae)	
Pacific halibut	Cod	Sharks	Poachers (Agonidae) and alligator fish	
	Yellowfin sole	Skates	Snailfish, lumpfishes, lump-suckers (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.

Historical Catch Statistics

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

Historical catch statistics since 1954 are shown for the eastern Bering Sea in Table 2. In this region, the initial target species of fisheries from Japan and the U.S.S.R. was yellowfin sole, Limanda aspera. During this early period of the fisheries, total recorded catches of groundfish reached a peak of 674,000 metric tons (t) in 1961. Following a decline in abundance of yellowfin sole, other species were targeted, principally pollock, and total catches of groundfish in the eastern Bering Sea rose to much higher levels; reaching more than 2.2 million t in 1972. Catches have since declined and ranged between 1.2 and 1.3 million t in 1977-83 as catch restrictions were placed on the fishery because of declining stock abundance of pollock and other species. More recently, landings have again increased reaching 1.6 million t in 1985 with walleye pollock, yellowfin sole, and Pacific cod (Gadus macrocephalus) accounting for most of this increase.

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

Fishery Restrictions

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

Table 2.--Groundfish and squid catches (metric tons) in the eastern Bering Sea, 1954-85[a].

Year	Walleye Pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Yellowfin sole	Turbots	Other flatfish	Atka mackerel	Squid	Other species	Total all species
1954						12,562						12,562
1955						14,690						14,690
1956						24,697						24,697
1957						24,145						24,145
1958	6,924	171	6			44,153					147	51,401
1959	32,793	2,864	289			185,321					380	221,647
1960			1,861	6,100		456,103	36,843					500,907
1961			15,627	47,000		553,742	57,348					673,717
1962			25,989	19,900		420,703	58,226					524,818
1963			13,706	24,500		85,810	31,565	35,643				191,224
1964	174,792	13,408	3,545	25,900		111,177	33,729	30,604			736	393,891
1965	230,551	14,719	4,838	16,800		53,810	9,747	11,686			2,218	344,369
1966	261,678	18,200	9,505	20,200		102,353	13,042	24,864			2,239	452,081
1967	550,362	32,064	11,698	19,600		162,228	23,869	32,109			4,378	836,308
1968	702,181	57,902	14,374	31,500		84,189	35,232	29,647			22,058	977,083
1969	862,789	50,351	16,009	14,500		167,134	36,029	34,749			10,459	1,192,020
1970	1,256,565	70,094	11,737	9,900		133,079	32,289	64,690			15,295	1,593,649
1971	1,743,763	43,054	15,106	9,800		160,399	59,256	92,452			33,496	2,157,326
1972	1,874,534	42,905	12,758	5,700		47,856	77,633	76,813			110,893	2,249,092
1973	1,758,919	53,386	5,957	3,700		78,240	64,497	43,119			55,826	2,063,644
1974	1,588,390	62,462	4,258	14,000		42,235	91,127	37,347			60,263	1,900,082
1975	1,356,736	51,551	2,766	8,600		64,690	85,651	20,393			54,845	1,645,232
1976	1,177,822	50,481	2,923	14,900		56,221	78,329	21,746			26,143	1,428,565
1977	978,370	33,335	2,718	6,600	1,678	58,373	37,162	14,393		4,926	35,902	1,173,457
1978	979,431	42,543	1,192	2,200	12,155	138,433	45,781	21,040	832	6,886	61,537	1,312,030
1979	913,881	33,761	1,376	1,700	10,048	99,017	42,919	19,724	1,985	4,286	38,767	1,167,464
1980	958,279	45,861	2,206	1,100	1,367	87,391	62,618	20,406	4,697	4,040	33,949	1,221,914
1981	973,505	51,996	2,604	1,200	1,111	97,301	66,394	23,428	3,028	4,179	35,551	1,260,297
1982	955,964	55,040	3,184	200	863	95,712	54,908	23,809	328	3,837	18,200	1,212,045
1983	982,363	83,212	2,695	200	460	108,385	53,659	30,454	116	3,455	11,062	1,276,061
1984	1,098,783	110,944	2,793	300	327	159,526	29,294	44,286	41	2,798	8,508	1,457,600
1985	1,178,759	132,736	2,248	800	82	227,107	21,986	71,179	5	1,610	11,503	1,648,015

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

Table 3.--Groundfish and squid catches (metric tons) in the Aleutian Islands region, 1962-85[a].

Year	Walleye Pollock	Pacific cod	Sablefish	Pacific ocean perch	Other rockfish	Turbots	Atka mackerel	Squid	Other species	Total all species
1962			-	200						200
1963			664	20,800		7				21,471
1964		241	1,541	90,300		504			66	92,652
1965		451	1,249	109,100		300			768	111,868
1966		154	1,341	85,900		63			131	87,589
1967		293	1,652	55,900		394			8,542	66,781
1968		289	1,673	44,900		213			8,948	56,023
1969		220	1,673	38,800		228			3,088	44,009
1970		283	1,248	66,900		559	949		10,671	80,610
1971		2,078	2,936	21,800		2,331			2,973	32,118
1972		435	3,531	33,200		14,197	5,907		22,447	79,717
1973		977	2,902	11,800		12,371	1,712		4,244	34,006
1974		1,379	2,477	22,400		11,983	1,377		9,724	49,340
1975		2,838	1,747	16,600		3,754	13,326		8,288	46,553
1976		4,190	1,659	14,000		3,437	13,126		7,053	43,465
1977	7,625	3,262	1,897	5,900	9,587	4,488	20,975	1,808	16,170	71,712
1978	6,282	3,295	821	5,300	8,737	6,548	23,418	2,085	12,436	68,922
1979	9,504	5,593	782	5,500	14,543	12,847	21,279	2,252	12,934	85,234
1980	58,156	5,788	274	4,700	1,361	8,299	15,793	2,332	13,004	109,707
1981	55,516	10,462	533	3,600	1,397	8,040	16,661	1,762	7,274	105,245
1982	57,978	11,526	955	1,000	2,792	8,732	19,546	1,201	5,167	108,897
1983	59,026	9,955	673	300	1,147	7,869	11,610	524	3,193	94,297
1984	81,834	22,216	1,043	600	292	3,275	36,013	326	1,669	147,268
1985	58,730	12,690	2,089	500	217	104	37,856	5	2,049	114,240

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

Time-area restrictions applicable to non-U.S. groundfish fisheries in the two management areas are illustrated in Figure 2. A new area regulation, not shown in Figure 2, precludes trawling year around by all nations, including U.S. vessels, north of the Alaska Peninsula between 160° and 162°W longitude and south of 58°N latitude to protect red king crab, *Paralithodes camtschatica* (Fig. 3). This new regulation also establishes incidental catch limits by trawl fisheries for certain species of crabs in zones 1 and 2 shown in Figure 3. In zone 1, U.S. trawl fisheries are limited to a by-catch of 80,000 snow (Tanner) crab *Chionoecetes bairdi* and 135,000 red king crab. In zone 2, U.S. trawl fisheries are limited to a by-catch of 326,000 bairdi Tanner crab. Non-U.S. fisheries are limited to a by-catch of 64,000 Tanner crab in the combined areas of zones 1 and 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 annually in 1984-86. Species accounting for the major part of this increase have been pollock, yellowfin sole, and Pacific cod.

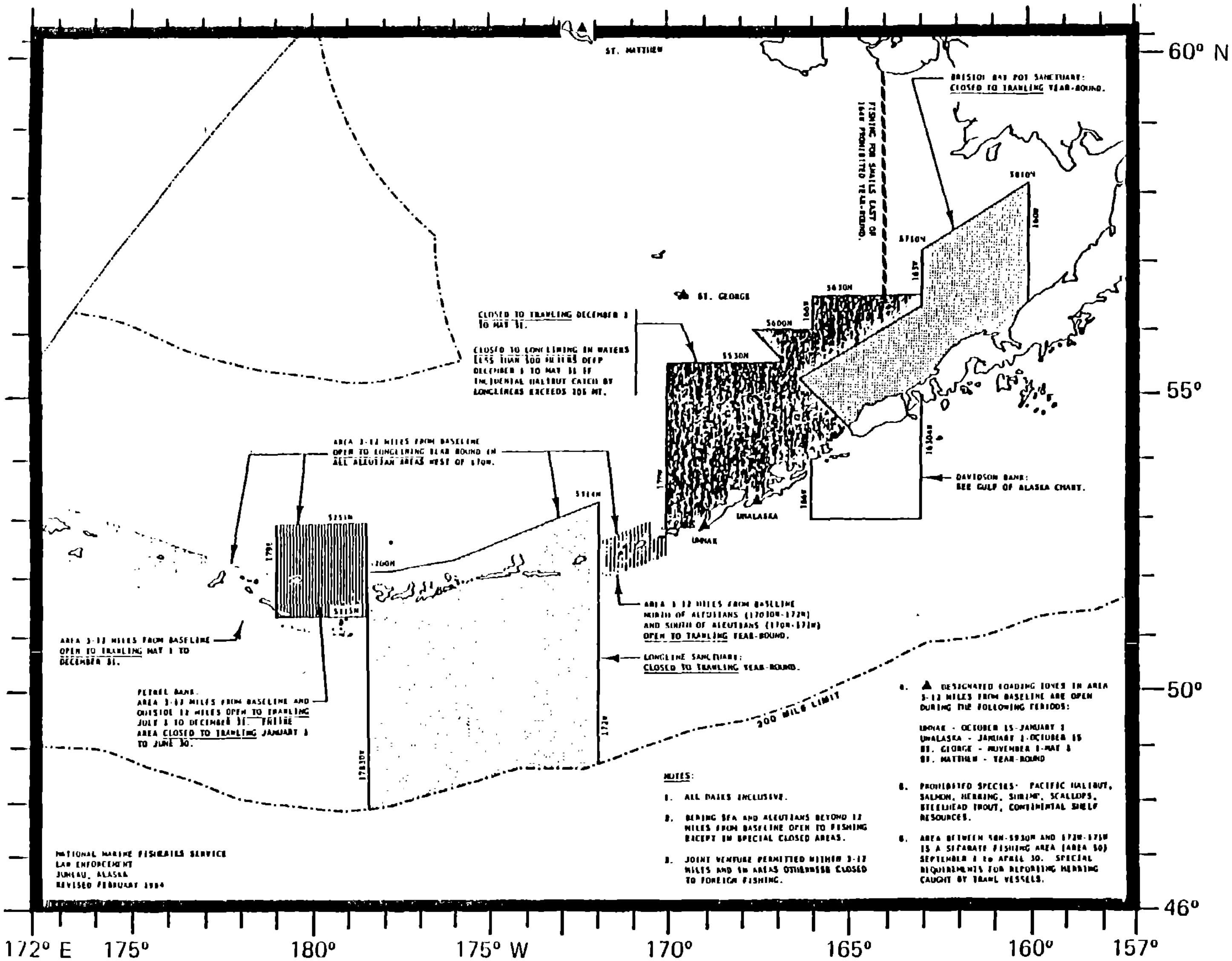

Figure 2.--Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions.

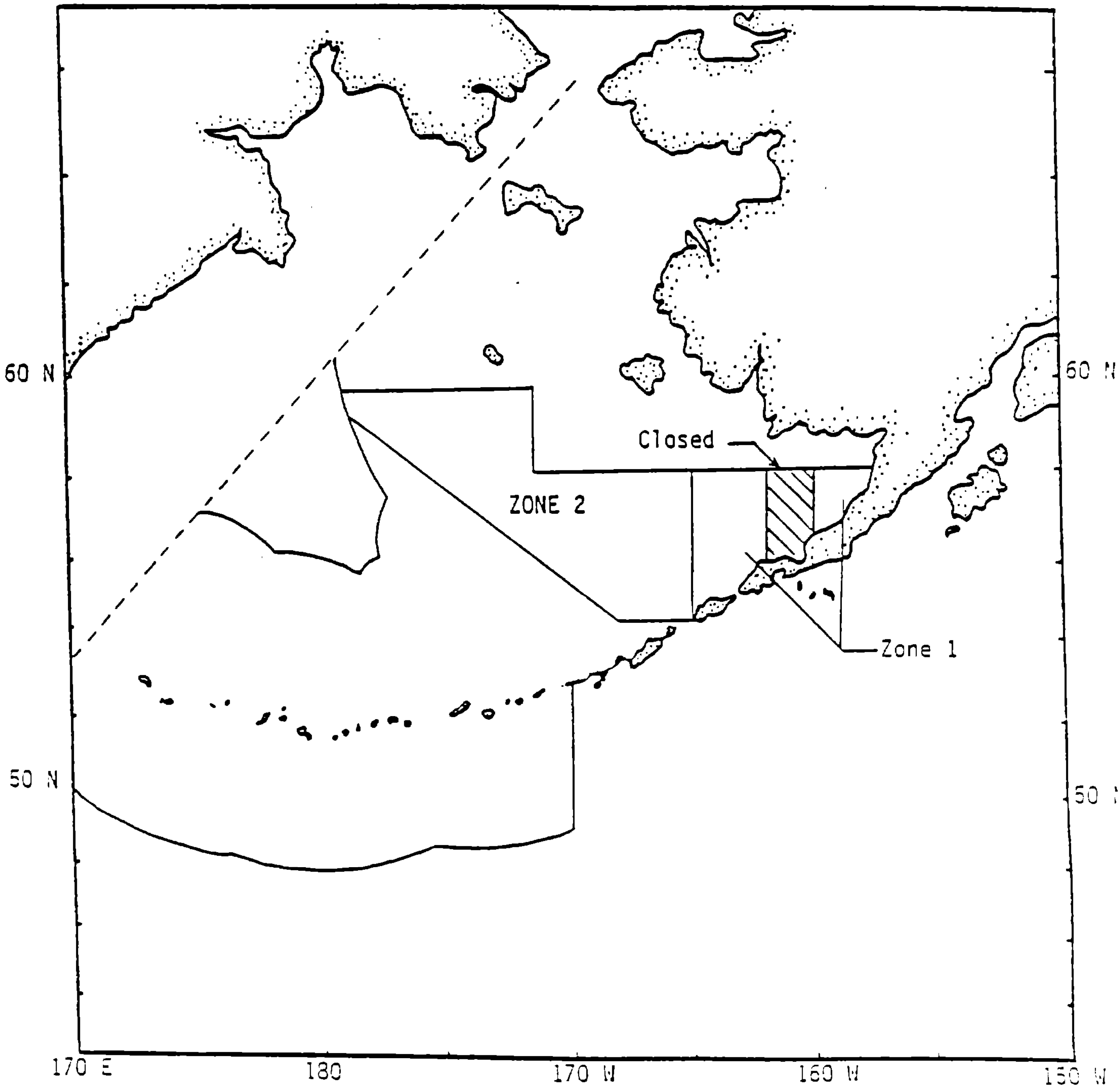

Figure 3.--Regulatory areas for controlling by-catches of red king crab and bairdi Tanner crab in trawl fisheries (see text).

Table 4.--Optimum yields (t) for groundfish of the eastern Bering Sea and Aleutian Islands region 1977-86.

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

[a]Optimum yields are for the eastern Bering Sea and Aleutian Islands areas combined for pollock in 1977-79, other rockfish 1980-83, other species in 1980-86, and in all years for yellowfin sole, turbot, other flounders, Pacific cod and squid.
[b]Excludes halibut but includes turbot until 1980.
[c]After 1979 herring no longer included with groundfish.

WALLEYE POLLOCK

by

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COMMERCIAL UTILIZATION

The walleye pollock, *Theragra chalcogramma*, resource in the eastern Bering Sea supports the largest single-species fishery in the northeast Pacific Ocean. In 1981-85, catches of pollock in this region averaged about 1.0 million metric tons (t) and during this period exceeded those (946,000 t) of all other species of groundfish in U.S. waters from off California to the Bering Sea. Pollock became a highly sought-after species when mechanized processing of minced meat was successfully implemented on Japanese commercial vessels in the mid-1960's. As a result, catches increased more than ten-fold between 1964 and 1972 (from 175,000 t to nearly 1.9 million t; Table 1). Catches have since declined, ranging between 914,000 t and 1,179,000 t in 1977-85, due in part to catch restrictions placed on the fishery as a result of declining stock abundance. An additional 55,500 to 81,800 t were taken annually in 1980-85 in the Aleutian Islands region (Table 2).

Japanese fisheries have historically accounted for over 80% of annual catches in the eastern Bering Sea, but their proportion has been declining and was 50% (584,500 t) in 1985. Most of the remainder of the annual catches were taken by the U.S.S.R. until 1978, but in 1979-83, catches by the Republic of Korea (R.O.K.) were the second largest, reaching about 170,000 t in 1983. Catches by joint venture operations between U.S. fishing vessels and processing vessels from Japan, Poland, the R.O.K., the Federal Republic of Germany (F.R.G.), and the U.S.S.R. have increased rapidly in recent years reaching 370,000 t in 1985 which represented the second largest catch after that by Japan. Pollock taken by U.S. vessels and delivered to U.S. processors have also increased rapidly from 900 t in 1983 to 38,000 t in 1985.

CONDITION OF STOCKS

Relative Abundance

Since the previous condition of resources report was completed (Bakkala et al. 1986b), Northwest and Alaska Fisheries center (NWAFC) bottom trawl survey data were reanalyzed to provide annual abundance estimates for pollock and other species of groundfish for a specific standardized survey area in the eastern Bering Sea (Fig. 1). In previous reports, abundance estimates were from approximately this area, but there was some minor variation in the sampling area from year to year. Abundance estimates given in this report may therefore vary to some extent from those in previous reports.

The new standardized area was sampled in 1975 and annually in 1979-86 with bottom trawls. Thus, an 8-year continuous time series of survey data is available for this area and the time series can be extended back 12 years

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]	Portugal	Joint ventures[d]	U.S.	Total
1964	174,792									174,792
1965	230,551									230,551
1966	261,678									261,678
1967	550,362									550,362
1968	700,981		1,200							702,181
1969	830,494	27,295	5,000							862,789
1970	1,231,145	20,420	5,000							1,256,565
1971	1,513,923	219,840	10,000							1,743,763
1972	1,651,438	213,896	9,200							1,874,534
1973	1,475,814	280,005	3,100							1,758,919
1974	1,252,777	309,613	26,000							1,588,390
1975	1,136,731	216,567	3,438							1,356,736
1976	913,279	179,212	85,331							1,177,822
1977	868,732	63,467	45,227	944						978,370
1978	821,306	92,714	62,371	3,040						979,431
1979	749,229	58,880	83,658	1,952	20,162					913,881
1980	786,768	2,155	107,608	4,962	40,340	5,967		10,479		958,279
1981	765,287		104,942	3,367	48,391	9,580		41,938		973,505
1982	746,972		150,525	4,220		1,625		52,622		955,964
1983	654,939		170,007			10,038		146,467	912	982,363
1984	626,335	12,268	167,887		46,900	8,304	48	230,314	6,727	1,098,783
1985	584,484	1,504	160,735		22,696			370,257	38,084	1,178,759

[a]Catch data for 1964-79 as reported by fishing nation (except 1967-76 R.O.K. catches which were based on U.S. surveillance reports). Non-U.S. and joint venture catch data for 1980-85 from U.S. observer estimates as reported by French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986. U.S. catches from Pacific Fishery Information Network (PACFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. 5th Ave., Portland, OR 97201.

[b]Republic of Korea.

[c]Federal Republic of Germany.

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

Table 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	U.S.	Others	Total
1977	5,667	1,618	325				15	7,625
1978	5,025	1,193	64					6,282
1979	8,047	1,412	45					9,504
1980	46,052	1	6,256	5,806			41	58,156
1981	37,980		11,074	5,593			869	55,516
1982	33,379		8,117		1,983		14,499	57,978
1983	29,485		13,420		2,547		13,574	59,026
1984	38,598		12,027	5,171	6,694	3,891	15,453	81,834
1985	35,628		5,872	9,364	7,283	583		58,730

[a]Catch data for 1977-79 as reported by fishing nations and for 1980-85 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986. U.S. catch data from Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. 5th Ave., Portland, OR 97201.
[b]Federal Republic of Germany and Republic of China (Taiwan).

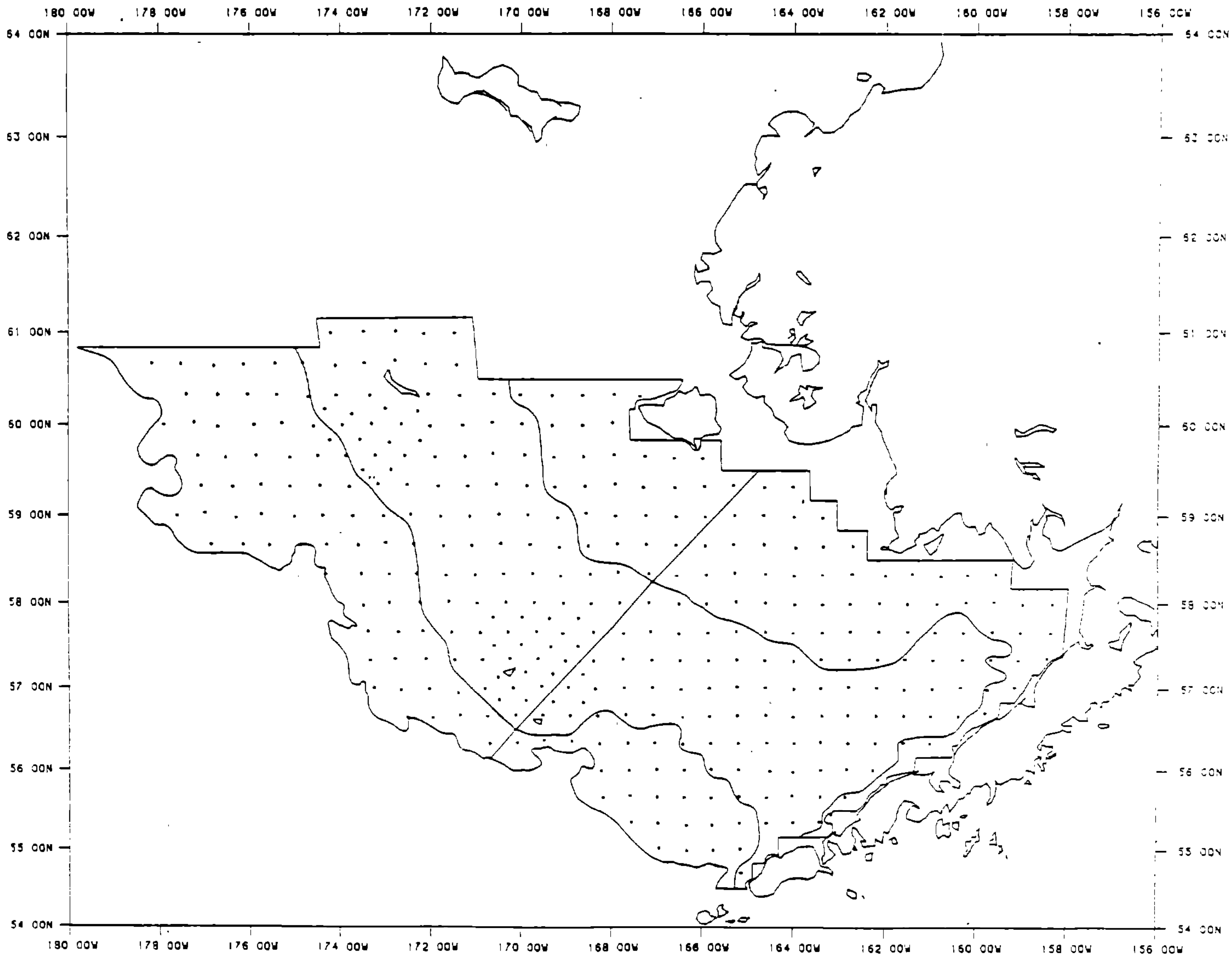


Figure 1 .--Standardized survey area on the eastern Bering Sea continental shelf sampled during Northwest and Alaska Fisheries Center bottom trawl resource assessment surveys in 1975 and annually since 1979. Stratification of the survey area used in analyses of assessment data is also shown.

with the 1975 data. The standardized area encompasses the major portion of the geographical distributions of economically important species of groundfish on the eastern Bering Sea continental shelf.

Groundfish resources in continental slope waters of the eastern Bering Sea have been intensively sampled by Japanese research vessels with bottom trawls during cooperative U.S.-Japan surveys in 1979, 1981, 1982, and 1985. These slope data are incorporated into the assessments of pollock and other species that are abundant in slope waters. In addition, the bottom trawl data for pollock from shelf and slope waters are supplemented by acoustic-midwater trawl survey data in 1979, 1982, and 1985. These acoustic surveys assess the off-bottom portion of the pollock population.

Because pollock are semidemersal, bottom trawl surveys only sample the near bottom portion of the population. Combined data from the acoustic and bottom trawl surveys provide abundance estimates for the overall population. These combined data have shown that the proportion of the pollock population vulnerable to bottom trawls varies. For example, these data indicated that 14%, 35%, and 45% of the combined population number estimates were sampled by the bottom trawl surveys respectively in 1979, 1982, and 1985. This variability appears to be related to age composition of the population and perhaps to other factors. Generally, younger age groups are higher in the water column and older age groups nearer the bottom. In 1979 age 4 and older pollock only made up about 3% of total population numbers while in 1982 and 1985 they made up 53% and 59%, respectively, of the overall estimated population numbers. Thus, abundance trends shown by bottom trawl data alone may be misleading and require some interpretation based on knowledge of the age composition and prior results from the combined bottom trawl and acoustic survey data.

Trends in relative abundance of pollock as shown by NWAFC bottom trawl survey data from the new standardized area on the eastern Bering Sea shelf and from the fishery are given in Table 3. Trends from the various sources are similar, indicating a rapid decline in abundance from the early to mid-1970's and then relative stability through 1982. Most of the available catch per unit of effort (CPUE) estimates were higher in 1983-86 than in 1975-82.

The trends in CPUE (Table 3) from NWAFC bottom trawl surveys have been more variable than those from the fishery. This may result from variability in the vertical distribution of pollock in the water column which would more severely influence abundance estimates from survey trawls with vertical openings of 1.5-2.3 m than fishery trawls with vertical openings of 7-12 m. The sharp decline in CPUE shown by survey data in 1980 represents an unrealistic fluctuation in abundance, and the fishery CPUE data appear to more accurately reflect the condition of the stock in that year. The 1983-86 survey data indicate a major increase in abundance because of an increase in abundance of older age groups (as described above) which are more vulnerable to the survey bottom trawls rather than to an actual increase in abundance of the overall population. Corresponding increases in CPUE from the 1983-85 fisheries also reflect this greater availability of large pollock.

The CPUE from the 1984-86 surveys (ranging from 97 to 107 kg/ha) were lower than that from the 1983 survey (130 kg/ha), but still much higher than

Table 3.--Relative indices of walleye pollock stock abundance in the eastern Bering Sea, 1964-86.

	Japanese pair trawl data			
Year	U.S. method[a] (t/1,000's of horsepower hours)	Japanese method[b] (t/h)	INPFC[c] workshop method[d] (% of 1975 value)	NWAFC bottom trawl 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	42.1
1976	10.0	9.8	98	--
1977	8.7	9.2	97	--
1978	9.2	9.7	100	--
1979	9.9	9.8	103	63.2
1980	9.7	9.3	92	32.0
1981	6.4	9.6	95	57.0
1982	6.0	10.9	100	62.5
1983	9.3	11.5	121	130.4
1984	9.2	14.6	173	99.6
1985	9.9	--	155	97.3
1986	--	--	--	107.0

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

the values (32-63 kg/ha) derived from the survey data in 1975 and 1979-82. The again relatively high CPUE value in 1986 indicates that the abundance of large pollock remains high in the eastern Bering Sea.

Biomass Estimates

Survey Based Estimates

As discussed earlier, there are three sources of survey data for estimating the biomass of eastern Bering Sea pollock: annual NWAFC bottom trawl surveys on the shelf, Japanese cooperative bottom trawl surveys in slope waters, and acoustic surveys of the off-bottom portion of the pollock population over shelf and slope waters. The 1979 acoustic survey, however, only assessed midwater pollock over the outer shelf and slope and the total biomass may have been underestimated to some extent that year. There may be other inaccuracies in biomass estimates from combined bottom trawl and acoustic survey data. These include biases in target strength values used to estimate fish density from the acoustic data, the inability to detect low densities of pollock by the acoustic gear, changes in the vertical distribution of pollock between the time the bottom trawl and acoustic surveys sampled various areas of the shelf region, and possible gaps or overlaps in the portion of the water column sampled by the hydroacoustic and bottom trawl surveys (Bakkala et al. 1985a).

The estimated biomass of the overall population of eastern Bering Sea pollock in years when all three surveys were conducted was 10.5 million t in 1979, 7.8 million t in 1982, and 9.4 million t in 1985 (Table 4). These estimates suggest that the biomass of pollock remains high and only moderately lower than in 1979. There has been a change in the proportions of the population biomass in midwater and near bottom over this period. The proportion in midwater has declined from 71% in 1979, to 61% in 1982 and 51% in 1985. This is believed to reflect the change in age composition of the population since 1979 as discussed earlier. In 1979 population numbers were dominated by age 1 and 2 year fish of the 1977 and 1978 year classes. Older 4 to 7 year fish contributed a much greater proportion of the overall population numbers in more recent years. These older pollock occupy near bottom water to a greater extent than young pollock.

The presence of greater numbers of older fish in the population and their tendency to remain closer to the bottom is believed mainly responsible for the higher biomass estimates from NWAFC bottom trawl surveys since 1983 in comparison to those in earlier years (Table 4). The 1986 estimate was again high at 5.0 million t indicating that the abundance of older pollock remains high.

In 1980 and 1983, the NWAFC and Fisheries Agency of Japan conducted cooperative bottom trawl surveys in the Aleutian Islands region. Methods and results of these surveys are described by Ronholt et al. (1987) and Wakabayashi et al. (1987). Biomass estimates (t) from those surveys were as follows:

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

Table 4.-- Biomass estimates (metric tons) for walleye pollock of the eastern Bering Sea from NWAFC and Japanese bottom trawl surveys and NWAFC acoustic surveys.

Year	NWAFC bottom trawl survey on continental shelf	Japanese bottom trawl survey on continental slope	NWAFC acoustic surveys over continental shelf and slope	Total all surveys
Mean Estimates				
1975	1,958,400			--
1979	2,939,000	93,100	7,458,000	10,490,100
1980	1,485,900			--
1981	2,168,600	273,400		--
1982	2,826,800	204,500	4,778,300	7,809,600
1983	6,064,800			--
1984	4,633,000			
1985	4,524,900	79,700	4,798,600	9,403,200
1986	4,977,900			
95% Confidence Intervals[a]				
1975	1,595,600-2,321,200			
1979	2,444,000-3,434,000	--	4,900,000-10,730,000	
1980	1,063,900-1,907,900			
1981	1,667,000-2,670,200	--		
1982	2,108,400-3,545,300	--	4,310,000-5,500,000	
1983	5,065,900-7,063,700			
1984	3,665,900-5,600,200			
1985	3,738,100-5,311,800	--	4,040,000-5,558,000	
1986	3,984,300-5,971,600			

[a]The 95% confidence intervals for the acoustic survey biomass estimates include only sampling error. They do not include errors associated with the estimation of parameters (e.g., target strength) needed to scale echo integration data to biomass estimates.

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

It should be noted that some of the commercial catch of pollock in the Aleutian region originates from midwater trawling in the Aleutian Basin (see Fig. 1 of the Introduction section of this report for the location of the basin). Japanese hydroacoustic surveys in the basin have indicated that the biomass of the pelagic basin population may range between 1.3 and 5.4 million t (Okada 1983). Whether pollock in the basin and Aleutians represent the same or independent populations is unknown.

Age Structured Model Based Estimates

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

The catch-at-age data used in both models is shown in Table 5. The catch data used in 1971-76 was that reported by the governments of nations fishing in the eastern Bering Sea and since 1977, that estimated from U.S. fishery observer sampling of foreign and joint venture catches. Age length keys were constructed from age readings obtained from otoliths collected by observers. The age length keys were applied to length frequency samples also collected by observers to estimate the age composition of the catch. Estimates of age composition were initially calculated for statistical areas 1 and 2 (see Figure 1 of the Introduction to this report), quarters of the year, and nation-vessel classes. If any of these cells lacked data they were combined with other quarterly cells having data over a semiannual or annual period. In some cases, length frequency samples were available for a strata but not age data. In these cases, age keys from similar cells were used, i.e., an age length key from Japanese small trawlers was used to age length frequency samples from Korean small trawlers fishing in the same quarter and statistical area.

Catch-at-age for each cell was obtained by multiplying the number of pollock caught in that cell by the percentage age composition. The number of pollock caught was obtained by dividing the catch weight in kilograms by the average weight of pollock in the catch. Average weights were derived from the average length of pollock in the catch using the length-weight relationship $W = 0.0075\ L^{2.977}$ (Pereyra et al. 1976). Total numbers at age were obtained by summing over cells.

Table 5.--Catch at age in number of walleye pollock for the years 1971-84.

Age	1971	1972	1973	1974	1975	1976
2	443,983,305	63,465,055	652,036,435	3,121,491,256	833,663,705	884,555,706
3	132,582,172	306,276,853	730,835,166	1,403,040,336	3,817,149,225	1,618,900,824
4	740,658,439	706,617,458	1,903,951,588	421,051,278	458,942,403	1,355,235,503
5	497,173,395	565,940,779	999,247,867	484,369,344	53,732,729	128,829,194
6	737,106,176	237,101,766	473,409,030	248,429,057	84,055,063	47,727,250
7	71,557,752	92,989,766	262,396,559	156,877,923	95,631,209	55,630,057
8	47,030,942	35,321,415	228,998,835	127,981,544	70,129,796	57,155,435
9	13,227,567	12,762,223	87,177,468	133,712,886	53,429,920	38,315,592

Age	1977	1978	1979	1980	1981	1982
2	1,073,816,172	722,678,783	958,318,125	1,120,060,875	76,514,479	25,378,068
3	1,195,774,141	1,097,359,561	1,235,419,499	1,041,523,325	1,442,684,307	214,940,910
4	847,525,659	944,443,475	682,467,001	430,156,165	662,889,545	1,466,504,870
5	274,558,181	391,272,633	540,965,602	228,463,365	149,673,091	389,070,688
6	74,979,679	94,394,232	231,774,924	153,058,035	74,749,419	62,695,091
7	32,114,379	26,330,318	53,803,793	75,204,515	45,412,822	21,177,588
8	45,992,258	17,719,477	22,826,600	51,415,520	38,000,626	23,989,227
9	41,234,111	19,145,347	29,169,814	21,146,821	23,281,868	14,936,765

Age	1983	1984
2	96,175,159	69,322,000
3	187,229,665	127,969,000
4	429,962,151	449,967,000
5	912,078,907	419,620,000
6	207,847,468	533,871,000
7	32,995,774	117,388,000
8	13,305,595	36,827,000
9	9,054,704	25,241,000

Other input parameters to the catch-age models were natural mortality and weight at age to convert numbers to biomass. In cohort analysis, age specific natural mortality rates (0.45 for age 2 and 0.3 for ages 3-9) as reported by Wespestad and Terry (1984) were used and a constant rate of 0.3 was used in the CAGEAN model. Average weight at age data from Smith (1981) were used to convert numbers at age to biomass at age.

Results from cohort analysis and the CAGEAN model were "tuned" using ancillary data from hydroacoustic and bottom trawl surveys. In cohort analysis, terminal F values were iteratively adjusted until the relative age composition in the terminal year differed by no more than + 2% by age from the relative age composition of the surveys. The terminal-year F values were further adjusted by a constant to produce a trend in total numbers equal to the trend in total numbers observed between the 1979 and 1982 surveys. Terminal F values for age 9 in years prior to the terminal year were computed by averaging the F's for ages 7 and 8 under the assumption of equal selectivity.

In the CAGEAN model, the 1979 and 1982 survey population estimates were used to compute fully recruited F values. In the case of pollock, cohort analysis results showed that selectivity increased to age 4 and then decreased, so age 4 was the only fully recruited or available age. The additional parameters for the analysis were taken from cohort analysis, and the procedures of Deriso et al. (1985) were followed.

Trends in pollock biomass from the two models were similar although the magnitude of biomass estimates, particularly in early years of the analyses, differed (Table 6). Biomasses were estimated at 9.3 to 12.4 million t in the early 1970's, declined to between 6.4 and 7.2 million t in 1977-79, and then increased again to 8.9-9.5 million t in 1981-82. Following this increase, the models show another decline to about 6.5 million t in 1984. However, it should be noted that results from age structured models for the last 2 or 3 years are sensitive to errors in the terminal fishing mortality estimate. Because of the iterative nature of the models, an error in the terminal fishing mortality has much less effect on estimates of cohort abundance for the earlier years.

Estimates (in million t) from the two models and from combined bottom trawl-acoustic surveys for age 2 and older pollock (ages included in the age structured models) are compared below:

		Model estimates	
Year	Survey estimates	Cohort analysis	CAGEAN
1979	8.7	6.4	7.2
1982	7.8	8.9	9.4
1984-85	9.3(1985)	6.5	6.6(1984)

The trends in abundance between 1979 and 1985 differ as do the magnitude of the estimates. Biomass may be underestimated by the models in 1984 because the last year of the model run does not include estimates for age 2 fish. Further, as discussed previously, estimates from the last 2 or 3 years may be biased. Thus it is assumed that the 1984 biomass of pollock is higher than that shown by the models and that the 1985 survey estimate may be closer to the actual biomass.

Table 6.--Biomass estimates (million t) for walleye pollock in the eastern Bering Sea based on cohort analysis[a] and CAGEAN[b] models and the 95% confidence interval for the estimates from the CAGEAN model.

Year	Cohort analysis	CAGEAN model	Confidence interval from CAGEAN model
1971	12.4	9.3	5.1 - 13.5
1972	11.8	9.7	5.5 - 13.9
1973	11.0	9.5	5.7 - 13.3
1974	9.4	7.1	3.5 - 10.7
1975	8.2	6.8	3.4 - 10.2
1976	7.4	7.2	4.4 - 10.0
1977	6.8	6.9	4.5 - 9.3
1978	6.4	6.6	4.4 - 8.8
1979	6.4	7.2	4.9 - 9.3
1980	8.0	8.7	6.3 - 11.1
1981	9.2	9.5	6.3 - 12.7
1982	9.4	8.9	5.7 - 12.1
1983	8.3	7.9	4.9 - 10.9
1984	6.6	6.5	4.5 - 8.5

[a] Method of Pope (1972).
[b] Catch-age analysis (Deriso et al. 1985).

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 1981, the age compositions derived from survey and fishery data were relatively consistent with survey catches composed primarily of ages 1-4 and fishery catches of ages 2-4 with age 3 fish usually predominating in the fishery catches. Age 5 and older fish were relatively rare in both survey and fisheries catches. Beginning in 1982, survey as well as fishery catches began to be dominated by age 4 and older pollock. The initial reason for the dominance of older fish has been the strength of the 1978 year class which continued to dominate fishery catches through 1985 at the relatively advanced age of 7 years. The 1979 and 1980 year classes beginning at age 4 have also contributed substantially to fishery catches in most recent years and the 1982 year class at age 3 began to make a substantial contribution in 1985.

As described in last year's condition of groundfish resources report, the 1982 year class appeared to be relatively strong at age 1 based on NWAFC survey data in 1983, but this strength was not evident at age 2 in 1984 from either survey or fishery data. In 1985, however, the 1982 year class appeared in bottom trawl survey and fishery catches to a greater extent than in 1984.

The 1982 year class was the dominant age, both in terms of numbers of fish and in biomass, in the midwater portion of the pollock population in 1985 based on the acoustic survey data (Fig. 3). Thus the majority of the 1982 year class have apparently occupied off-bottom waters at least as 2- and 3-year-old fish. Based on estimates from the acoustic and bottom trawl surveys, 81% of the biomass of the 1982 year class was in midwater during the 1985 survey.

The distribution of the biomass among age groups in 1985 based on combined estimates from the acoustic and bottom trawl surveys was as follows:

Age	1	2	3	4	5	6	7	8+
Year class	1984	1983	1982	1981	1980	1979	1978	1977 and earlier
Biomass (million t)	0.10	0.12	1.70	0.56	2.24	1.95	1.80	0.58

These data indicate that a major part of the overall biomass (about 6.6 million t) in 1985 was made up of relatively old age 5 and older pollock. With the addition of age 3 and 4 fish, the exploitable biomass may have been as high as 8.8 million t in 1985.

Length-frequency data from NWAFC bottom trawl surveys in 1979 and 1981-86 were used to further examine recruitment and abundance of age groups through 1986 (Fig. 4). As discussed earlier, survey data are not believed to be representative of pollock abundance in 1980. These data show a continuation in the pattern observed since 1983 of larger-older fish dominating the population

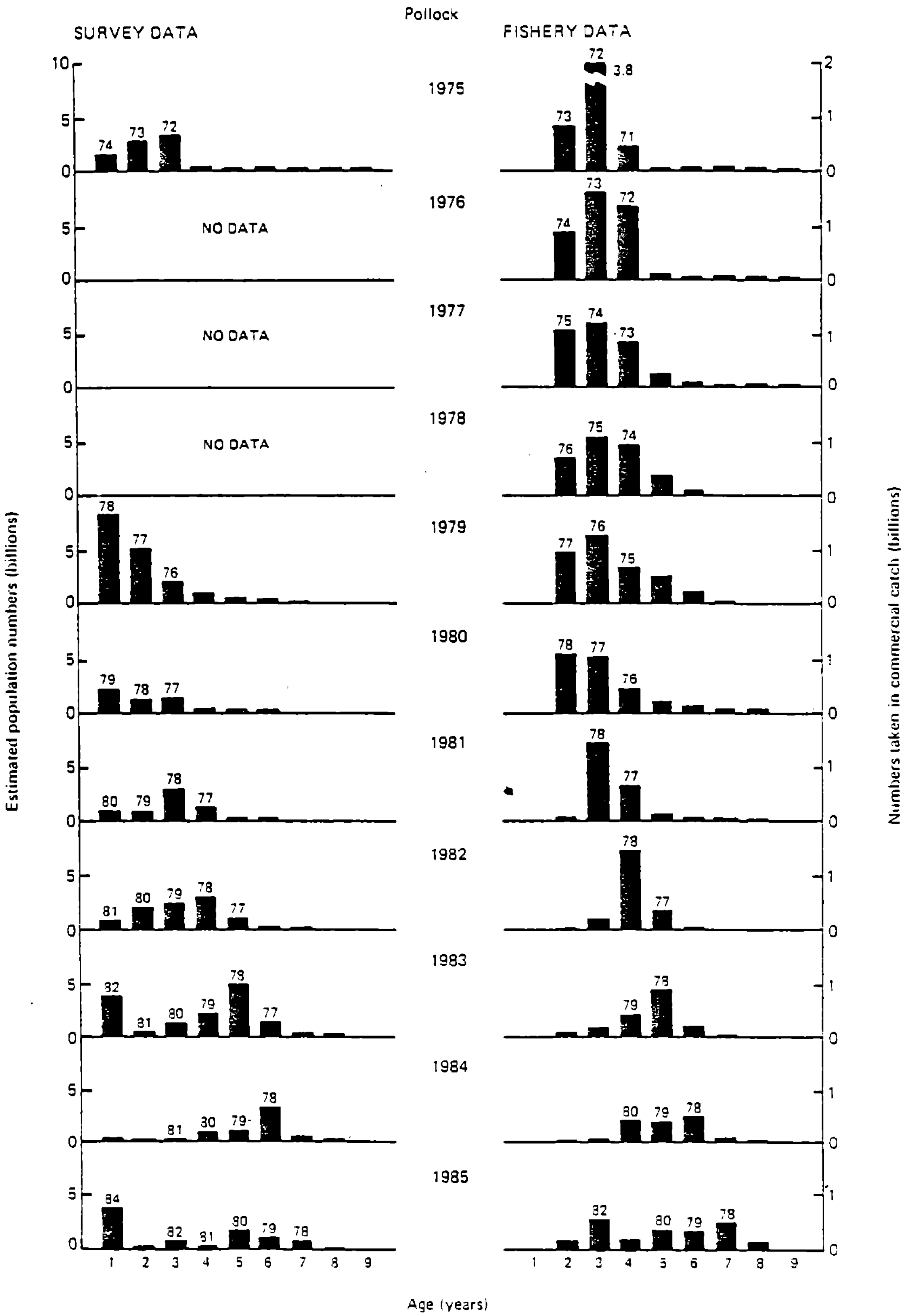
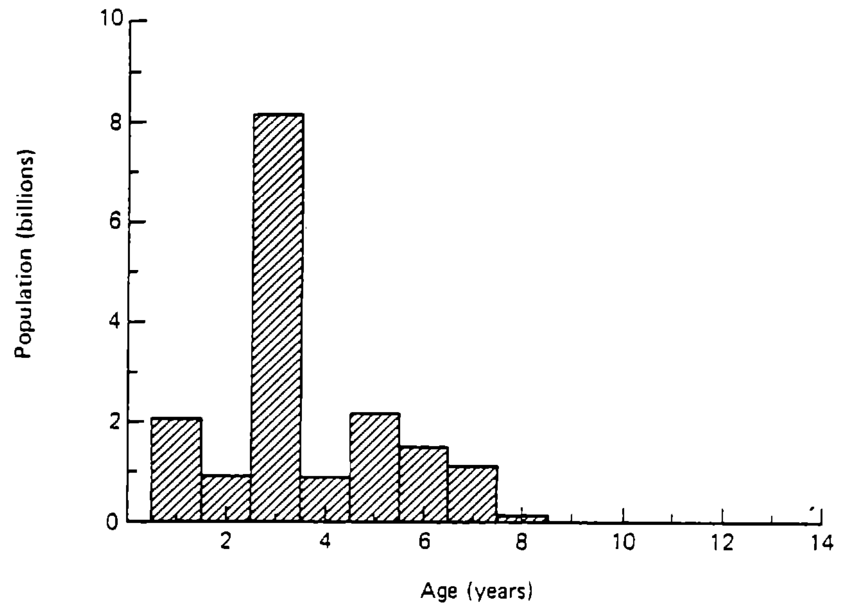


Figure 2.--Age composition of walleye pollock in the eastern Bering Sea as shown by data from Northwest and Alaska Fisheries Center bottom trawl resource assessment surveys and by data collected in the commercial fishery by U.S. observers. Numbers above the bars indicate the principal year classes.



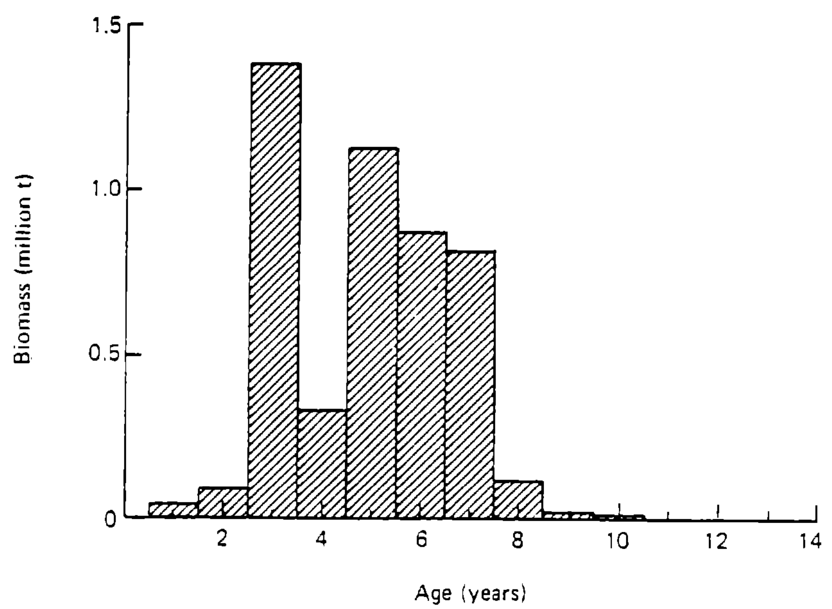


Figure 3.--Age composition of walleye pollock in midwater in terms of population estimates and biomass as shown by the 1985 Northwest and Alaska Fisheries Center acoustic survey in the eastern Bering Sea.

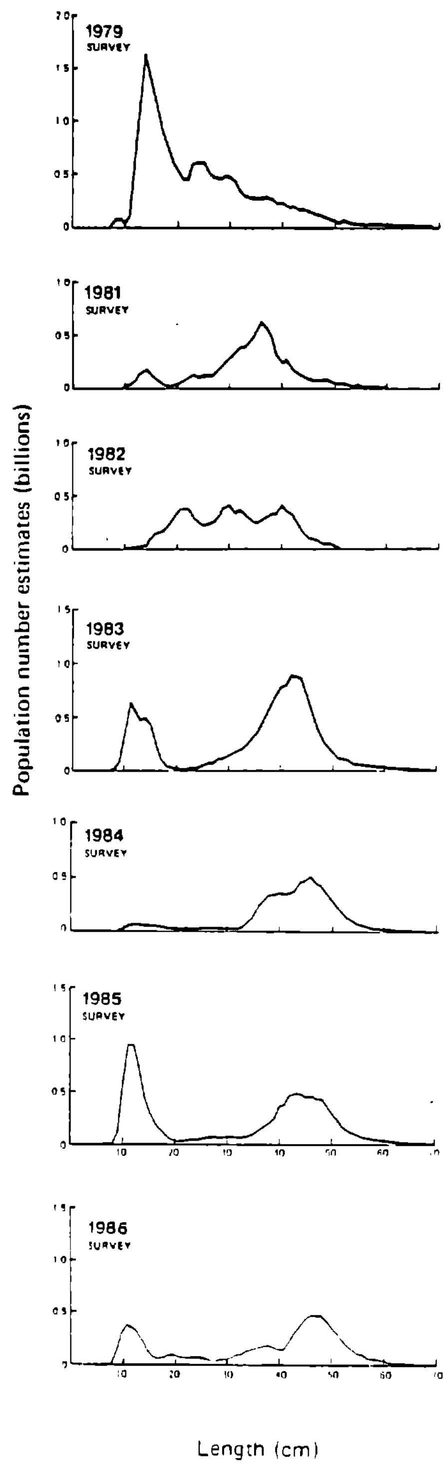


Figure 4.--population estimates of walleye pollock by centimeter length interval as shown by Northwest and Alaska Fisheries Center resource assessment surveys on the continental shelf of the eastern Bering Sea.

and low numbers of 2- and 3-year-old fish (represented by lengths from about 20-35 cm). Most of the larger fish in 1986 were greater than 40 cm, which would represent mainly age 5 and older pollock.

The 1984 year class, which appeared to be relatively abundant as age 1 fish based on the bottom trawl data in 1985 (10-20 cm mode) did not produce a sizable mode at age 2 (between 20 and 30 cm) in the 1986 length distribution. This has occurred with other strong year classes such as the 1978 year class which ultimately proved to be very strong, but which was not abundant at age 2 in bottom trawl survey catches (Fig. 2). This apparently results from age 2 fish being higher in the water column than at other ages. However, the strength of the 1984 year class is questionable because it was not abundant in midwater at age 1 based on the 1985 acoustic survey data (Fig. 3). Population estimates (in billions of fish) for age 1 pollock from the 3 years of acoustic and bottom trawl survey have been as follows:

Year	Acoustic midwater estimate	Bottom trawl estimate	Combined estimate
1979	69.11	8.17	77.28
1982	0.10	0.84	0.94
1985	2.08	4.04	6.12

The abundance of age 1 fish in 1979 and 1982 (the 1978 and 1981 year classes) represent the extremes in observed year class strength. The 1978 year class was exceptionally abundant and by far the strongest year class yet observed while the 1981 year class is the weakest yet observed. Thus, population estimates for a year class of average strength is not available from the acoustic-bottom trawl surveys to compare with the estimate for the 1984 year class.

Population estimates of age 1 pollock from bottom trawl surveys based on age analyses in 1979-85 (Fig. 2) and population numbers under 20 cm from the 1986 survey data (Fig. 4) were as follows:

Year	Year class	Population number estimates (billions)
1979	1978	8.2
1981	1980	1.0
1982	1981	0.8
1983	1982	3.7
1984	1983	0.3
1985	1984	4.0
1986	1985	2.2

The average of these seven estimates is 2.4 billion. If the bottom trawl data are representative of the abundance of age 1 pollock in 1986, the strength of the 1985 year class may be about average.

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 million t (Low 1974). The incorporation of 1974-76 data, and the application of the procedure of Rivard and Bledsoe (1978), resulted in an estimated MSY of 1.5 million t (Low et al. 1978).

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

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

ACCEPTABLE BIOLOGICAL CATCH

Biomass estimates from age structured models indicate that the abundance of pollock in the eastern Bering Sea increased from about 7 million t, in the late 1970's to about 9 million t in 1981-82. This increase appears logical because of the recruitment of the exceptionally strong 1978 year class during this period. Since 1982, the models show a declining trend in abundance. However, estimates from the last 2 or 3 years of the model runs may be less reliable than those for earlier years as explained earlier. Trends in abundance and biomass levels shown by combined acoustic-bottom trawl survey data between 1979 and 1985 differ from those shown by the age structured models. The survey data for age 2 and older pollock indicated a moderate decline in biomass between 1979 (8.7 million t) and 1982 (7.8 million t) and then an increase to 9.3 million t in 1985. Because of possible inaccuracies in estimates from the most recent years of the model runs, the survey data may be more representative of the actual biomass in 1985.

As described earlier, the age structure of the eastern Bering Sea population of pollock has changed with older age groups being much more abundant in the 1980's than in the 1970's. Older pollock tend to occupy water nearer bottom then younger pollock. For example the acoustic and bottom trawl survey data indicate that 29% of the pollock biomass was near bottom in 1979 and 49% in 1985. This change in age composition and distribution of pollock in the water column has resulted in a sharp increase in abundance estimates from bottom trawl survey and fishery data. This trend continued in 1986.

Biomass estimates from NWAFC bottom trawl surveys on the shelf increased moderately from 4.5 million t in 1985 to 5.0 million t in 1986. These data, in addition to length frequency information from the 1986 survey (Fig. 4), indicate that the abundance of older pollock has not diminished. The exploitable biomass of age 3 and older pollock was estimated to be 8.8 million t in 1985 based on combined results from the acoustic-bottom trawl surveys. If the 1986 bottom trawl results are representative of the trend in abundance of the overall exploitable biomass, then this level of biomass should have been available to the fishery again in 1986.

In summary, abundance estimates from surveys and the fishery give no evidence of a decline in abundance of pollock through 1986 when the exploitable biomass may have been as high as 8.8 million t. If the older age 5 to 7 pollock continue to form the principal ages in commercial catches as they have since 1982, the 1982 year class should help to maintain the biomass at a relatively high level as it recruits to this age range in 1987. Abundance of the 1984 and 1985 year classes which will recruit to the fishery at age 2 and 3 years in 1987 is still questionable.

In view of the apparent stability in abundance of the eastern Bering Sea population through 1986, acceptable biological catch (ABC) in 1987 should be maintained at a level similar to that in 1986. However, based on the advanced age of the main portion of the exploitable stock, it is recommended that ABC be increased from the 1.1 million t recommended for 1986 to 1.2 million t in 1987. This ABC level represents an exploitation rate of 13.6% assuming the exploitable biomass is 8.8 million t.

For the Aleutian region stock, no new information is available to change last year's ABC estimate of 100,000 t. To reiterate, the biomass in the Aleutian region was estimated to be about 1.0 million t from U.S.-Japan trawl surveys conducted in 1983. Because of uncertainties about this estimate, however, the ABC was set at 10% of the estimate or 100,000 t. This 100,000 t ABC level should be available again for 1987.

Exploitation rates of 10.0 to 13.6% may actually be conservative for a species like pollock. Based on the fishing strategy derived from yield per recruit theory (ICES 1984, Deriso in press), the optimal fishing rate may be as high as 22% (when $M = 0.30$, $L_{\infty} = 85$ cm, $k = 0.15$, $L_c = 44$ cm).

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PACIFIC COD: ANALYSIS OF SURVEY RESULTS AND AN ORIGINAL AGE-STRUCTURED SIMULATION

by

Grant G. Thompson and Allen M. Shimada

INTRODUCTION

Pacific cod, *Gadus macrocephalus,* are distributed widely over the Bering Sea continental shelf and slope and have a distributional range similar to that of walleye pollock, *Theragra chalcogramma*. During the early 1960s, a fairly large Japanese longline fishery harvested cod for the frozen fish market. Beginning in 1964, the Japanese North Pacific trawl fishery for pollock expanded, and cod became an important incidental catch in the pollock fishery and an occasional target species when high concentrations were detected during pollock operations. At present, cod is an incidental species for all foreign trawl fisheries, although it remains a target species of the Japanese longline fishery. In 1981, a U.S. domestic trawl fishery and several joint venture fisheries began operations in the eastern Bering Sea and Aleutian Islands areas. These two U.S. fisheries have dominated catches in the last 2 years, and in 1985 took 88,000 t, or 61% of the total catch.

Annual catches of Pacific cod by all nations in the eastern Bering Sea and Aleutians increased from 13,600 t in 1964 to 70,400 t in 1970, but then declined to range between 36,600 and 63,800 t in 1971-79 (Table 1). Catches in 1980-85 increased markedly from the level of the previous 3 years because of increases in abundance of the resource (as will be discussed later) and catches by the new U.S. joint venture and domestic fisheries. All-nation catches of cod reached a historic high of 145,400 t in 1985, with the great majority of this total (132,700 t) originating from the eastern Bering Sea.

CONDITION OF STOCKS

Relative Abundance

The abundance of Pacific cod in the eastern Bering Sea has increased substantially since the mid-1970s. Strong year classes spawned in 1977 and 1978 were the major factors contributing to the initial increase. The relative abundance of cod increased about seven-fold between 1976 and 1983 (Fig. 1), according to results from Northwest and Alaska Fisheries Center (NWAFC) surveys conducted 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 of the section of this report on walleye pollock for the area sampled), the catch per unit effort (CPUE) of cod increased approximately nine times (from 2.7 to 24.8 kg/ha) between 1975 and 1983. In 1986, CPUE was 24.4 kg/ha, indicating that relative abundance remains high.

Biomass Estimates

Estimates of biomass from large-scale NWAFC demersal trawl surveys in the eastern Bering Sea since 1978 are displayed in Table 2. Estimated biomass increased steadily from 1978 through 1983. Abundance has remained

Table 1 .--Commercial catches (t) of Pacific cod by area and nation, 1964-84[a]

	Eastern Bering Sea						
Year	Japan	U.S.S.R.	R.O.K.[b]	Other nations[c]	Joint ventures[d]	U.S.[e]	Total
1964	13,408	-					13,408
1965	14,719	-					14,719
1966	18,200	-					18,200
1967	32,064	-	-				32,064
1968	57,902	-	-				57,902
1969	50,351	-	-				50,351
1970	70,094	-	-				70,094
1971	40,568	2,486	-				43,054
1972	35,877	7,028	-				42,905
1973	40,817	12,569	-				53,386
1974	45,915	16,547	-	-			62,462
1975	33,322	18,229	-	-			51,551
1976	32,009	17,756	716	-			50,481
1977	33,141	177	-	2		15	33,335
1978	41,234	419	859	-		31	42,543
1979	28,532	1,956	2,446	47		780	33,761
1980	27,334	7	6,346	1,371	8,370	2,433	45,861
1981	27,570	0	6,147	2,481	7,410	8,388	51,996
1982	17,380	0	8,151	647	9,312	19,550	55,040
1983	29,411	0	9,792	32	9,662	34,315	83,212
1984	46,346	688	10,030	169	24,382	29,329	110,944
1985	51,296	288	4,889	20	35,634	40,609	132,736

	Aleutian Islands Area							E.Bering Sea and Aleutians
Year	Japan	U.S.S.R.	R.O.K.	Other nations	Joint ventures	U.S.	Total	Comb.Total
1964	241	-	-				241	13,6 9
1965	451	-					451	15,170
1966	154	-					154	18,354
1967	293	-					293	32,357
1968	289	-	-				289	58,191
1969	220	-	-				220	50,571
1970	283	-	-				283	70,377
1971	425	1,653	-				2,078	45,132
1972	435	-	-				435	43,340
1973	566	411	-				977	54,363
1974	1,334	45	-				1,379	63,841
1975	2,581	257	-				2,838	54,389
1976	3,862	312	16				4,190	54,671
1977	3,162	100	-				3,262	36,597
1978	3,165	120	6			4	3,295	45,838
1979	5,171	414	6			2	5,593	39,354
1980	2,834	4	58	9	86	2,797	5,788	51,649
1981	2,426	0	476	12	1,749	5,799	10,462	62,458
1982	1,730	0	259	7	4,280	5,250	11,526	66,566
1983	1,845	0	392	34	4,700	2,984	9,955	93,167
1984	1,244	0	1	32	6,390	14,549	22,216	133,161
1985	829	0	0	10	5,638	6,213	12,690	145,425

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

[b] Republic of Korea.

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

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

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

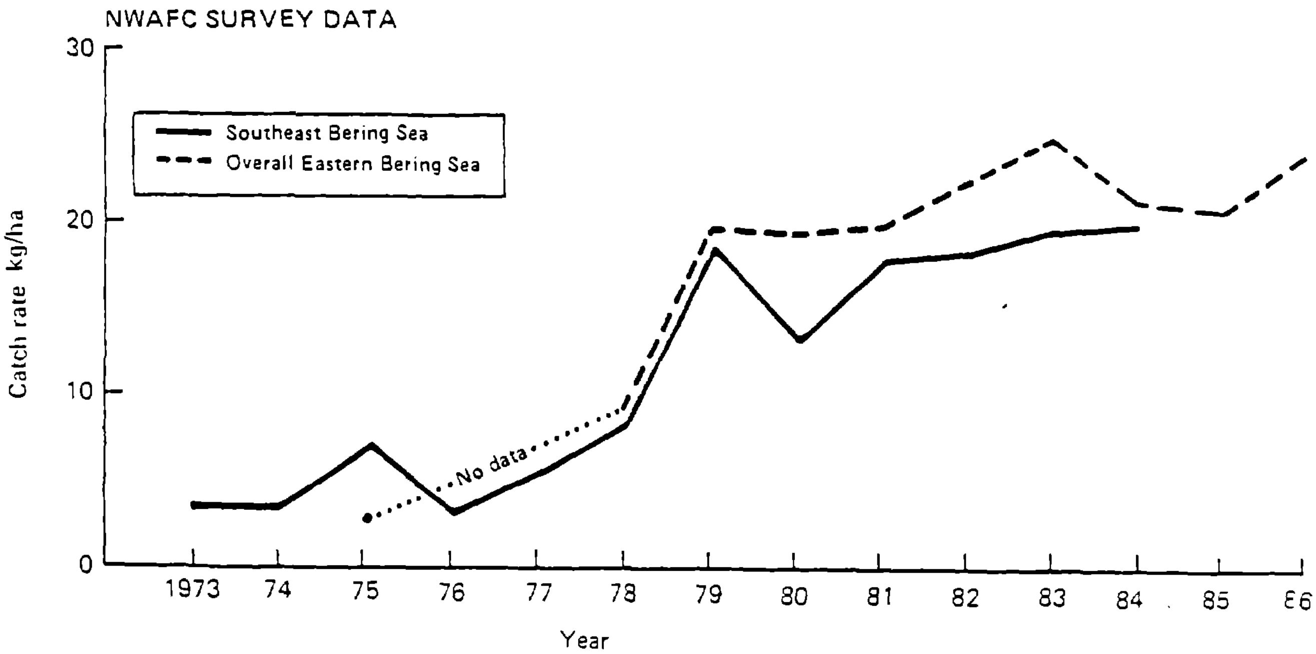

Figure 1 .--Relative abundance of Pacific cod as shown by Northwest, and Alaska Fisheries Center (NWAFC) bottom trawl surveys.

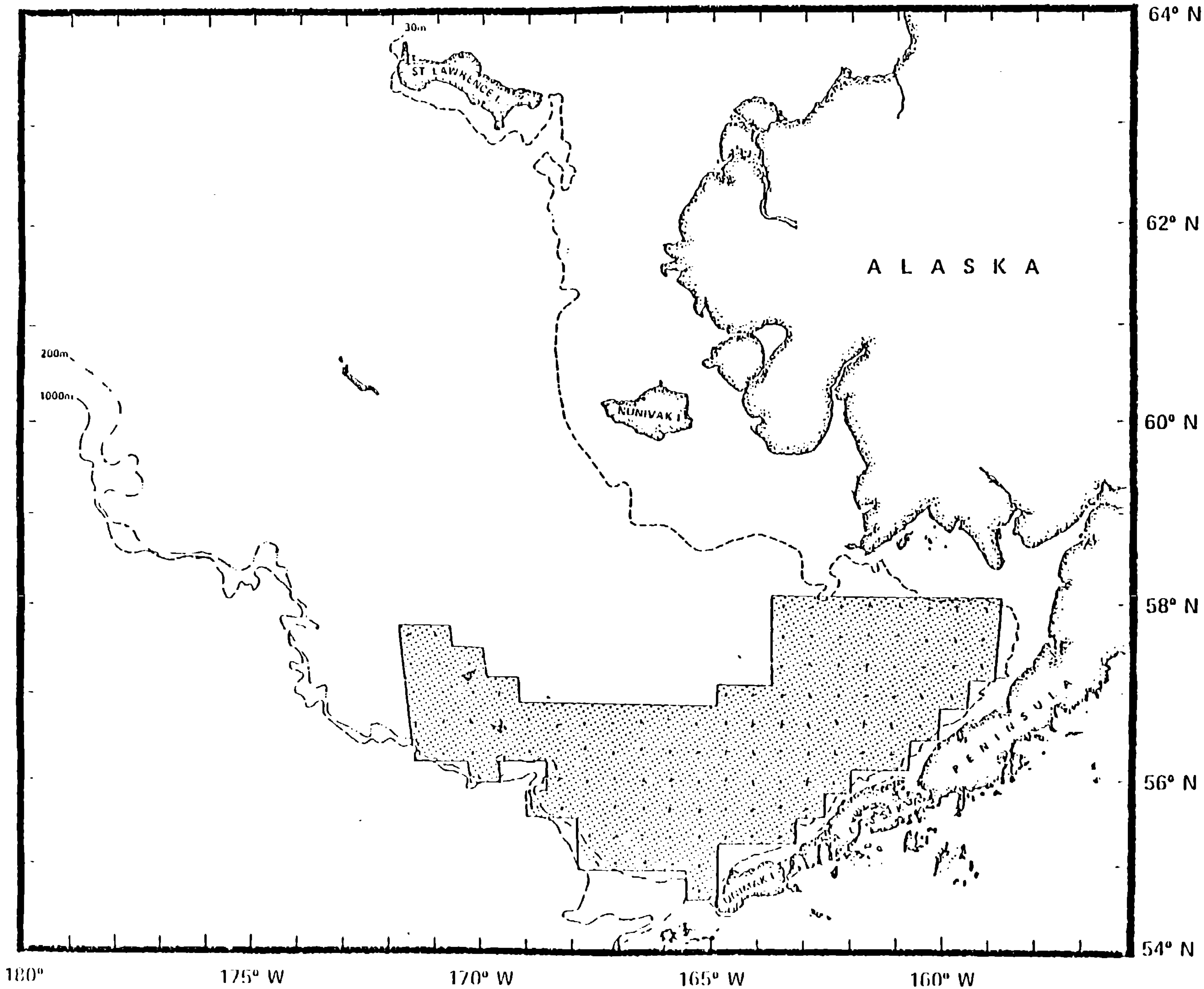

Figure 2.-- Comparative fishing area sampled annually during Northwest and Alaska Fisheries Center demersal trawl surveys in 1973-1986.

Table 2.--Estimates of Pacific cod stock biomass from large-scale NWAFC demersal trawl surveys in the eastern Bering Sea since 1978.

	Biomass	
Year	Mean estimate (t)	95% Confidence intervals (t)
1978	312,000	87,300 - 536,800
1979	792,300	603,200 - 981,400
1980	913,300	795,700 - 1,031,000
1981	840,100	691,700 - 988,400
1982	1,013,900	875,000 - 1,152,800
1983	1,126,400	904,000 - 1,348,800
1984	999,700	872,900 - 1,126,500
1985	957,600	855,500 - 1,059,800
1986	1,134,100	993,400 - 1,274,900

Table 3.--Estimates of Pacific cod stock biomass from demersal trawl surveys in the Aleutian Islands.

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

relatively constant since 1983, with each biomass estimate falling within the range of the other years' confidence intervals. The biomass estimate for 1986 is the highest to date (1,134,100 t).

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 are displayed in Table 3. The estimates from the summer surveys covering the entire Aleutian chain (170 E-165 W) showed a moderate increase (26%) in the mean values between 1980 and 1983, similar to the 23% increase shown by estimates from the eastern Bering Sea in the same period. The 1982 winter survey estimate from the eastern Aleutians (170 W-165 W) exceeds that from the 1980 and 1983 summer surveys for the entire Aleutian region, suggesting that cod may migrate from other areas in winter to spawn in the eastern Aleutian region.

Size and Age Composition

Length-frequency curves are plotted in terms of numbers and weight in Figure 3. These curves illustrate, among other things, the progression of the large 1977 and 1978 year classes through the population age distribution over time. The length-frequency mode representing the 1977 and 1978 year classes provides a means of corroborating possible ageing methodologies.

One method of ageing cod which compares favorably with the evidence provided by the 1977-78 length-frequency mode is the fin ray technique developed by Lai (1985) at the NWAFC. A total of 326 fish from the 1984 survey were aged by this method. It is well known that an age-length key derived from a given year's length-frequency distribution cannot be applied directly to a length-frequency sample taken in another year without biasing the results to some extent (Kimura 1977). Since fin rays were not available for earlier years' samples, the problem of bias was circumvented by utilizing the "iterated age-length key" approach developed by Kimura and Chikuni (in press). Applying the technique of Kimura and Chikuni to the length-frequency data for 1981-85 gave the numbers at age shown in Table 4. It should be stressed that the accuracy of the fin ray technique has not been formally validated; it was used because of its precision and because it produces results that seem to match the evidence provided by the progression of the 1977-78 length-frequency mode.

When translated from numbers at age to biomass at age, the results summarized in Table 4 indicate that the members of the 1977-78 year classes, though reduced in number, still accounted for about 25% of the stock biomass in 1985. Importantly, the gradual disappearance of the 1977-78 year classes from the fishery seems to be coinciding with the recruitment of strong year classes spawned in 1982-54. At ages 2 and 3 in 1985, the 1982-1983 year classes do not appear quite as strong as did the 1977-78 year classes at similar ages, but they still managed to account for about 35% of the stock biomass. Early indications are that the 1984 year class may be stronger than either the 1982 or the 1983 year class, but by 1985 it had not yet contributed significantly to stock biomass.

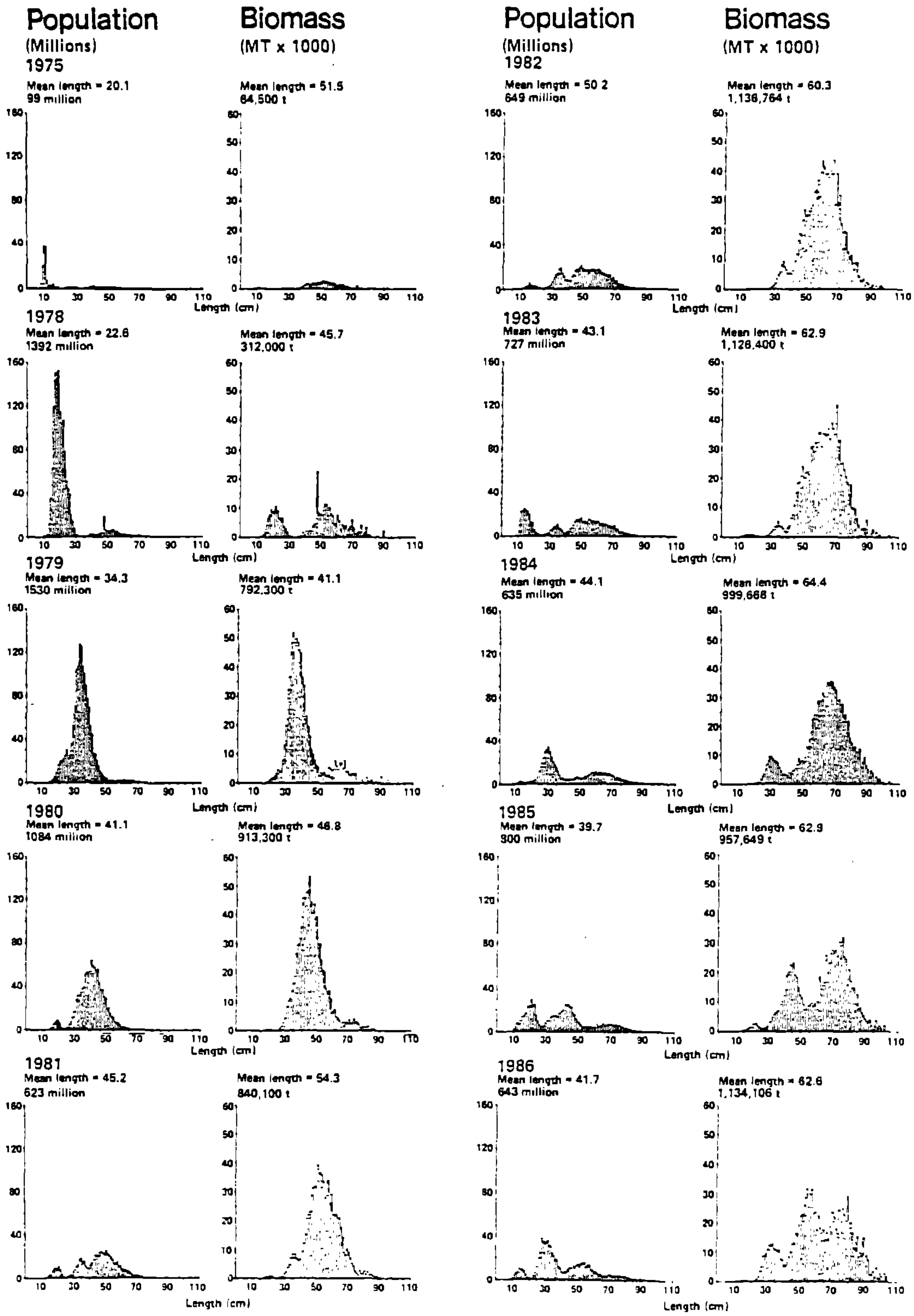

Figure 3.--Population and biomass estimates by centimeter length interval for Pacific cod as shown by NWAFC bottom trawl surveys in 1975-1986.

Table 4 .--Estimated numbers (millions) of Pacific cod at age in 1981-85 based on an iterative application of a 1984 age-length key and annual length-frequency samples from NWAFC surveys in the eastern Bering Sea.

Age	1981	1982	1983	1984	1985
0	0.50	5.65	104.40	9.40	27.52
1	61.43	23.49	106.29	31.05	212.64
2	135.69	136.42	81.06	304.67	193.28
3	229.45	173.61	140.17	58.74	194.40
4	107.47	93.91	77.57	32.45	23.68
5	56.38	98.84	76.92	58.48	19.52
6	22.30	68.01	78.73	71.57	54.24
7	3.74	22.72	38.31	45.40	57.92
8	0.56	2.53	0.36	6.35	3.44
9	5.05	19.99	17.30	9.27	5.44
10+	0.50	3.76	5.96	7.68	7.92
Total	623.07	648.93	727.07	635.06	800.00

Table 5 .--Catches (millions) of Pacific cod at age in 1981-1985 from observer records (trawl catches extrapolated to include all domestic landings).

	Trawl					Longline				
Age	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
2	10.61	2.54	1.01	5.78	2.86	0.08	0.03	0.02	0.20	0.09
3	17.75	6.81	6.86	7.67	15.00	0.99	0.30	0.56	2.53	2.09
4	8.07	5.37	2.96	1.60	2.57	1.21	0.33	0.59	0.94	2.82
5	3.73	8.37	13.38	8.78	4.27	1.28	0.57	0.82	2.98	2.22
6	3.15	14.05	27.51	23.44	23.55	1.14	0.98	1.80	7.71	8.11
7	1.62	8.57	17.70	27.60	35.74	0.76	0.62	1.97	9.02	16.65
8	0.22	0.43	1.30	3.63	4.28	0.12	0.06	0.22	1.04	2.30
9	0.80	3.49	3.92	2.90	2.02	0.19	0.17	0.19	0.92	0.03
10+	0.19	2.26	2.12	2.89	5.70	0.08	0.08	0.27	1.35	2.43
Total	46.14	51.89	76.76	84.29	95.99	5.86	3.14	6.44	26.69	36.74

PROJECTIONS OF ABUNDANCE

Methods

Overview

To help understand how this fishery might best be managed, a computer simulation was developed which modeled the dynamics of both the eastern Bering Sea cod stock and its fishery. In broad terms, the simulation could be classed as an example of catch-age analysis with auxiliary information (Deriso et al., 1985). More specifically, the simulation consisted of three separate programs: 1) an initial value generation (IVG) program, 2) a nonlinear parameter estimation (NPE) program, and 3) a population and fishery projection (PFP) program. The IVG program was used to obtain preliminary estimates of the simulation parameters. These were then used to seed the NPE program, which computed final parameter estimates based on a modified version of the Levenberg-Marquardt algorithm (Levenberg 1944; Marquardt 1963). The final parameter estimates were then used by the PFP program to simulate future numbers-at-age and catch-at-age data for the population.

The population was simulated on a monthly basis. The choice of a monthly time scale was a prudent one, because data collection involved three conceptually distinct 12-month cycles, each of which began in a different calendar month: 1) a biological year, which determined the number of months since each cohort's "birthday" (either the month in which the last annular ring was deposited on the structure used to age the fish, or the month of spawning); 2) a survey year, which determined the number of months since the last survey assessment of the population; and 3) a harvest year, which determined the number of months since the beginning of the current catch reporting period. In the eastern Bering Sea cod fishery, the harvest year is equivalent to the calendar year.

Data and Input Parameter Preparation

The data set was comprised of three subsets, each constituting a time series spanning the years 1981-85: 1) the numbers-at-age data shown in Table 4, 2) length-frequency data from the foreign fishery observer program for both foreign longline and joint venture trawl operations; and 3) catch by month for both foreign and domestic annual harvest (domestic plus joint venture) effort categories from the PacFIN database.

The length-frequency data from the joint venture trawl fleet had to be expanded to encompass catches by domestic operations. It was assumed that the length-frequency distributions for joint venture and domestic trawlers were identical. It was also necessary to convert the length-frequency data from the surveys and the observer records into numbers-at-age estimates. The same technique used to convert the survey length-frequency data into numbers-at-age data (see above) was applied here. The resulting time series of catch-at-age data is shown in Table 5.

Since the monthly catch statistics were measured in terms of weight, it was necessary to convert these data into the equivalent numbers of fish. This was accomplished by adjusting all of the monthly catches for a given year proportionately so that the year total would match the year total shown in the bottom row of Table 5. The adjusted monthly catch statistics are displayed in Table 6.

The input parameters consisted of fishing effort indices by gear and year, and the starting months of the survey and biological years. The effort parameters were taken from foreign fishery observer records. The observer database includes data which deals specifically with foreign longliners targeting on cod. However, to obtain an index of effort for the DAH (domestic annual harvest) trawlers, a more indirect approach was required. This approach made use of the most applicable effort data available, which were the number of boat days fished by all joint venture operations (not just those targeting on cod). The following equation was used to obtain an index of effort for the DAH effort category:

$$E(tr,yr) = C_c(tr,yr)*B(JV,yr)/Ca(JV,yr),$$

where $E(tr,yr)$ = effort by cod trawlers in the given calendar year, $C_c(tr,yr)$ = catch of cod by all trawlers in the given calendar year, $B(JV,yr)$ = boat days by all joint venture operations in the given calendar year, and $C_a(JV,yr)$ = catch of all species by all joint venture operations in the given calendar year. Equation (1) implies that the ratio of cod trawl effort to cod trawl catches is equal to the ratio of all joint venture trawl effort (measured in boat days) to all joint venture catches. The resulting effort levels are shown in Table 7.

July was chosen as the starting month for the survey year, being the approximate mid-point of the survey season. The choice of a starting month for the biological year was based on the understanding that spawning activity is greatest between January and April (Bakkala 1984; Hirschberger and Smith 1983). Within this range, the starting month for the biological year was determined by trial and error; the simulation performed best when February was used as the starting month of the biological year.

Parameter Estimation

Since the simulation was designed to model the actual population, allowance had to be made for the fact that the surveys may tend to assess only part of that population. Such an allowance was made by assuming that the proportion of the actual population covered by the survey is a sigmoid function of age, giving the following description for the population at the time of the survey in each year and at each age:

$$S(yr,ag)/N(yr,ag) = 1/(1 + \exp(c_1 - c_2*ag)),$$

where S = survey population, yr = calendar year, ag = age index (beginning with 1 for age zero), N = actual population, and the c_i are estimated parameters. Use of equation (2) allowed simulated numbers at age to be converted to survey numbers at age.

Given the number of age zero individuals in each year and the numbers at each age in year 1 (1981), the NPE program attempted to reconstruct the three data subsets (survey numbers at age, catch at age by gear, and monthly catch by gear). For each month, population numbers at age were computed as the

Table 6 .--Catches (millions) of Pacific cod by month, converted from PacFIN catches reported in metric tons.

	Trawl					Longline				
Mo.	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
1	0.20	1.50	3.99	1.98	2.70	0.30	0.11	0.17	0.32	0.60
2	3.04	2.27	14.17	8.89	11.77	0.38	0.03	0.32	1.12	5.64
3	2.15	8.47	11.51	21.10	18.37	0.26	0.06	0.44	0.70	0.85
4	2.64	4.59	12.47	16.10	14.92	0.24	0.25	0.61	1.12	1.59
5	5.52	3.79	5.47	3.54	10.33	0.37	0.25	0.50	0.34	1.08
6	10.69	2.69	11.86	3.42	6.31	0.37	0.16	0.45	2.45	0.68
7	3.90	8.47	9.76	7.02	11.73	0.48	0.25	0.62	1.61	1.35
8	7.61	8.01	5.38	5.44	8.66	0.44	0.42	0.54	2.34	2.70
9	7.68	2.10	0.57	6.03	5.66	0.66	0.48	0.47	2.19	2.84
10	1.77	3.48	1.24	2.05	3.89	0.62	0.37	0.41	3.32	6.88
11	0.01	3.92	0.27	3.11	0.76	0.81	0.42	0.69	5.36	6.87
12	0.95	2.61	0.08	5.62	0.88	0.94	0.34	1.24	5.77	5.67
Total	46.16	51.90	76.77	84.30	95.98	5.87	3.14	6.46	26.64	36.75

Table 7 .--Estimates of fishing effort targeting on Pacific cod in the eastern Bering Sea (longline effort is measured in boat days; trawl effort is a dimensionless index).

Year	Longline Effort	Trawl Effort
1981	1206	283
1982	927	399
1983	1012	370
1984	1604	591
1985	1789	851

numbers at age from the previous month times the appropriate survival rate, unless that particular month happened to be the beginning of the biological year, in which case population numbers at age were computed as the numbers at age from the previous month and age times the appropriate survival rate. Also, monthly harvests were computed for each gear and age. Summing catch across months enabled simulated harvests to be compared with observer catch-at-age data, while summing across age enabled comparison with PacFIN monthly catch records.

Since the Levenberg-Marquardt algorithm attempts to minimize the sum of squared deviations from the data, and since the three data subsets differed substantially in terms of both mean value and standard deviation, the NPE program was configured to allow different weights to be assigned to the deviations from the data in each of the three data subsets.

Mortality Rates

The instantaneous rate of total mortality (Z) was computed as the sum of a population-wide instantaneous rate of natural mortality (M) and an instantaneous rate of fishing mortality (F) which was specific to gear (gr), calendar year (yr), age index (ag), and calendar month (mo). This relationship is shown below:

$$Z(gr,yr,ag,mo) = M + F(gr,yr,ag,mo). \tag{3}$$

The fishing mortality rate was in turn equal to the product of four other terms: a gear-specific catchability term (Q), a gear- and year-specific effort term (E), a gear- and age-specific vulnerability term (V), and a gear- and month-specific effort distribution term (D):

$$F(gr,yr,ag,mo) = Q(gr)*E(gr,yr)*V(gr,ag)*D(gr,mo). \tag{4}$$

As described above, effort was an input parameter taken from statistical records, i.e., it was not an output of the NPE program. Catchability was constant for each gear type, and was an estimated parameter. Vulnerability was described by the following gear-specific, sigmoid function of age:

$$v(gr,ag) = 1/(1 + exp(v_1(gr) + v_2(gr)*ag), \tag{5}$$

where the $v_i(gr)$ are estimated parameters.

The distribution of effort over the calendar year was described by the following gear-specific, trigonometric function of time:

$$D(gr,mo) = (1/12) + d_1(gr)*sin(2\pi*(t + d_2(gr)), \tag{6}$$

where the $d_i(gr)$ are estimated parameters, and t = (mo-1)/12.

Initial Value Generation

The IVG program was divided into seven steps, each of which produced an estimate of some parameter or set of parameters that would be needed by the other two programs in the simulation. The first step in the IVG program was to produce an estimate of the instantaneous rate of natural mortality. The estimation procedure was begun by determining the age of maximum survey abundance (A). This was computed by summing survey numbers at age over all years, and finding the age associated with the maximum. Then, an initial estimate of the instantaneous total mortality rate (($\hat{Z}$) was calculated for each year as follows:

$$\hat{Z}(yr) = -\ln\left(\sum_{ag=A}^{10} S(yr+1,ag+1) \Big/ \sum_{ag=A}^{10} S(yr,ag) \right), \tag{7}$$

where 10 is the index of the second-oldest age class (age 9).

The second step in the IVG program was to produce an initial estimate of the instantaneous rate of fishing mortality (F) for each year, as follows:

$$\hat{F}(yr) = \frac{\hat{Z}(yr) * \sum_{gr=1}^{2} \sum_{ag=A}^{10} C(gr,yr,ag)}{\sum_{ag=A}^{10} S(yr,ag) - \sum_{ag=A}^{10} S(yr+1,ag+1)}, \tag{8}$$

where C(gr,yr,ag) = catch subscripted by gear, calendar year, and age index.

The third step in the IVG program was to produce estimates of the parameters defining the survey coverage equation (2). For the purpose of this initial estimation, it was assumed that survey coverage was complete at age A and above. The following equation was then regressed for age indices 1 through A:

$$\ln\left(\frac{N(yr,ag) - S(yr,ag)}{S(yr,ag)} \right) = \hat{c}_1 - \hat{c}_2 * ag \tag{9}$$

where N(yr,ag) = N(yr+1,ag+1)*exp($\hat{F}$ (yr)+M) for ages 1 through A minus one and years 1 through 4.

A similar procedure was used to produce initial estimates of the parameters defining the two commercial vulnerability schedules. First, preliminary gear-, year-, and age-specific exploitation rates (U(gr,yr,ag)) were calculated as follows:

$$U(gr,yr,ag) = C(gr,yr,ag)/N(yr,ag). \tag{10}$$

Next, a search was conducted to find the maximum value of U(gr,yr,ag) for each gear and year (U_{max}(gr,yr)). Finally, the following equation was regressed for all ages:

$$\ln \frac{U_{max}(gr,yr) - U(gr,yr,ag)}{U(gr,yr,ag)} = \hat{v}_1(gr) - \hat{v}_2(gr) * ag. \tag{11}$$

The fifth step in the initial value generation program was to produce initial estimates of the parameters used to define the monthly effort distribution schedule. Monthly catch percentages for each gear (P(gr,mo)) formed the basis of this procedure, and were calculated according to the following equation:

$$P(gr,mo) = \sum_{yr=1}^{5} C(gr,yr,mo) \Big/ \sum_{mo=1}^{12} \sum_{yr=1}^{5} C(gr,yr,mo). \tag{12}$$

A search was then conducted for the minimum and maximum values of P for each gear ($P_{min}(gr)$ and $P_{max}(gr)$, respectively). To avoid any months of negative effort, the $d_1(gr)$ parameter was estimated as follows:

$$\hat{d}_1(gr) = \min(1/12,(P_{max}(gr)-P_{min}(gr))/2). \tag{13}$$

The months corresponding to $P_{min}(gr)$ and $P_{max}(gr)$ were designated $t_{min}(gr)$ and $t_{max}(gr)$, respectively. The $d_2(gr)$ parameter was then estimated by the following equation, which centers the interval between the minimum and maximum of the estimated effort distribution on the interval between $t_{min}(gr)$ and $t_{max}(gr)$:

$$\hat{d}_2(gr) = \frac{4 - t_{max}(gr)}{12} + \frac{abs(t_{dif}(gr))*(abs(t_{dif}(gr))-6)}{t_{dif}(gr)*24}, \tag{14}$$

where $t_{dif}(gr) = t_{max}(gr) - t_{min}(gr)$.

The sixth step in the IVG program was to produce an estimate of catchability for each gear type. This procedure was begun by estimating average vulnerability ($V_{ave}(gr,yr)$) for each gear in years 1 through 6 minus A as follows:

$$V_{ave}(gr,yr) = \left(\sum_{ag=1}^{11} N(yr,ag)*\hat{V}(gr,ag)\right) * \left(\sum_{ag=1}^{11} N(yr,ag)\right). \tag{15}$$

where the $\hat{V}(gr,ag)$ were determined by equation (5) using the parameters estimated by equation (11).

One estimate of catchability (q(gr,yr)) was then obtained for each year (in years 1 through 6 minus A) by solving the exploitation equation as follows:

$$q(gr,yr) = \frac{\hat{Z}(yr)*\sum_{ag=1}^{11} C(gr,yr,ag)}{(1-\exp(-\hat{Z}(yr)))*E(gr,yr)*V_{ave}(gr,yr)*\sum_{ag=1}^{11} N(yr,ag)}. \tag{16}$$

The q(gr,yr) were then averaged across years for each gear type to obtain an estimate of catchability by gear ($\hat{Q}$((gr)).

The seventh and final step in the IVG program was to produce estimates of age zero population numbers in all years. Note that such estimates were obtained for some years prior to estimation of equation (9). The estimates for the remaining years were taken simply to be the average of the existing estimates.

Results

Nonlinear Parameter Estimation

The output from the IVG program was used as input to seed the NPE program. The NPE program basically attempted to find parameter values for equations (2)-(6) which minimized the sum of squared deviations between simulation results and the data (survey numbers at age, catch at age by gear type, and monthly catch by gear type).

The NPE program allowed the user to assign weights to the residuals from each of the three data subsets. The default weight applied to the residuals in each data subset was equal to the ratio of the mean of the survey numbers-at-age data to the mean of that particular data subset. Thus, the default weight for the survey data subset was equal to 1.0, the default weight for the catch-at-age data subset was equal to the mean of the survey data divided by the mean of the catch-at-age data, and the default weight for the monthly catch data subset was equal to the mean of the survey data divided by the mean of the monthly catch data.

A run of the NPE program entailed 600 passes through the data. After making a run, the user could examine the results to see which data subset was being matched least well, and increase the default weight for that subset's residuals in the next run. The criterion chosen for goodness of fit was R^2, calculated as $1 - (Y_i - y)^2 / (Y_i - Y)^2$. Although R^2 may be calculated in a number of equivalent ways for linear models with an intercept, this formulation of R^2 turns out to be the only one which is generally satisfactory for measuring goodness of fit in nonlinear models (Kvalseth 1985).

The program was designed so that the residual weights were adjustable by a user-determined multiple (lambda) of the default value. When the program was run under the default multiples of 1.0, the R^2's for the monthly catch data subset were lower than the R^2's for the other two data subsets. To determine whether the performance of the simulation could be improved, the lambda value associated with the monthly catch data subset was increased in increments of 0.1 during successive runs. Running the program with lambda set at 1.5 for the monthly catch data subset seemed to produce the best results in terms of average R^2. Increasing lambda for the other two data subsets did not increase the average R^2. The parameters obtained from the "best fit" run are summarized below:

Survey coverage by age:

$$S(yr,ag)/N(yr,ag) = 1/(1+\exp(8.4210-3.9327*ag)). \tag{17}$$

Vulnerability by age (trawl gear):

$$V(gr,ag) = 1/(1+\exp(9.9818 - 0.8117*ag)). \tag{18}$$

Vulnerability by age (longline gear):

$$V(gr,ag) = 1/(1+\exp(16.5948 - 1.9996*ag)). \tag{19}$$

Effort distribution by month (trawl gear):

$$D(gr,mo) = (1/12) + 0.0363*\sin(2\pi*(t + 0.0001)). \tag{20}$$

Effort distribution by month (longline gear):

$$D(gr,mo) = (1/12) + 0.0814*\sin(2\pi*(t + 0.4549)). \tag{21}$$

Catchability (trawl gear):

$$Q(gr) = 48.484. \tag{22}$$

Catchability (longline gear):

$$Q(gr) = 0.967. \tag{23}$$

Instantaneous rate of natural mortality:

$$M = 0.220. \tag{24}$$

It should be noted that since the effort indices used for the two gear types were not the same, the two catchability coefficients (equations (22) and (23)) are not strictly comparable. The catchability coefficients could be made somewhat more comparable by standardizing the vulnerability schedules to a value of 1.0 at the maximum age. This could be accomplished by increasing the entire vulnerability schedule proportionately, and decreasing catchability by the same proportion.

It should further be noted that the estimated value of M (equation (24)) is substantially lower than other values previously calculated for the species. For the same stock, Low (1974) estimated that M might range from 0.30 to 0.45, Bakkala and Wespestad (1985) arrived at a figure of 0.45, and Wespestad et al. (1982) set M = 0.70. Ketchen (1964) argued that M for Pacific cod in Hecate Strait, British Columbia, could be as high as 0.99. Thus, while a value of 0.22 produced the best fit in this simulation, such a result should be viewed with caution.

Equations (17)-(24) gave results which matched the input data fairly well. The following R^2 values give some idea of the degree to which the simulation was successful in this regard:

Survey Numbers at age:	$R^2 = 0.8108$
Catch at age (trawl):	$R^2 = 0.7735$
Catch at age (longline):	$R^2 = 0.6342$
Monthly Catch (trawl):	$R^2 = 0.4918$
Monthly Catch (longline):	$R^2 = 0.2969$
Average:	$R^2 = 0.6015$

Tables 8-10 show the results corresponding to the parameters described in equations (17)-(24).

Population and Fishery Projection

The output parameters from the NPE program became the parameters governing the dynamics of the PFP program. In addition to these parameters, the program required 1985 numbers at age as starting values. This initial numbers-at-age vector was obtained by multiplying simulated numbers at age for 1985 (Table 8) by the ratio of 1985 survey abundance (Table 4) to 1985 simulated abundance (Table 8). The PFP program also required estimates of DAH and total allowable catch (TAC) as inputs. Estimates of DAH and total catch for 1986 were obtained by extrapolating catches reported by PacFIN as of 12 August 1986. The extrapolation was based on a regression of the ratio of reported catches to final catches on given dates in 1985. The regression yielded the following equation:

$$PFC = 0.356*day - 16.6, \tag{25}$$

where PFC = percent of final catch, and day = day of the year (1 to 365). On 12 August (day 224), then, the catches reported by PacFIN were estimated to be 63.1% of the final catches for the year. Using this figure to extrapolate the reported PacFIN catches, DAH was projected to reach 105,800 t, and total catch was projected to reach 135,900 t for the year.

The program iterated over varying combinations of effort levels until it found the combination that resulted in both DAH and total catch for 1986 being met. Since the program operates in terms of numbers at age while catch is measured in metric tons, it was necessary to convert numbers at age to weight at age. This was accomplished by using a length-age relationship and a weight-length relationship to obtain the weight of an average fish of given age. The length-age and weight-length equations appeared as shown below:

$$L(age) = 84.008*(1.-\exp(-.203*(age+.806))), \tag{26}$$

and

$$W(L) = 0.00608*L^{3.1635}, \tag{27}$$

Table 8.--Simulated numbers (millions) of Pacific cod at age in the eastern Bering Sea.

Age	1981	1982	1983	1984	1985
0	1.31	5.48	3.05	6.87	0.97
1	38.18	33.47	139.71	77.54	174.42
2	159.23	79.93	70.08	291.58	161.05
3	224.25	130.00	65.25	56.80	233.76
4	162.11	173.64	100.64	49.70	42.21
5	81.35	119.65	128.13	71.54	33.42
6	27.45	53.45	78.64	77.10	37.85
7	4.64	13.15	25.79	30.54	21.90
8	1.65	0.98	2.94	3.50	1.90
9	0.62	0.08	0.06	0.06	0.01
10+	0.09	0.00	0.00	0.00	0.00
Total	700.88	609.83	614.29	665.23	707.49

Table 9.--Simulated catch (millions) of Pacific cod at age in the eastern Bering Sea.

	Trawl					Longline				
Age	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
0	0.16	0.89	0.52	1.69	0.52	0.00	0.00	0.00	0.00	0.00
1	0.36	0.41	1.49	1.49	4.36	0.00	0.00	0.00	0.00	0.00
2	1.25	0.90	0.69	4.27	3.82	0.00	0.00	0.00	0.01	0.01
3	3.61	3.13	1.48	1.94	10.78	0.04	0.02	0.01	0.01	0.06
4	5.76	8.88	5.05	4.07	4.71	0.22	0.19	0.13	0.10	0.09
5	6.43	13.56	13.69	13.03	9.00	0.82	0.94	1.12	1.07	0.57
6	4.82	13.53	18.60	30.24	22.98	1.88	2.86	4.66	7.30	4.25
7	1.91	7.50	13.64	27.45	30.72	1.58	3.22	6.96	12.62	10.12
8	1.68	1.41	3.74	8.49	8.41	1.21	0.50	1.53	2.91	2.00
9	1.65	0.37	0.21	0.60	0.38	0.56	0.06	0.04	0.09	0.05
10+	0.78	0.08	0.01	0.01	0.00	0.09	0.01	0.00	0.00	0.00
Total	28.35	50.66	59.12	93.28	95.68	6.40	7.80	14.45	24.11	17.15

Table 10.--Simulated catch (millions) of Pacific cod by month in the eastern Bering Sea.

	Trawl					Longline				
Mo.	1981	1982	1983	1984	1985	1981	1982	1983	1984	1985
1	1.54	2.47	3.00	5.56	6.39	0.62	0.35	0.70	1.77	1.66
2	3.81	6.52	7.82	13.95	15.42	0.80	0.89	1.70	3.64	3.19
3	3.96	6.98	8.31	14.09	15.01	0.31	0.36	0.69	1.39	1.15
4	3.85	6.90	8.15	13.24	13.66	0.07	0.09	0.17	0.32	0.25
5	3.47	6.28	7.37	11.55	11.60	0.06	0.07	0.13	0.24	0.18
6	2.90	5.28	6.14	9.32	9.17	0.21	0.26	0.49	0.86	0.61
7	2.25	4.12	4.75	7.00	6.78	0.45	0.56	1.06	1.77	1.21
8	1.66	3.06	3.50	5.01	4.80	0.68	0.88	1.64	2.63	1.74
9	1.25	2.31	2.62	3.65	3.47	0.84	1.11	2.04	3.15	2.03
10	1.08	2.00	2.24	3.05	2.89	0.89	1.19	2.18	3.23	2.02
11	1.15	2.14	2.36	3.14	2.97	0.82	1.12	2.02	2.88	1.76
12	1.41	2.61	2.86	3.72	3.51	0.66	0.92	1.64	2.24	1.34
Total	28.33	50.67	59.12	93.28	95.67	6.41	7.80	14.46	24.12	17.14

Table 11.--Projected age distributions (1000's of t) of biomass at time of survey and catch (1987 catch = equilibrium yield) for Pacific cod in the eastern Bering Sea.

	1986		1987	
Age	Biomass	Catch	Biomass	Catch
0	0.1	0.0	0.1	0.1
1	5.9	0.1	19.7	0.6
2	262.1	2.7	37.1	1.2
3	185.9	4.0	419.5	17.7
4	406.1	16.8	225.5	24.6
5	97.3	9.6	401.3	110.3
6	87.2	21.6	69.9	72.6
7	84.6	51.5	26.8	97.6
8	21.9	28.4	4.7	48.6
9	0.4	1.2	0.1	4.4
10+	0.0	0.0	0.0	0.0
Total	1,151.6	135.9	1,204.7	377.7

where L = length in cm, and W = weight in kg. Equation (26) was estimated from the 1984 pooled (male and female) sample using Fabens' (1965) technique. Because the estimation of equation (26) was based on fish ages which were rounded down to the nearest whole number of years, an age correction factor was applied in all subsequent uses of this equation. Equation (27) was obtained by examination of over 3,000 specimens taken between 1975 and 1983.

Application of length-age and weight-length equations to a numbers-at-age distribution tends to underestimate true stock biomass (Pienaar and Ricker 1968). To compensate for this tendency, the following procedure was adopted: First, stock biomass for 1985 was estimated by applying equations (26) and (27) to 1985 numbers at age. Then, equation (27) was multiplied by the ratio of true 1985 biomass to estimated biomass. The resulting equation was then used in all subsequent weight-length computations.

The following results were obtained for the 1986 population and fishery (population numbers and biomass refer to the survey population, not the actual population):

Numbers at time of survey (millions):	880.9
Biomass at time of survey (1000's of t):	1,151.6
Catch in numbers by all gears (millions):	38.4
Catch in biomass by all gears (1000's of t):	135.9

The above estimates of population numbers and biomass compare very favorably to the 1986 survey results. The simulation's projection of population numbers is within 4.5% of the survey estimate of 843.5 million. Likewise, the simulation's projection of population biomass is within 1.5% of the survey estimate of 1,134,100 t.

After projecting the population and fishery through the 1986 calendar year, the program projected the population and fishery through the 1987 calendar year and through the first month of the 1988 calendar year. Generally, the strategy was to impose the highest harvest possible without driving the projected biomass for January 1988 below the projected biomass for January 1987. This was accomplished subject to the constraint that DAH receive priority in harvest allocation. The resulting harvest strategy was considered to be the equilibrium yield for 1987.

The estimate of 1987 DAH was obtained by assuming that the exponential rate of growth observed over 1981-85 (and the 1986 extrapolation) would continue. Regressing DAH against time gave the following equation (R^2 of the linearized equation = 0.98):

$$DAH = 8871 * \exp(0.434 * (year - 1980)). \tag{28}$$

Equation (28) implies that DAH increases by approximately 54% per year, giving a 1987 DAH of 185,100 t. The program iterated over varying combinations of effort until it found the combination that satisfied the following three conditions: 1) 1987 catch was maximized, 2) survey biomass in January of 1988 was maintained at the same level as survey biomass in January of 1987, and 3) DAH priority was preserved without exceeding the projected 1987 DAH capacity of 185,100 t. The following results were obtained:

Numbers at time of survey (millions):	774.9
Biomass at time of survey (1000's of t):	1204.7
Catch in numbers by all gears (millions):	109.3
Catch in biomass by all gears (1000's of t):	377.7

MAXIMUM SUSTAINABLE YIELD

It is apparent that the eastern Bering Sea cod population is subject to wide fluctuations in abundance (Fig. 3). Most data come from a period when the population was either undergoing a rapid increase in abundance or at a high level of abundance. Thus, observations of the population over a range of stable abundances are not available. It is conceivable that the recruitment of the strong 1977-78 year classes has shifted the stock to a new "domain of attraction" (Holling 1973), or that some unknown change in environmental conditions is causing the stock to move toward a new equilibrium state (Thompson et al. 1986). In addition to the difficulty imposed by the recent changes in stock abundance, the situation is further complicated by the fact that the recruits-per-spawner data do not seem to follow any readily identifiable pattern. For these reasons, an attempt to estimate maximum sustainable yield is considered inappropriate at the present time.

EQUILIBRIUM YIELD

Equilibrium yield is usually defined as the annual yield which allows a stock to finish the year at the same level of abundance found at the start of the year. In the simulation described above, however, equilibrium yield entails not just a single catch, but a harvest strategy. This strategy includes a specific mix between trawl and longline catches. Other catch levels by the two gear types, even if they totaled to 377,700 t, might not constitute a true equilibrium yield, because the two gear types exploit the resource in different ways. Another respect in which the equilibrium yield indicated by the simulation entails an entire harvest strategy is that the projected equilibrium yield is predicated on the assumption that the trawl and longline fleets will deploy their effort according to the schedules described by equations (20) and (21).

Including a catch component for the Aleutian Islands area involves some extrapolation, since the simulation is calibrated for the eastern Bering Sea area only. One possible basis for such an extrapolation is the historical trend in catches for the eastern Bering Sea area versus the eastern Bering Sea and Aleutian Islands areas combined. For the years 1981-85, the proportion of the total catch (combined areas) taken from the eastern Bering Sea fits the following equation (R^2 = 0.81):

$$\ln(1-P_{EBs}) = -0.9794 - 0.2513*yr, \qquad (29)$$

where P_{EBS} = proportion of total catch (combined areas) taken from the eastern Bering Sea area, and yr = year-1980.

Solving equation (29) for P_{EBS} in 1987 gives a figure of 0.9353, implying an equilibrium yield for the Aleutian Islands area in 1987 of approximately 25,000 t, or a total equilibrium yield of approximately 400,000 t for the combined areas. It should be noted that the Aleutian Islands extrapolation is fairly rudimentary, since it is not based on any biological understanding of the stock other than total catch.

Compared to past catch levels, the projected equilibrium yield is notably high. The reason for the high equilibrium yield projection lies in the projected growth of the 1982-84 year classes and the concentration of the fishery on the older year classes. Table 11 displays projected age distributions of biomass and catch for 1986-87, assuming that 1986 catches follow the projections obtained from equation (25) and that 1987 catch follows the equilibrium yield strategy. The projected age distributions for 1987 show that over 92% of the stock biomass at the time of the survey will be concentrated in ages 0-5, while over 59% of the year's catch will come from ages 6 and older. Largely unaffected by harvest mortality, the 1982-84 year classes decrease by less than 23% in terms of numbers while increasing by over 22% in terms of biomass.

Although projected equilibrium yield is relatively high, actual 1987 catches may end up being considerably lower. Given that the actual catch for the region has consistently been less than total allowable catch in recent years, and given that the projected equilibrium yield is more than twice as high as the 1985 record catch, it appears unlikely that the 1987 catch will reach equilibrium yield. The portion of equilibrium yield which the simulation allocates to the longline fleet may be particularly difficult to realize, since it would represent more than a seven-fold increase over the projected 1986 catch. The trawl fleet may be more likely to reach its share of equilibrium yield, since its projected harvest capacity is based on a simple extrapolation of past catch levels.

YELLOWFIN SOLE

by

Richard G. Bakkala and Vidar G. Wespestad

INTRODUCTION

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

CONDITION OF STOCK

Catch Statistics

Following a period of intense exploitation in 1959-62, when catches averaged 404,000 metric tons (t) annually, catches declined, particularly in the 1972-77 period (ranging from 42,000 to 78,000 t). This decline was due primarily to the absence of a directed fishery for yellowfin sole by the U.S.S.R. (Table 1). With the resumption of the U.S.S.R. fishery in 1978 and 1979 and the initiation of joint venture and directed Republic of Korea (R.O.K.) fisheries for yellowfin sole in 1980, catches increased to a range of 87,000 to 138,000 t in 1978-83. Catches since 1983 have again increased reaching 227,000 t in 1985, the highest catch since 1962.

Relative Abundance

The two sources of information used to examine trends in relative abundance for yellowfin sole are pair trawl data from the Japanese commercial fishery and survey data from Northwest and Alaska Fisheries Center (NWAFC) resource assessment surveys. The pair trawl catch and effort data used are from 0.5° 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.

From 1969 to 1976 the Japanese commercial fishery for yellowfin sole operated mainly in the months of October-March, but since then operations have shifted to summer and fall months. Catch per unit of effort (CPUE) values

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	U.S.S.R.	R.O.K.[b]	Others	Joint venture	Total
1954	12,562					12,562
1955	14,690					14,690
1956	24,697					24,697
1957	24,145					24,145
1958	39,153	5,000				44,153
1959	123,121	62,200				185,321
1960	360,103	96,000				456,103
1961	399,542	154,200				553,742
1962	281,103	139,600				420,703
1963	20,504	65,306				85,810
1964	48,880	62,297				111,177
1965	26,039	27,771				53,810
1966	45,423	56,930				102,353
1967	60,429	101,799				162,228
1968	40,834	43,355	-			84,189
1969	81,449	85,685	-			167,134
1970	59,851	73,228	-			133,079
1971	82,179	78,220	-			160,399
1972	34,846	13,010	-			47,856
1973	75,724	2,516	-			78,240
1974	37,947	4,288	-			42,235
1975	59,715	4,975	-			64,690
1976	52,688	2,908	625			56,221
1977	58,090	283	-			58,373
1978	62,064	76,300	69			138,433
1979	56,824	40,271	1,919	3		99,017
1980	61,295	6	16,198	269	9,623	87,391
1981	63,961		17,179	115	16,046	97,301
1982	68,009		10,277	45	17,381	95,712
1983	64,824		21,050		22,511	108,385
1984	83,909	7,951	34,855	47	32,764	159,526
1985	59,460	8,205	33,041		126,401	227,107

[a]Sources of catch data: 1954-76, Hakabayashi and Bakkala 1978; 1977-79, data submitted to the United States by fishing nations; 1980-84, French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986.
[b]Republic of Korea.

were originally calculated for the October-March period, but because of the seasonal changes in the fishery, they have been calculated for the September December and July-October periods. The trends shown by the October-March and September-December data were similar (Bakkala and Wespestad 1986).

The catch per unit of effort (CPUE) trend lines from the 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, Table 2). 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. The decline in CPUE between 1979-80 and 1983 from the Japanese pair trawl data is not believed to be representative of the actual abundance trend during this period in view of the increases in abundance shown by surveys and a cohort analysis that will be discussed later in this report.

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

The NWAFC survey data also showed a major increase in abundance of yellowfin sole during the late 1970s (Fig. 1). The CPUE values from these comprehensive surveys showed an approximate doubling of relative abundance (21-40 kg/ha) from 1975 to 1979. There was an apparent leveling off of abundance in 1980, but CPUE values showed further apparent substantial increases through 1983. The increases between 1981 and 1982 (51.5 to 70.4 kg/ha) and between 1982 and 1983 (70.4 to 84.1 kg/ha) were extremely large and unreasonable considering the slow growth and long life span of yellowfin sole. These apparent large increases were followed by unreasonably large decreases in CPUE which declined from 84.1 kg/ha in 1983 to 71.4 kg/ha in 1984 and to 49.0 kg/ha in 1985. The 1986 value was lower still at 40.2 kg/ha.

Abundance estimates from the 1982 survey were considerably higher than those from the 1981 survey for a number of flatfish. In addition to yellowfin sole, substantial increases were shown for Pacific halibut, Hippoglossus stenolepis; flathead sole, Hippoglossoides elassodon; rock sole, Lepidopsetta bilineata; and Alaska plaice, Pleuronectes quadrituberculatus. The reason for these major increases in CPUE, which were so large for some species that they cannot be accounted for biologically, is believed to be a change in

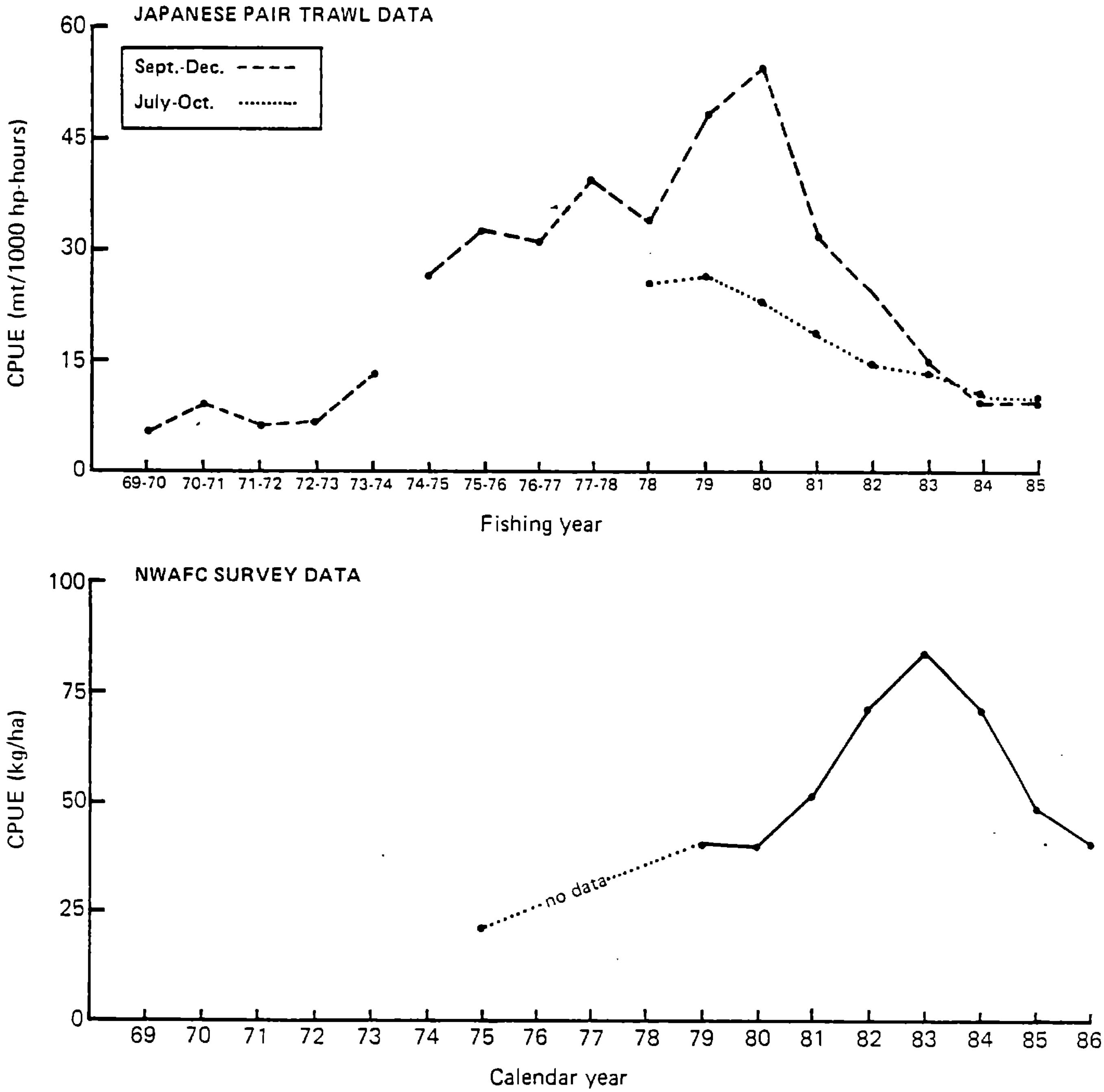

Figure 1 .--Catch per unit of effort (CPUE) of yellowfin sole in the eastern Bering Sea as shown by Japanese pair trawl data and by Northwest and Alaska Fisheries Center (NWAFC) survey data. Breaks in trend lines indicate changes in fishing gear or fishing techniques (see text).

Table 2.--Catch, effort, and catch per unit of effort (CPUE) for yellowfin sole by Japanese pair trawlers in 0.5° lat. by 1° long. statistical blocks and months in which yellowfin sole made up 50% or more of the total catch of groundfish.

Period	Fishing year	Catch (t)	Hours	Average hp	Thousands of hp hours	CPUE (t/thousand hp hours)
Sept.- Dec.	1969	7,009	1,051	1,200	1,261	5.56
	1970	11,768	1,052	1,200	1,262	9.32
	1971	23,447	2,546	1,400	3,564	6.58
	1972	15,978	1,666	1,400	2,332	6.85
	1973	19,291	1,059	1,400	1,483	13.01
	1974	20,911	563	1,400	788	26.54
	1975	25,825	566	1,400	792	32.61
	1976	22,243	517	1,400	724	30.72
	1977	26,407	476	1,400	666	39.65
	1978	21,692	458	1,400	641	33.84
	1979	16,088	238	1,400	333	48.31
	1980	13,231	174	1,400	244	54.23
	1981	19,658	440	1,400	616	31.91
	1982	21,993	648	1,400	907	24.25
	1983	17,390	868	1,400	1,215	14.31
	1984	13,926	1,112	1,400	1,557	8.94
	1985	14,525	1,138	1,400	1,593	9.12
July- Oct.	1978	22,373	631	1,400	883	25.34
	1979	30,619	826	1,400	1,156	26.49
	1980	30,330	950	1,400	1,330	22.80
	1981	29,717	1,155	1,400	1,617	18.38
	1982	27,855	1,411	1,400	1,975	14.10
	1983	28,936	1,594	1,400	2,232	12.96
	1984	28,202	2,054	1,400	2,876	9.81
	1985	25,860	2,037	1,400	2,852	9.07

the standard trawls used during the surveys. The 400-mesh eastern trawl was the standard trawl used by most survey vessels until 1981, but due to the increasing size of survey vessels in recent years, it has been necessary to adopt a larger trawl. The new standard trawl with an 83-ft footrope and 112-ft headrope is a larger version of the 400-mesh eastern trawl. Prior to the beginning of the 1982 survey, test fishing operations were conducted in the Bering Sea to assure that the footrope of the new trawl was in contact with the bottom. As a consequence of these studies, the 83-112 trawl was rigged differently than in the past. Dandylines were changed from a single 25-fathom (46 m) section branching into two 15-fathom (27 m) bridles for an overall length of 40-fathoms (73 m) to two 30-fathom (55 m) double dandylines. In addition, 24-in (61 cm) chain extensions were attached between each end of the footrope and the lower dandyline to improve bottom contact of the footrope. The new rigging was assumed to result in good contact with the bottom because substantial amounts of bottom debris were observed in catches.

Even though the new 83-112 trawl has been used during all subsequent surveys, abundance estimates have continued to fluctuate widely as described above. The reason for these wide fluctuations is not now apparent. However, cohort analyses are used later to evaluate the survey abundance trends. In addition, trawling experiments are planned in which catch rates from the standard rigged trawl will be compared with those from a trawl attached directly to the otter doors to investigate possible herding of flatfish by the dandylines.

Age Composition

The primary reason for the increased abundance of yellowfin sole since the early 1970's has been the recruitment of strong year classes. Initial increases in abundance were from the strong 1966-70 year classes which were the principal ages in commercial catches until the early 1980's (Fig. 2). These year classes are now relatively old, but the 1969 and 1970 year classes at age 14 and 15 still contributed substantially to commercial catches, as late as 1984.

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

The 1981 to 1985 age data show substantial fluctuations in abundance of given year classes even after they were fully recruited to the survey trawls (Fig. 2). These fluctuations are a reflection of the unreasonable variation in abundance of yellowfin sole during this period that was discussed earlier. Another anomaly in the 1982 and 1983 data is the indication that the 1971 and 1972 year classes are relatively strong; previous age data had consistently shown these year classes to be weaker than adjacent year classes. However, the 1971 and 1972 year classes were also relatively abundant in commercial catches in 1981-84. The reason for the change in the apparent strength of the 1971 and 1972 year classes is unknown, but may reflect some error in ageing or delayed recruitment of these year classes to the survey area.

The 1985 survey age data shows that the 1973-77 year classes now form the core of the population. These year classes, which began to contribute heavily to the fishery in 1983 and 1984, should support the fishery over the next few years. The 1985 survey age data show no obvious signs of more recent

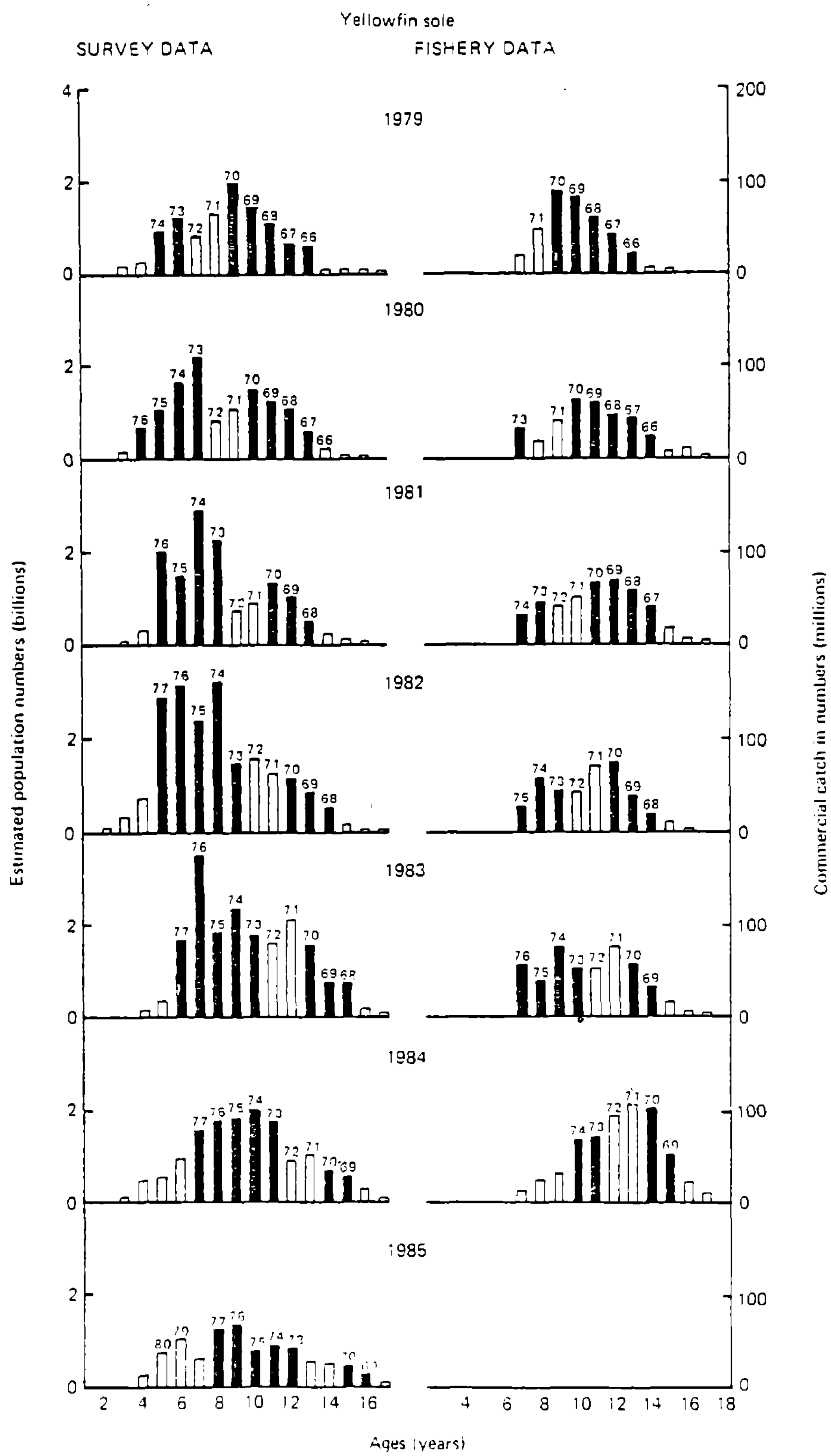

Figure 2.--Age composition of yellowfin sole of the eastern Bering Sea as shown by Northwest and Alaska Fisheries Center survey data and U.S. observer data from the commercial fishery. Year classes for more abundant ages are shown above the appropriate bars, and darkened bars represent stronger than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

exceptionally strong year classes, but the strength of the later year classes will become clearer as they more fully recruit to the survey trawls.

Biomass Estimates

Survey Based Estimates

Biomass estimates from NWAFC surveys and 95% confidence intervals around the mean estimates are given in Table 3. The estimates show an approximate doubling of the biomass between 1975 and 1979 with a further increase to 2.4 million t in 1981. Following 1981, the estimates increased sharply to 3.9 million t in 1983 and then decreased just as sharply to 2.3 million t in 1985. There was a more moderate decline between 1985 and 1986 to 1.9 million t. AS discussed previously, the fluctuations in abundance shown by the survey data between 1981 and 1985 are unreasonable considering the long life span and slow growth of this species. The reason for these wide fluctuations in abundance estimates is not apparent, but in the following section cohort analysis is used to evaluate the survey results.

Cohort Based Estimates

Cohort analyses have previously been carried out for eastern Bering Sea yellowfin sole by Wakabayashi (1975), Wakabayashi et al. (1977), and Bakkala et al. (1982). This latter analysis has been updated through 1984 for this report. The updated cohort analysis and data preparation followed the procedures described in Bakkala et al. (1981), Bakkala et al. (1982), and Bakkala and Wespestad (1984). A natural mortality (M) estimate of 0.12 was employed since this value was found by Bakkala et al. (1981), to best describe the observed trends of the yellowfin sole population. The F values in the terminal year (1985) were tuned in two steps. First F's were iteratively adjusted until the relative age composition of the estimated population in the terminal year (1985) was the same as the 1985 groundfish survey relative age composition. Next, the terminal F values were adjusted until the change in total numbers was the same percentage change as the fishery CPUE between 1981 (the terminal year of the last analysis) and 1985. The F values for the terminal age in years prior to 1985 were computed as the average of ages 14-16 under the assumption that selectivities were the same for these ages. The F values for the terminal and earlier ages (ages 7-17) are shown in Table 4. Age 7 was chosen as the starting age because it is the youngest age to be fully recruited to the groundfish survey. Yellowfin sole of this age are taken in the fishery, but full recruitment to the fishery does not occur until about age 10.

The trend in abundance shown by the cohort analysis during the late 1970's is similar to that shown by the NWAFC survey data indicating a major increase between the middle and late 1970's (Table 5). During the 1980's the trends in abundance shown by the two methods have been similar, but the magnitude of the estimates (in million t) differed substantially in 1982-84 as shown below:

Year	1979	1980	1981	1982	1983	1984	1985	1986
Biomass from survey data	1.866	1.842	2.395	3.275	3.911	3.320	2.277	1.868
Biomass from cohort analysis	1.613	1.797	2.007	2.149	2.214	2.035	-	

Table 3.--Estimated biomass of yellowfin sole in the eastern Bering Sea based on Northwest and Alaska Fisheries Center resource assessment surveys[a].

Year	Mean estimates (t)	95% Confidence intervals (t)
1975	972,500	812,300 - 1,132,700
1979	1,866,500	1,586,000 - 2,147,100
1980	1,842,400	1,553,200 - 2,131,700
1981	2,394,700	2,072,900 - 2,716,500
1982	3,275,400	2,733,600 - 3,817,100
1983	3,910,600	3,447,800 - 4,373,300
1984	3,320,300	2,929,800 - 3,710,800
1985	2,277,400	2,003,000 - 2,551,900
1986	1,868,100	1,587,000 - 2,149,300

[a]Estimates are from the sampling area shown in Figure 1 of the section of this report on walleye pollock. Note that these values differ slightly from those in previous "condition of groundfish resources" reports as explained in the walleye pollock section of this report.

Table 4.--Estimates of fishing mortality (F) by age for yellowfin sole of the eastern Bering Sea, 1976-84.

Age (yr)	1976	1977	1978	1979	1980	1981	1982	1983	1984
7	0.0106	0.0086	0.0297	0.0125	0.0163	0.0133	0.0142	0.0449	0.0000
8	0.0195	0.0209	0.0714	0.0255	0.0137	0.0262	0.0290	0.0232	0.0245
9	0.0592	0.0281	0.0656	0.0585	0.0246	0.0334	0.0297	0.0438	0.0230
10	0.0771	0.0625	0.0921	0.0574	0.0498	0.0358	0.0394	0.0411	0.0480
11	0.1392	0.0817	0.1137	0.0705	0.0500	0.0623	0.0584	0.0592	0.0660
12	0.0644	0.1093	0.0805	0.0604	0.0663	0.0696	0.0843	0.0760	0.1290
13	0.1480	0.0437	0.1958	0.0573	0.0683	0.0994	0.0467	0.0796	0.1330
14	0.0409	0.0648	0.1401	0.0838	0.0697	0.0787	0.0414	0.0449	0.1800
15	0.3377	0.0607	0.1248	0.0580	0.1074	0.0670	0.0241	0.0399	0.0950
16	0.2318	0.0628	0.0909	0.0528	0.1820	0.1047	0.0114	0.0139	0.0680
17	0.2300	0.0630	0.0900	0.0530	0.1820	0.1036	0.0100	0.0140	0.0350

Table 5.--Estimated numbers and biomass of yellowfin sole (for ages fully recruited to survey trawls) in the eastern Bering Sea, 1976-84, based on cohort analysis.

Age (yr)	1976	1977	1978	1979	1980	1981	1982	1983	1984
Numbers (billions)									
7	2.494	2.307	2.425	1.763	2.171	2.496	2.095	1.360	0.000
8	1.574	2.189	2.029	2.088	1.544	1.895	2.185	1.832	1.154
9	1.480	1.369	1.901	1.675	1.805	1.351	1.637	1.882	1.588
10	0.796	1.237	1.180	1.579	1.401	1.562	1.159	1.409	1.598
11	0.210	0.653	1.031	0.955	1.322	1.183	1.337	0.988	1.200
12	0.141	0.162	0.534	0.816	0.789	1.116	0.985	1.118	0.826
13	0.064	0.118	0.129	0.437	0.681	0.655	0.923	0.803	0.919
14	0.046	0.049	0.100	0.094	0.366	0.564	0.526	0.781	0.658
15	0.016	0.039	0.041	0.077	0.077	0.303	0.463	0.448	0.662
16	0.006	0.010	0.033	0.032	0.064	0.061	0.251	0.401	0.381
17	0.002	0.004	0.008	0.027	0.027	0.048	0.049	0.220	0.350
Total	6.830	8.138	9.410	9.542	10.249	11.233	11.609	11.244	9.336
Biomass (1,000 t)									
7	279.	258.	272.	197.	243.	280.	235.	152.	0.
8	212.	295.	274.	282.	208.	256.	295.	247.	156.
9	235.	218.	302.	266.	287.	215.	260.	299.	252.
10	147.	229.	218.	292.	259.	289.	214.	261.	296.
11	44.	137.	216.	201.	278.	248.	281.	208.	252.
12	33.	38.	124.	189.	183.	259.	229.	259.	192.
13	17.	31.	34.	115.	180.	173.	244.	212.	243.
14	13.	14.	28.	26.	103.	159.	148.	220.	185.
15	5.	12.	12.	23.	23.	90.	137.	132.	196.
16	2.	4.	12.	11.	23.	22.	90.	143.	136.
17	1.	2.	3.	10.	10.	17.	18.	80.	128.
Total	989.	1237.	1495.	1613.	1797.	2007.	2149.	2214.	2035.

The estimates are not directly comparable because results from cohort analysis are for ages 7-17 while younger ages are partially recruited to the survey gear. Estimates from the survey data and cohort analysis were similar in 1979, 1980, and 1981, but the survey results diverged from the cohort analysis estimates in 1982-84. The estimates from cohort analysis in this latter period. appear much more reasonable than those from survey data. Both series of estimates declined after reaching peaks in 1983 suggesting that the abundance of yellowfin sole is now declining after a long period of increase that began in the early 1970's. The survey estimates in 1985 and 1986, which appear compatible with the trend in abundance shown by the cohort analysis, indicate that the biomass of yellowfin sole is still high and has declined only moderately from the peak level of 2.2 million t in 1983 shown by cohort analysis.

MAXIMUM SUSTAINABLE YIELD

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

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

ACCEPTABLE BIOLOGICAL CATCH

Wakabayashi (1985) has estimated equilibrium yield (EY) for yellowfin sole from a yield per recruit analysis using age specific values of selectivity by the fishery and assuming that the fishing mortality coefficient which maintains the parent stock at one-half the level of the stock prior to the onset of fishing is the optimum fishing mortality coefficient (F_{opt}) that will ensure an adequate number of parents and recruits. The expected EY from this analysis for various values of natural mortality (M) and two levels of recruitment are as follows:

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

Based on this analysis, Wakabayashi (1985) estimated EY to be at least 230,000 t through the mid-1980's based on the strong recruitment of the 1973-77 year classes.

Cohort analysis indicates that the exploitable biomass of yellowfin sole, after a long period of increase, reached a peak of 2.21 million t in 1983. Based on NWAFC survey data, the biomass has declined to 1.87 million t since then. These estimates indicate that abundance is still high and has only declined moderately from the observed historic high in 1983 and remains well above the levels of the early and mid-1970's. The decline in abundance of yellowfin sole is expected to continue, but based on the present age structure of the population the decline will be slow.

In estimating acceptable biological catches (ABC) in previous years, a 10% exploitation rate has been used which is compatible with, although somewhat conservative in relation to, the exploitation rate (12-14%) derived from yield per recruit analysis. Applying the 10% exploitation rate to the 1986 survey biomass estimate produces an ABC value of 187,000 t.

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GREENLAND TURBOT AND ARROWTOOTH FLOUNDER

by

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

INTRODUCTION

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

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

The Japanese fishery that has targeted on turbot is distinct from other flatfish fisheries since commercial concentrations of older juveniles and adult turbot are located on the continental slope and generally segregated from other flatfish. The turbots have therefore been managed as an independent unit. The Japanese mothership-North Pacific trawl fishery has often accounted for more than one-half of the catch of turbot (Table 1), presumably as an incidental part of the target fishery for walleye pollock, *Theragra chalcogramma*, and other species. A large part of these incidental catches of turbot are assumed to come from waters on the continental shelf and consist primarily of juvenile fish. The overall fishery, therefore, takes both juvenile and adult turbot.

Following a long period of relatively small catches in the eastern Bering Sea and Aleutian Islands region during the 1960's, catches of turbot increased, reaching an all-time high of approximately 103,000 t in 1974 (Table 1). Catches then declined but still ranged between 61,500 and 74,400 t in 1980-83. Catches, however, have since dropped to 22,100 t in 1985, due in part to catch restrictions placed on the fishery because of evidence of declining recruitment to the exploitable stock.

Greenland turbot has been the target species of the turbot fishery; arrowtooth flounder are only taken incidentally. Since 1970 Greenland turbot have usually represented more than 70% of the combined catch of the two species (Table 1).

Table 1 .-- All nation catches (t) of arrowtooth Flounder and Greenland turbot, 1960-85[a].

	Eastern Bering Sea (east of long. 180°)							Aleutian Islands area							E. Bering Sea and Aleutians
	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	comb. total
Arrowtooth Flounder and Greenland Turbot Combined															
1960	36,843	-	-				36,843	-	-	-				-	36,843
1961	57,348	-	-				57,348	-	-	-				-	57,348
1962	58,226	-	-				58,226	-	-	-				-	58,226
1963	31,565	-	-				31,565	-	7	-				7	31,572
1964	33,726	3	-				33,729	475	29	-				504	34,233
1965	7,648	299	1,800				9,747	299	1	-				300	10,047
1966	10,752	90	2,200				13,042	63	0	-	-			63	13,105
1967	20,574	656	2,639	-			23,869	167	227	-				394	24,263
1968	17,702	2,278	15,252	-			35,232	106	107	-	-			213	35,445
1969	13,525	5,706	16,798	-			36,029	51	177	-	-			228	36,257
1970	14,212	9,857	8,220	-			32,289	278	281	-	-			559	32,848
1971	29,313	12,483	17,460	-			59,256	1,329	1,002	-	-			2,331	61,587
1972	25,949	27,687	23,998	-			77,633	900	13,030	267	-			14,197	91,831
1973	31,082	17,201	16,214	-			64,497	1,478	10,531	362	-			12,371	76,868
1974	38,824	22,833	29,470	-	-		91,127	2,281	9,663	39	-	-		11,983	103,110
1975	32,382	21,484	31,785	-	-		85,651	926	2,685	143	-	-		3,754	89,405
1976	34,221	19,109	24,999	-	-		78,329	933	2,392	112	-	-		3,437	81,766
1977	16,375	15,454	5,333	-	-		37,162	640	3,824	24	-	-		4,488	41,650
1978	21,299	20,244	4,119	119	-		45,781	1,182	5,363	2	1	-		6,548	52,329
1979	24,492	14,885	1,574	1,948	20		42,919	1,227	11,620	0	0	-		12,847	55,766
1980	-	-	-	-	-		62,618	-	-	-	-	-	-	8,299	70,917
1981	-	-	-	-	-		66,394	-	-	-	-	-	-	8,040	74,434
1982	-	-	-	-	-		54,908	-	-	-	-	-	-	8,732	63,640
1983	-	-	-	-	-		53,659	-	-	-	-	-	-	7,869	61,528
1984	-	-	-	-	-		29,294	-	-	-	-	-	-	3,275	32,569
1985	-	-	-	-	-		21,986	-	-	-	-	-	-	104	22,090

Table 1.--Continued.

	Eastern Bering Sea (east of long. 180°)							Aleutian Islands area						
	Japan							Japan						E. Bering
					Other	Joint						Joint		Sea and
Year	MS-LG-NPT[b]	LBD[c]	USSR	ROK[d]	nations[e]	ventures[f]	Total	MS-LG-NPT	LBD	USSR	ROK	ventures	Total	Aleutians
Arrowtooth Flounder														
1970	9,047	307	3,244	-			12,598	274	0	-	-		274	12,872
1971	6,235	5,368	7,189	-			18,792	44	537	-	-		581	19,373
1972	1,261	2,562	9,300	-			13,123	194	1,023	106	-		1,323	14,446
1973	1,915	3,014	4,288	-			9,217	483	3,199	23	-		3,705	12,922
1974	1,221	1,602	18,650	-	-		21,473	1,378	1,817	0	-		3,195	24,668
1975	330	911	19,591	-	-		20,832	115	526	143	-		784	21,616
1976	139	1,535	16,132	-	-		17,806	96	1,274	-	-		1,370	19,176
1977	4,000	2,160	3,294	-	-		9,454	158	1,857	20	-		2,035	11,489
1978	4,598	1,093	2,576	91	-		8,358	524	1,256	2	0		1,782	10,140
1979	4,122	1,166	948	1,680	5		7,921	371	6,065	0	0		6,436	14,357
1980	-	-	-	-	-	-	13,762	-	-	-	-	-	4,603	18,365
1981	-	-	-	-	-	-	13,473	-	-	-	-	-	3,640	17,113
1982	-	-		-	-	-	9,103	-	-	-	-	-	2,415	11,518
1983	-	-	-	-	-	-	10,217	-	-	-	-	-	3,753	13,970
1984	-	-	-	-	-	-	7,977						1,472	9,449
1985	-	-	-	-	-	-	7,289	-	-	-	-	-	70	7,359
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	-		2,874	77,384
1973	29,167	14,187	11,926	-			55,280	995	7,332	339	-		8,666	63,946
1974	37,603	21,231	10,820	-	-		69,654	903	7,846	39	-		8,788	78,442
1975	32,052	20,573	12,194	-	-		64,819	811	2,159	0	-		2,970	67,789
1976	34,082	17,574	8,867	-	-		60,523	837	1,118	112	-		2,067	62,590
1977	12,375	13,294	2,039	-	-		27,708	482	1,967	4	-		2,453	30,161
1978	16,701	19,151	1,543	28	-		37,423	658	4,107	0	1		4,766	42,189
1979	20,370	13,719	626	268	15		34,998	856	5,555	0	0		6,411	41,409
1980	-	-	-	-	-	-	48,856	-	-	-	-	-	3,696	52,552
1981	-	-	-	-	-	-	52,921	-	-	-	-	-	4,400	57,321
1982	-	-	-	-	-	-	45,805	-	-	-	-	-	6,317	52,122
1983	-	-	-	-	-	-	43,442	-	-	-	-	-	4,116	47,558
1984	-	-	-	-	-	-	21,317	-	-	-	-	-	1,803	23,120
1985	-	-	-	-	-	-	14,698	-	-	-	-	-	33	14,731

[a]Sources of data: 1960-76, Wakabayashl and Bakkala 1978; 1977-79, data submitted to United States by fishing nations; 1980-84, French et al. 1981, 1982; Nelson et al. 1983a; 1984; Berger et al. 1985b, 1986.
[b]Hothership, North Pacific longline, and North Pacific trawl fisheries combined.
[c]Landbased dragnet trawl fishery.
[d]Republic of Korea. [e]Taiwan, Poland, and Federal Republic of Germany.
[f]Joint ventures between U.S. fishing vessels and foreign processing vessels.

As mentioned earlier, the two species of turbot have been managed as a complex. However, because of marked differences in the condition of the two species in recent years, management starting in 1986 will be by individual species. To conform with this management policy, the condition of these resources are discussed individually.

CONDITION OF STOCKS

Greenland Turbot

Relative Abundance

Two sources of data have been used to examine trends in relative abundance of Greenland turbot: catch and effort data reported by the Japanese from their landbased dragnet fishery, and data from Northwest and Alaska Fisheries Center (NWAFC) research vessel surveys. The Japanese landbased stern trawlers have targeted Greenland turbot, and these data may provide reasonably good indices of abundance for older juveniles and adults of this species in continental slope waters.

The landbased dragnet fishery data come from west of 170°W because this fleet is not allowed to fish east of 170°W longitude by Japanese fishery regulations. Greenland turbot catch and effort data from the landbased fishery were analyzed by statistical blocks measuring 0.5° latitude and 1° longitude and by months in which Greenland turbot comprised 50% or more of the overall reported catch. This method is assumed to be a fairly accurate reflection of abundance trends of the slope population, since it is based on effort targeting on Greenland turbot.

Starting with last year's condition of resources report (Bakkala et al. 1986a), catch and effort data were also examined from the entire eastern Bering Sea slope region (>184 m) by incorporating data from small trawlers of other Japanese fleets that fished in waters both east and west of 170°W longitude. Data collected by U.S. observers aboard the small trawlers during the months of May-August were selected because the fishery in 1984 and 1985 were mainly restricted to these months. In this latter analysis, all catch and effort data were used regardless of the proportion of Greenland turbot in the catches.

The NWAFC research vessel surveys have been limited to continental shelf waters in most years and essentially sample only the juvenile portion of the population. The 1979, 1981, 1982, and 1985 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.

Relative abundance values from NWAFC shelf surveys in 1975 and 1979-86 (the survey area is shown in Figure 1 of the section of this report on walleye pollock) reflected relatively stable abundance of young juvenile Greenland turbot between 1975 and 1980 and then a marked decline, with CPUE falling from 2.7 kg/ha in 1980 to 0.1 kg/ha in 1986 (Fig. 1). These CPUE values mainly represent the abundance of young age 1-3 year juvenile Greenland turbot. When the abundance of these juveniles is shown by 5 cm length intervals (Fig. 2) the data demonstrate that recruitment of age 1 Greenland turbot (fish about 15 cm and smaller) declined sharply between 1979 and 1982 and has remained at very low levels through 1986.

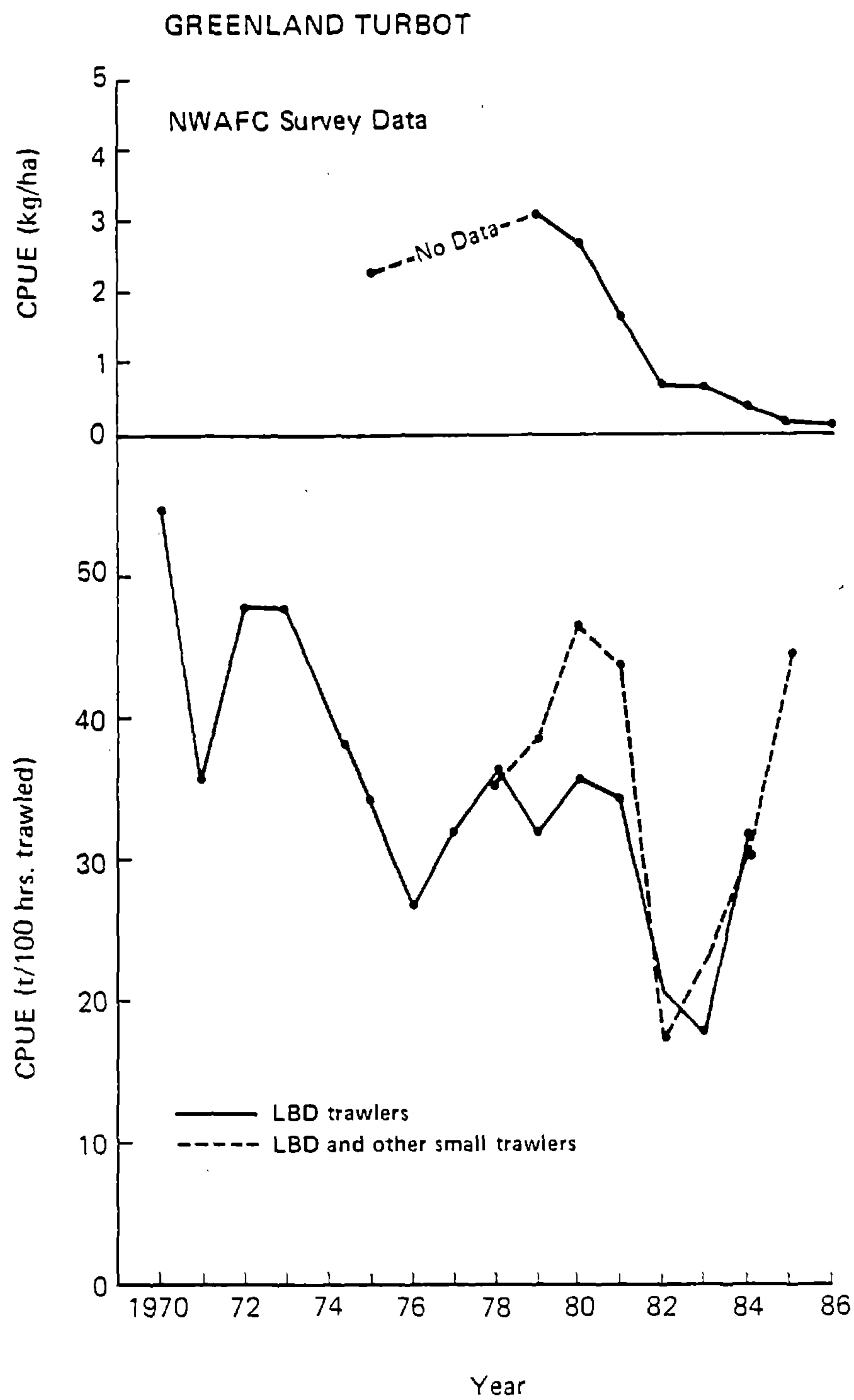

Figure 1.--Catch per unit effort (CPUE) of young juvenile Greenland turbot on the eastern Bering Sea continental shelf as shown by Northwest and Alaska Fisheries Center (NWAFC) survey data and of older juveniles and adults on the continental slope as shown by data from landbased dragnet (LBD) and other small trawlers.

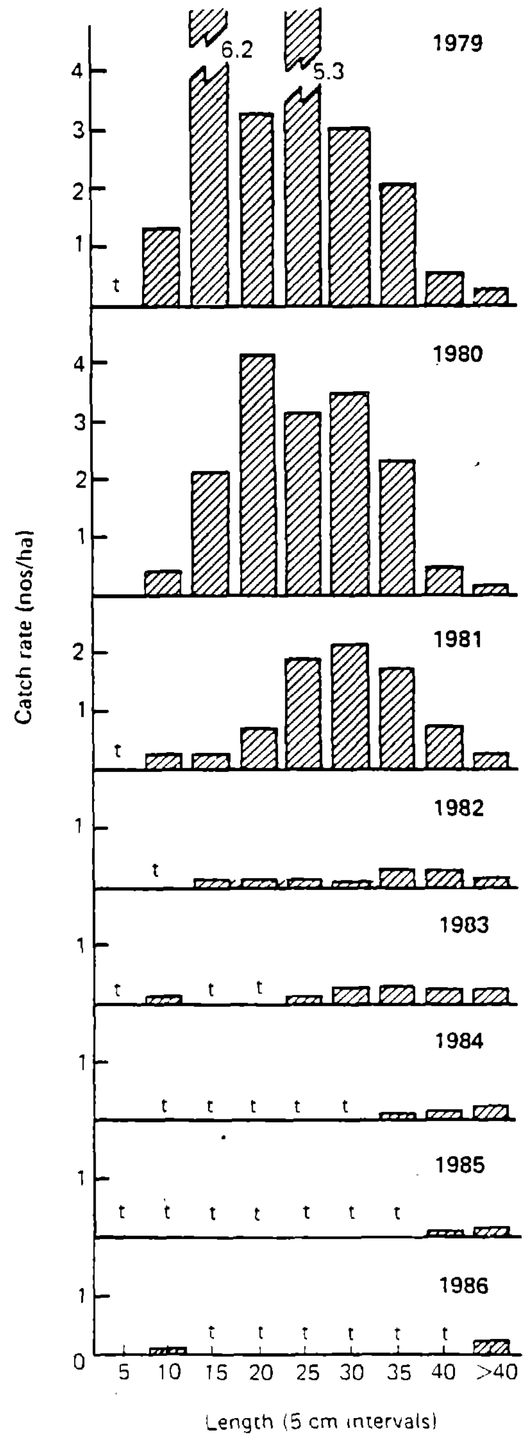

Figure 2.--Catch per unit effort of young juvenile Greenland turbot on the continental shelf of the eastern Bering Sea as shown by Northwest and Alaska Fisheries Center survey data. The letter t represents trace catches.

This absence of any significant recruitment of age 1 fish has resulted in a reduction of numbers of immature fish on the shelf to extremely low levels.

Catch rates from the landbased fishery (which represent the abundance of older juveniles and adults on the continental slope) were relatively high (48 t/100 h trawled) during years of peak catches of Greenland turbot in 1972-73 (Fig. 1). The CPUE then fell to a range of 27 to 36 t/100 h trawled in 1976-81, and then declined sharply to 18 t/100 h in 1983. The 1984 value, however, increased to 32 t/l00 h trawled. Data to calculate a 1985 value are not yet available.

The trend in CPUE for all small trawlers fishing the eastern Bering Sea slope region was quite similar to that for the landbased trawlers (Fig. 1). These data also show a sharp decline in CPUE between 1981 and 1982-83, but a sharp increase between 1983 and 1985.

When catch rates of all small Japanese trawlers fishing in slope waters are separated into medium and large sized fish (representing larger immature and adult Greenland turbot) (Fig. 3), the decline in CPUE on the slope is seen to result from reduced numbers of the intermediate sized or older immature fish. The decline in catch rates of older immatures on the continental slope between 1981 and 1983 apparently reflect the poor recruitment of younger juveniles from the continental shelf. There was no apparent decline in abundance of adult Greenland turbot during 1978 to 1984 and some indication of an increase between 1983 and 1984 which was also shown by data in Figure 1.

Biomass Estimates

Biomass estimates from NWAFC surveys on the eastern Bering Sea shelf, U.S.-Japan cooperative surveys on the eastern Bering Sea slope, and cooperative U.S.-Japan surveys in the Aleutian Islands region are shown in Table 2. The estimates from the NWAFC surveys on the eastern Bering Sea shelf, which primarily represent the biomass of young age 1-3 year juveniles, show an increase in biomass of juvenile Greenland turbot between 1975 (126,700 t) and 1979 (225,600 t) but a persistent decline since 1979. The estimate in 1986 was only 5,600 t, reflecting the recruitment failure illustrated in Figure 2.

Biomass estimates for older juveniles and adult Greenland turbot on the continental slope are available from cooperative U.S.-Japan surveys in 1979, 1981, 1982, and 1985. These estimates show a decline from 123,000 t in 1979 to 79,200 t in 1985. Based on the magnitude of commercial catches in 1981 and 1982 of 52,900 and 45,800 t in this region, it is assumed that the biomass of the adult stock is underestimated by survey data. In the Aleutian region the biomass estimates increased from 48,700 t in 1980 to 63,000 t in 1983.

Estimates of current exploitable biomass (age 5 and older) were also derived from stock reduction analysis (SRA) (Table 3). These estimates are for the eastern Bering Sea and Aleutian Islands regions combined and thus are higher than estimates derived in last year's condition of resources report (Bakkala et al. 1986a) which were limited to the eastern Bering Sea portion of the stock. The SRA provides estimates of initial population biomass (B_1), the change in biomass due to catch (P), and recruitment biomass consistent with

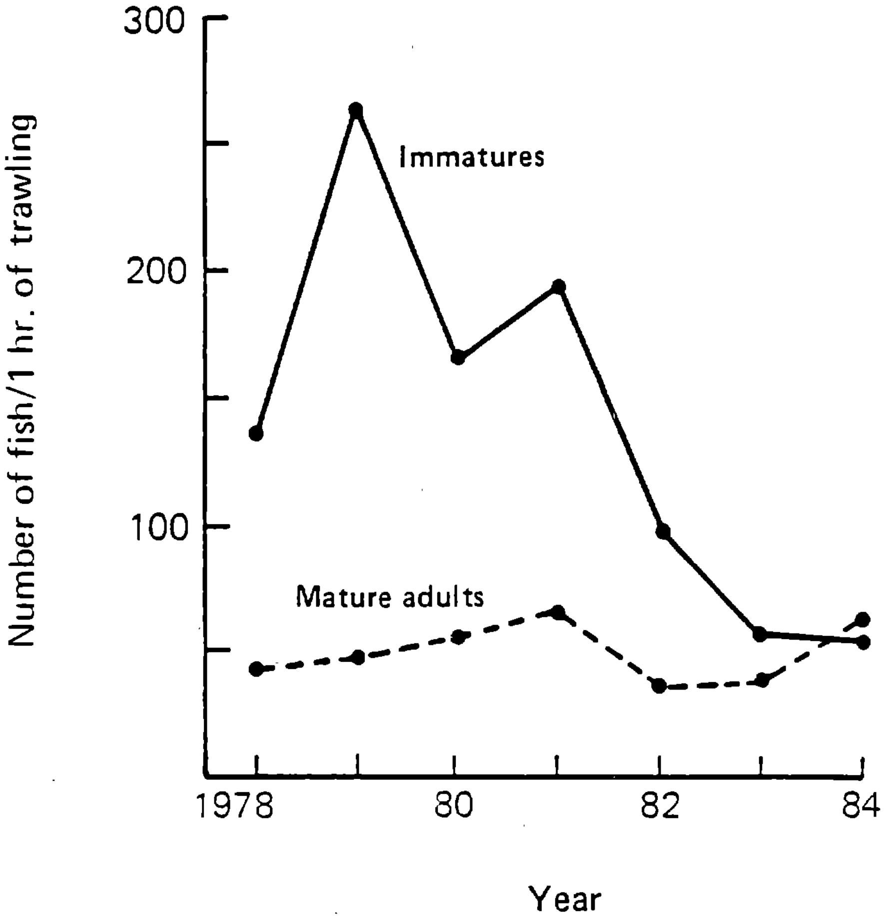

Figure 3 .--Catch per unit effort of older immature and adult Greenland turbot on the continental slope of the eastern Bering Sea as shown by data from Japanese small trawlers.

Table 2.---Biomass estimates (in metric tons, t) for Greenland turbot and arrowtooth flounder from U.S. and Japanese surveys in the eastern Bering Sea and Aleutian Islands region.[a]

	Eastern Bering Sea			
Year	Shelf	Slope	Shelf and slope combined	Aleutians
Greenland turbot				
1975	126,700	---	---	---
1979	225,600	123,000	348,600	---
1980	172,200	---	---	48,700
1981	86,800	99,600	186,400	---
1982	48,600	90,600	139,200	---
1983	35,100	---	---	63,800
1984	17,900	---	---	---
1985	7,700	79,200	86,900	---
1986	5,600	---	---	---
Arrowtooth flounder				
1975	28,000	---	---	---
1979	35,000	36,700	71,700	---
1980	47,800	---	---	40,400
1981	49,500	34,900	84,400	---
1982	67,400	24,700	92,100	---
1983	149,300	---	---	45,100
1984	182,900	---	---	---
1985	159,900	74,400	234,300	---
1986	232,100	---	---	---

[a]Biomass estimates for most other species assessed in this report are from the standardized survey area shown in Figure 1 of the section of the report on walleye pollock. For turbots, however, biomass estimates are derived from total sampling areas which in some years extended north of the standardized survey area where juvenile Greenland turbot are found. These more northern areas were sampled in 1979, 1982, and 1985.

Table 3.--Biomass estimates for Greenland turbot of the eastern Bering Sea and Aleutian Islands regions derived from stock reduction analysis of Kimura et al. (1984) and Kimura (1985).

Cushing recruitment coefficient (r)	Virgin biomass in 1960 (t)	Recruitment biomass 1960 (t)	Ratio:biomass in 1986 to biomass in 1960	Current biomass (t)	MSY (t)
0	913,000	43,200	0.448	409,000	43,500
0.125	971,000	46,000	0.442	429,000	39,500
0.250	1,028,000	48,700	0.437	449,100	33,600

[a]Assumptions: k = 5, M = 0.18, B_{84}/B_{70} = 0.500 based on change in the landbased fishery CPUE over this period.

[b]Growth parameters were estimated to be: Brody weight coefficient (P) = 1.034 and W. = W_k-1/w_k = 0.516/0.847 = 0.609.

the catch history and expected levels of recruitment. For SRA annual catches and estimates of the age at recruitment, natural mortality, Brody growth-coefficients, and abundance change (annual CPUE's) are required. Cohort analysis could not be performed because of the absence of annual catch-at-age data.

The age at recruitment for Greenland turbot was assumed to be 5 years, natural mortality 0.18, the Brody weight coefficient 1.034 and $W_4/W_5 = 0.609$. Cushing recruitment coefficients were also used. These coefficients represent the strength of the stock-recruitment relationship and the values used range from constant recruitment (r = 0.0) to a moderate relationship (r = 0.25). The analysis assumed that biomass had declined in 1984 to 50% of the 1970 biomass which equals the decline in fishery CPUE during this period.

Estimates from SRA indicate that the virgin fishable biomass of Greenland turbot in the eastern Bering Sea ranged between 913,000 and 1,028,000 t and that the current fishable biomass is between 409,000 and 449,000 t (Table 3). These estimates are approximately three times greater than the combined estimates (143,000 t) from the U.S. -Japan surveys in the Aleutians and eastern Bering Sea slope regions in 1983 and 1985 (Table 2).

Size and Age Composition

Age samples for Greenland turbot have been collected during U.S. research vessel surveys and by U.S. observers from the commercial fishery. Most Of these samples have not been read, however. Age data from earlier years for Greenland turbot show that catches on the continental shelf are mainly age 1-3 year fish. Age data collected from catches by small Japanese trawlers in 1978 and 1979 indicated that a wide range of age groups (3 or 4 to 19 years) were represented in commercial catches with age groups 4 and 5 predominant in those years.

Arrowtooth flounder

Relative Abundance

In sharp contrast to Greenland turbot, the recruitment of arrowtooth flounder has improved substantially in recent years. The relative abundance of juvenile arrowtooth flounder, as shown by NWAFC survey data on the continental shelf, has risen sharply since 1981 (Fig. 4). The CPUE has increased from 1.2 kg/ha in 1981 to 5.0 kg/ha in 1986. Catch per unit of effort values from the Japanese landbased fishery have not been considered a reliable index of abundance for arrowtooth flounder because the species is only taken as a by-catch. However, the sharp rise in CPUE in this fishery since 1982 apparently reflects the movement to the slope area of the relatively abundant juvenile fish that have been observed in shelf waters in recent years (Fig. 4). Landbased fishery catch and effort data were not available to calculate a CPUE value for 1985.

Biomass Estimates

Biomass estimates for juvenile arrowtooth flounder from NWAFC survey data on the continental shelf show consistent increases since 1975 (Table 2). These increases were small between 1975 and 1981 (28,000 t to 49,500 t) but much greater between 1981 and 1986 (49,500 t to 232,100 t). Based on Japanese survey data

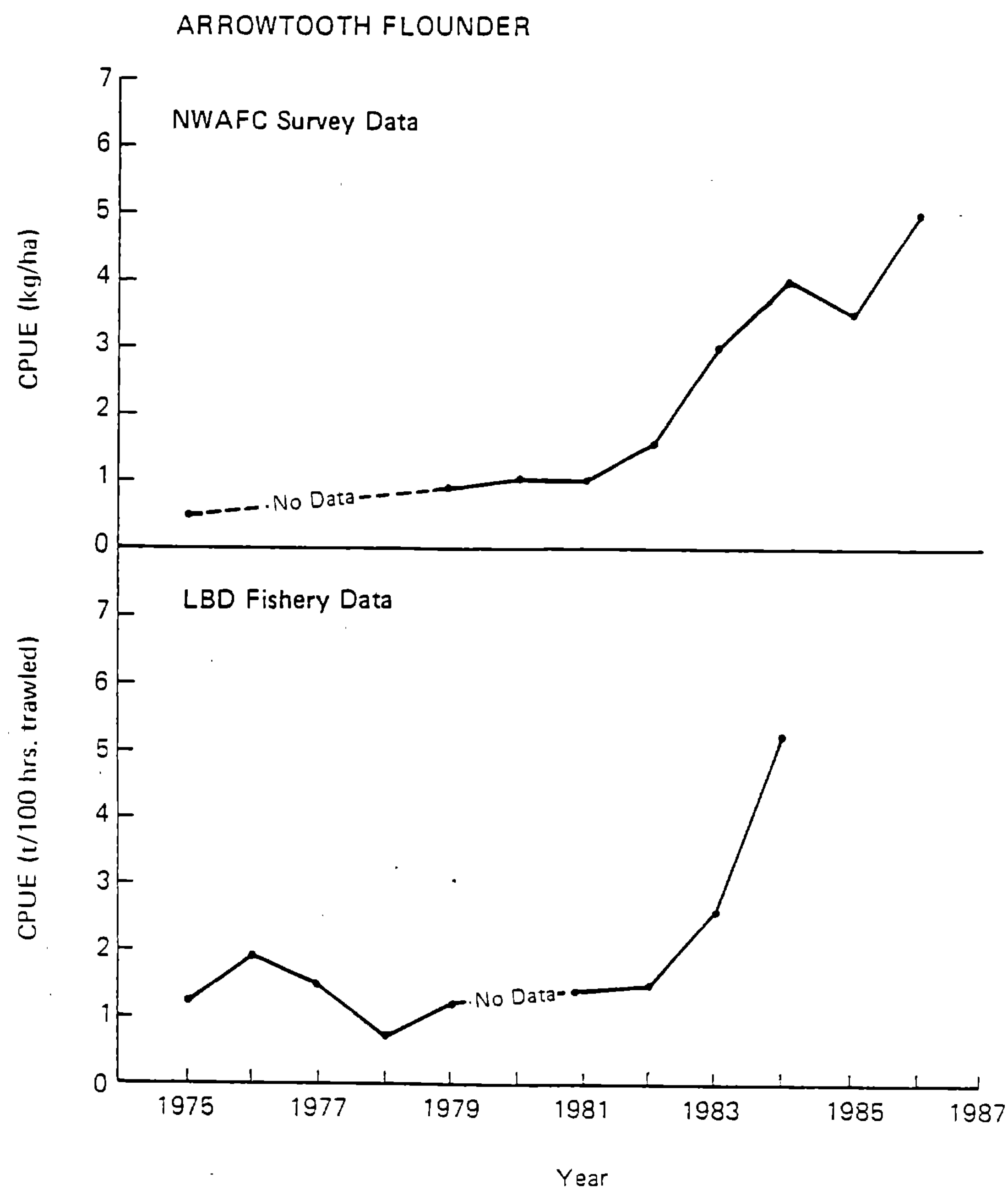

Figure 4.--Catch per unit effort (CPUE) of young juvenile arrowtooth flounder on the eastern Bering Sea continental shelf as shown by Northwest and Alaska Fisheries Center (NWAFC) survey data and of older juveniles and adults on the continental slope as shown by Japanese landbased dragnet (LBD) fisheries data.

during U.S.-Japan cooperative surveys, biomass estimates for the older fish on the continental slope showed no increase between 1979 and 1982 but a substantial increase from 24,700 t in 1982 to 74,400 t in 1985. Thus, CPUE data from the Japanese landbased fishery and survey data both show sharp increases in abundance of older arrowtooth flounder.

Biomass estimates from cooperative U.S.-Japan surveys in the Aleutian Islands region show a modest increase between 1980 (40,400 t) and 1983 (45,100 t).

Age Composition

Age samples are collected annually for arrowtooth flounder from both NWAFC surveys and the fishery. Recent samples have not been read, however. Age data presented in previous conditions of resources report (Bakkala et al. 1986a) have shown that arrowtooth flounder taken on the continental shelf during NWAFC surveys are mainly age 2 to 4 year juvenile fish. Arrowtooth flounder taken by the fishery on the continental slope consist mainly of ages 4-7.

MAXIMUM SUSTAINABLE YIELD

Greenland Turbot

Maximum sustainable yield (MSY) for Greenland turbot was previously estimated at 67,000 t (Bakkala 1985a). Based on historic catch records (Table 1) and CPUE data (Fig. 1), the MSY estimate of 67,000 t appears too high. Average landings of 50,000 t between 1970 and 1984 reduced the stock substantially and thus MSY is probably lower than 50,000 t. Estimates of MSY from SRA range from 33,600 t to 43,500 t. The mid-portion of this range (38,500 t) would appear to be a reasonable estimate of MSY based on historic trends in CPUE and catches.

Arrowtooth Flounder

Stock reduction analysis (SRA) was not used to estimate MSY for arrowtooth flounder as for Greenland turbot, because a sufficient time series of abundance estimates was not available. The estimate instead is based on survey results. Combined biomass estimates for the 1979 trawl survey in the eastern Bering Sea and the 1980 survey in the Aleutian Islands region (112,000 t) was considered most representative of the overall biomass of arrowtooth flounder during that period. Assuming that arrowtooth flounder had been fully exploited and that in 1979 the population had been reduced to a level that produces MSY (one-half the virgin population size), the virgin population was estimated at 224,000 t. Based on the Alverson and Pereyra (1969) yield equation and a natural mortality coefficient of 0.2 (Okada et al. 1980), MSY would be estimated as 0.5 x 0.2 x 224,000 or 22,400 t.

ACCEPTABLE BIOLOGICAL CATCH

Greenland turbot

The condition of the Greenland turbot resources is of concern. There has been essentially a recruitment failure of age 1 turbot since 1982 leading to a severe reduction in abundance of young juveniles on the eastern Bering Sea shelf with CPUE falling from 2.7 kg/ha in 1980 to 0.1 kg/ha in 1986 (Fig. 1). This poor recruitment of young juveniles has resulted in a reduction in abundance of older juveniles on the continental slope (Fig. 3). Even with improved abundance of age 1 fish starting in 1987, these fish would not recruit to the exploitable slope population until 1990. Despite this poor recruitment, there has been no evidence, as yet, of a decline in abundance of the adult stock and CPUE values from small Japanese trawlers fishing on the slope actually increased in 1984-85 (Fig. 1).

Estimates from SRA indicate that the exploitable biomass of Greenland turbot in the eastern Bering Sea and Aleutians regions combined ranged between 409,000 and 449,000 t in 1986. Projections from SRA, assuming no recruitment to the exploitable biomass through 1990 indicate that the exploitable biomass will decline to between 241,300 t and 345,900 t by 1990, depending on the magnitude of catches after 1986 (Table 4). The decline is anticipated to continue past 1990 because improved recruitment of age 1 fish cannot occur before 1987 and these fish would not contribute significantly to the exploitable stock before 1990 or 1991.

Catches in 1987 and immediate future years should be established at a level that will allow some fishing to continue but that will not reduce the adult population beyond a point that will limit reproduction. This threshold level is unknown but a conservative approach would be to maintain an exploitable biomass of about 30% of virgin biomass which based on SRA (Table 3) would be in the range of about 274,000-308,000 t. Projections from SRA suggest that annual catches of 15,000-20,000 t in 1987-90 should maintain the exploitable biomass at this level into the early 1990's (Table 4). Thus it is recommended that the 1987 allowable catch be set within the range of 15,000-20,000 t.

Arrowtooth Flounder

Evidence from surveys and the fishery are supportive in showing that the condition of arrowtooth flounder has improved considerably since 1981. The abundance of juveniles on the continental shelf has increased substantially and was the highest yet observed in 1986. This good recruitment of juveniles has also been reflected by increases in abundance of older fish on the continental slope. Thus the EY for arrowtooth flounder is considered to higher in 1987 than in 1986.

The combined biomass estimate from the 1985 U.S.-Japan survey of the eastern Bering Sea continental shelf and slope waters and the 1983 U.S.-Japan survey of the Aleutian Islands waters was 279,400 t. A conservative estimate of ABC is 10% of the biomass or 28,000 t.

Table 4.--Projected biomass (t) of Greenland turbot from stock reduction analysis based on various catch levels in 1987-90. The projections were made assuming no recruitment in 1987-90 and using a starting biomass of 409,100 t in 1986 and an estimated catch of 16,000 t in 1986.

	Catch level 1987-90 (t)							
Year	0	5,000	10,000	15,000	20,000	25,000	30,000	35,000
1987	390,400	390,400	390,400	390,400	390,400	390,400	390,400	390,400
1988	380,800	375,400	370,100	364,800	359,400	354,200	348,800	343,500
1989	365,300	354,900	344,600	334,200	323,900	313,600	308,300	292,900
1990	345,900	330,900	316,000	301,000	286,100	271,100	256,200	241,300

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OTHER FLATFISH

by

Gary E. Walters and Karen L. Halliday

INTRODUCTION

The "other flatfish" species complex is made up of the following small flatfishes which have distributions that are mainly restricted to continental shelf waters of the eastern Bering Sea: flathead sole, *Hippoglossoides elassodon*; rock sole, *Lepidopsetta bilineata*; Alaska plaice, *Pleuronectes quadrituberculatus*; and small amounts of miscellaneous flatfishes including rex sole, *Glyptocephalus zachirus*; Dover sole, *Microstomus pacificus*; starry flounder, *Platichthys stellatus*; longhead dab, *Limanda proboscidea*; butter sole, *Isopsetta isolepis*; and Bering flounder, *Hippoglossoides robustus*. This latter species may be included in catches of flathead sole, since taxonomic differences between the two species are not readily apparent. Only small amounts of other flatfish are taken in the Aleutian Islands region.

Previous condition of groundfish reports (for example, see Bakkala and Walters 1986) have recommended that Alaska plaice be managed separately because historically it has not been exploited as heavily as rock sole and flathead sole. When the allowable biological catch (ABC) is combined for all three species, most of the combined ABC might be used for rock sole and flathead sole, thus potentially leading to over-exploitation of these latter species. In addition, there has been recent special interest in rock sole by the commercial fishery and the North Pacific Fishery Management Council. Because of these considerations, estimates of maximum sustainable yield (MSY) and recommended ABC are derived for each of the three principal species and the miscellaneous flatfish group to provide the council with management options for the complex.

All-nation catches of these species increased from around 30,000 metric tons (t) in the 1960's 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 1970's. After 1971, catches declined to less than 25,000 t in 1975-82 but increased to 30,000 t in 1983, 44,000 t in 1984, and 71,000 t in 1985.

CONDITION OF STOCKS

Relative Abundance

Because "other flatfishes" are usually 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. Large-scale surveys of the eastern Bering Sea shelf were made over a comparable area in 1975 and 1979-86 (see

Table 1 .--All-nation catches of other flatfishes in the eastern Bering Sea and Aleutian Islands region in metric tons (t) (1980-85 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	1,117	-	43,119
1974	20,011	14,958	2,388	-	37,347
1975	12,014	5,888	2,491	-	20,393
1976	9,964	8,162	3,620	-	21,746
1977	2,914	7,909	2,589	981	14,393
1978	3,323	6,957	10,420	340	21,040
1979	1,468	4,351	13,672	233	19,724
1980	7,601	5,247	6,908	650	20,406
1981	9,021	5,218	8,653	536	23,428
1982	11,844	4,509	6,811	645	23,809
1983	13,618	5,240	10,766	830	30,454
1984	18,750	4,458	18,982	2,096	44,286
1985	37,678	5,636	24,888	2,977	71,179

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

1963-76, Wakabayashi and Bakkala 1978;
1977-85, Nelson et al. 1978, 1979, 1980, 1981b, 1982, 1983a Berger et al. 1984, 1985b, 1986.

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

Figure 1 of the walleye pollock section of this report). This comparative area encompasses almost the entire distribution of the "other flatfish" species in the eastern Bering Sea and provides a time-series of data to assess the condition of these resources.

As described in the section on yellowfin sole, abundance estimates from the 1982 Northwest and Alaska Fisheries Center (NWAFC) survey were substantially higher than from the 1981 survey data for a number of bottom-tending species such as the flatfishes. The increase in catch per unit of effort (CPUE) was particularly large for rock sole (6.5 to 12.3 kg/ha) and Alaska plaice (11.5 to 15.1 kg/ha) while that for flathead sole was moderate (3.5 to 4.2 kg/ha). These higher 1982 estimates may have been due in part to better bottom contact or greater herding effects of the trawl rigging in 1982 compared to that used in 1981 and earlier years. The CPUE values have remained high in succeeding years, suggesting that the new rigging has increased the efficiency of the trawls for flatfish and plays some part in the increased CPUE levels seen in recent years.

The CPUE values from the comparative area 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 moderately from 1975 to 1979 and increased more substantially in 1980-84. The abundance of flathead sole was relatively stable from 1975 to 1979 and then increased moderately each year in 1980-84. Values of CPUE for these species were lower in 1985, suggesting that abundance may have peaked. However, in 1986, the values for rock sole and flathead sole were higher than the previous peak in 1984. A hypothesis for the apparent aberration in 1985 is discussed in the next section.

Biomass Estimates

Estimates from large-scale NWAFC surveys (Table 2) indicate that the biomass of Alaska plaice steadily increased from 103,500 t in 1975 to 700,200 t in 1982 before decreasing slightly in 1983. The biomass peaked in 1984 at 734,400, then declined to 550,600 t in 1986. For rock sole, biomass estimates were relatively stable through 1979, but then increased substantially from 194,700 t in 1979 to 950,600 t in 1984. In 1985, the estimate declined to 720,300 t but increased again in 1986 to over 1 million t. The estimates for flathead sole increased from 104,900 t in 1979 to 344,800 t in 1984. After a moderate decrease in 1985, the estimate increased again to a new high of 369,300 t in 1986. The biomass of the miscellaneous species of flatfish increased through 1982, declined through 1985, and increased moderately in 1986.

The large increases in biomass between 1981 and 1982, representing an 89% increase for rock sole, a 21% increase for flathead sole, and a 31% increase for Alaska plaice, are believed due in part to the greater efficiency of the trawls used in 1982 and later years.

The declines in biomass for rock sole and Alaska plaice between 1984 and 1985 were relatively large and larger than might be expected from natural causes and fishing mortality. The decline was 24% for rock sole and 25% for Alaska plaice. A similar decline of 31% was observed in the

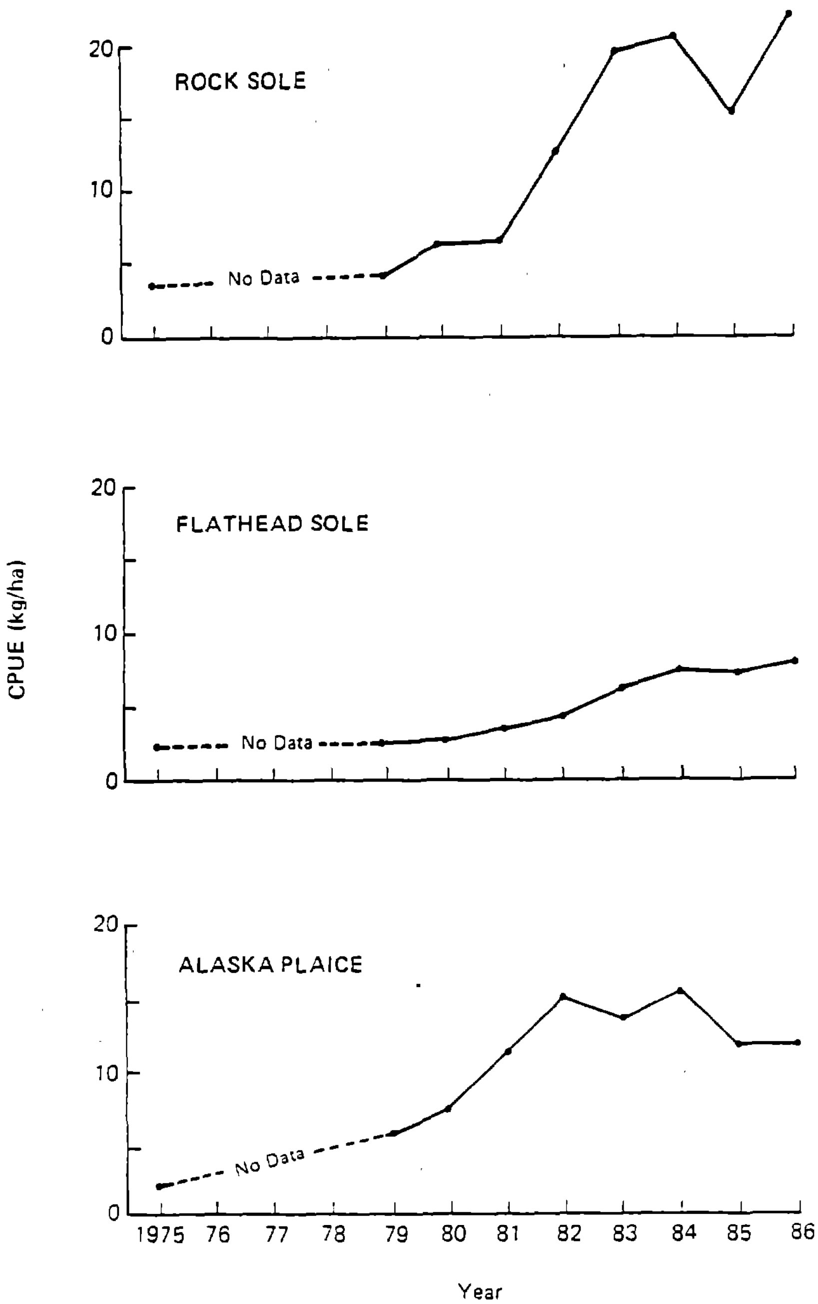

Figure 1. --Relative abundance (catch per unit effort, CPUE) of rock sole, flathead sole, and Alaska plaice from Northwest and Alaska Fisheries Center bottom trawl surveys.

Table 2.--Estimated biomass (in metric tons) of species in the other flatfish complex in the eastern Bering Sea and Aleutian regions based on Northwest and Alaska Fisheries Center survey data in 1975 and 1979-86.

Year	Area	Species				Total all species excluding Alaska plaice	Total all species
		Rock sole	Flathead sole	Alaska plaice	Others		
1975	EBS[a]	175,500	100,700	103,500	22,200	298,400	401,900
1979	EBS	194,700	104,900	277,200	50,900	350,500	627,700
1980	EBS	283,800	117,500	354,000	56,500	457,800	811,800
	Aleut.[b]	28,500	3,300	0	2,700	34,500	34,500
1981	EBS	302,400	162,900	535,800	88,000	553,300	1,089,100
1982	EBS	572,200	197,400	700,200	147,800	917,400	1,617,600
1983	EBS	911,200	279,900	646,600	76,300	1,267,400	1,914,000
	Aleut.	23,300	1,500	0	2,700	27,500	27,500
1984	EBS	950,600	344,800	734,400	51,600	1,347,000	2,081,400
1985	EBS	720,300	329,900	553,300	33,000	1,083,200	1,636,500
1986	EBS	1,013,700	369,300	550,600	47,400	1,430,400	1,981,000

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

biomass estimate for yellowfin sole between 1984 and 1985. The similarity in these declines among most of the small flatfishes and the apparent unreasonable magnitude of the declines suggest that they may not be entirely real. Surveys of the eastern Bering Sea shelf by the NWAFC are normally conducted from inner Bristol Bay to the shelf edge in an east-to-west progression. This ensures that fish populations undergoing an on-shelf migration in spring-summer are adequately covered and sampled only once (Smith and Bakkala 1982). In 1985, this pattern was broken due to a special need to sample blue king crab, Paralithodes platypus, earlier than scheduled in the area around St. Matthew Island. The survey was disrupted on the central shelf and was reconvened nearly 4 weeks later. After examining the results from 1986, it is now believed that the disruption in 1985 resulted in the unreasonable estimates shown. It is apparent that the biomass increases for rock sole and flathead sole are real and continue their upward trend. The decline in Alaska plaice is apparently real but was probably not as precipitous as 1985 data indicated.

Age Composition and Year-Class Strength

Age samples for rock sole have only been read through 1983 for the eastern Bering Sea (Fig. 2). After that year, we depend on size distributions as indicators of recruitment. Rock sole are recruited to the survey trawl beginning at age 2 and are almost fully recruited by age 5. Examination of age-length keys for prior years reveals that the majority of age 2 fish are less than 14 cm in length and age 3 fish are primarily 14-18 cm. Population estimates for fish in these two length intervals, representing two pre-recruit ages, 2 and 3, were used as a semi-independent measure of year-class strength. Two intervals were used to see if the trends were consistent. The trend of population estimates between these length groups shows strong correlation for most year classes from 1977 to 1984 (Fig. 3). The apparent decreases in age 3 fish for the 1982 year class and age 2 fish for the 1983 year class are probably due to the 1985 survey problem discussed above. We have no evidence, as yet, that the population estimates of these length intervals have predictive value. However, if population estimates in these length groups are truly representative of year-class strength, the recruitment of rock sole has increased since 1978 and remains strong through 1986. The age composition based on aged samples in 1982 and 1983 (Fig. 2) indicates that the 1977-80 year classes were stronger than earlier years. This new analysis suggests that the 1981-84 year classes may be even stronger. This good recruitment explains the increasing trend in biomass and CPUE estimates for rock sole and suggests that the trend will continue for the foreseeable future as the incoming year classes grow and mature.

Age samples for flathead sole have been read only through 1982 (Fig. 4) and again we rely on size distributions as an indicator of recruitment in more recent years. Similar to rock sole, recruitment of flathead sole begins with ages 2-3 at lengths from 10 to 20 cm. The age composition results show good recruitment from the 1974-80 year classes. Size composition data from the later years was analyzed by using fish less than 16 cm as representative of age 2 and fish from 16-20 cm as representative of age 3 (Fig. 3) with the same limiting assumptions as above. Similar to the rock sole, the correlation

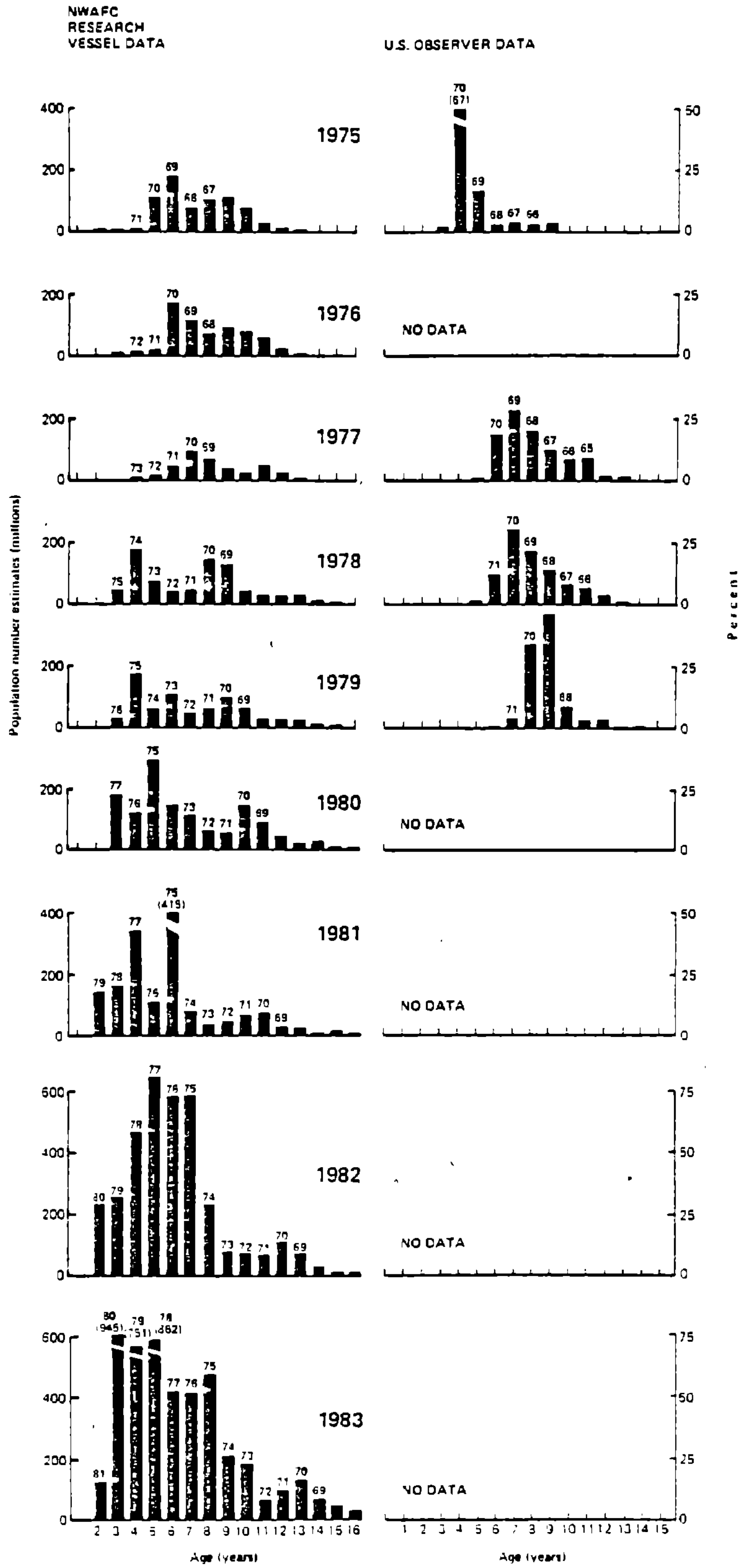

Figure 2.-- Age composition of rock sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

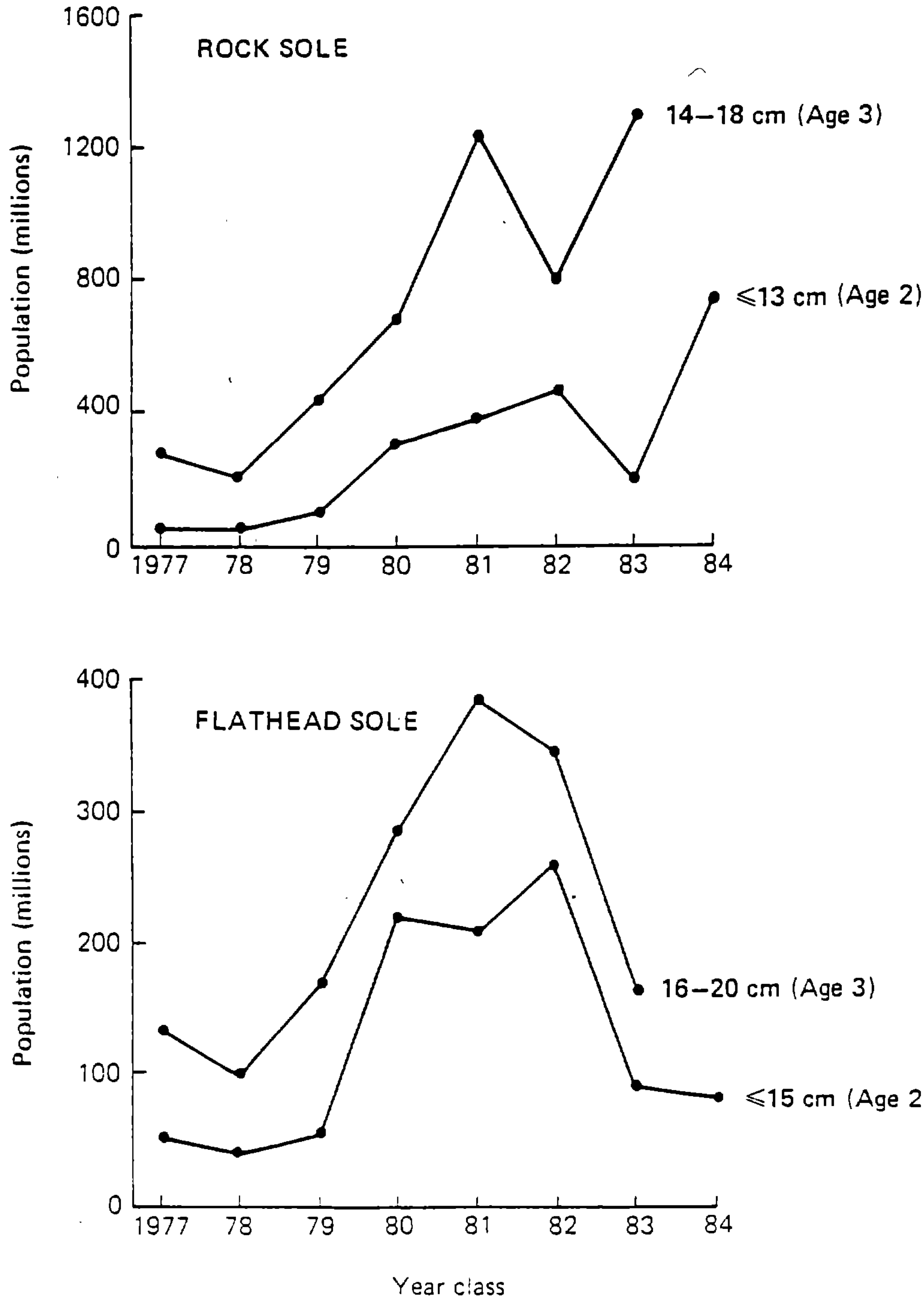

Figure 3. --Population estimates for pre-recruit year classes of rock sole and flathead sole as measured by length intervals from Northwest and Alaska Fisheries Center bottom trawl surveys.

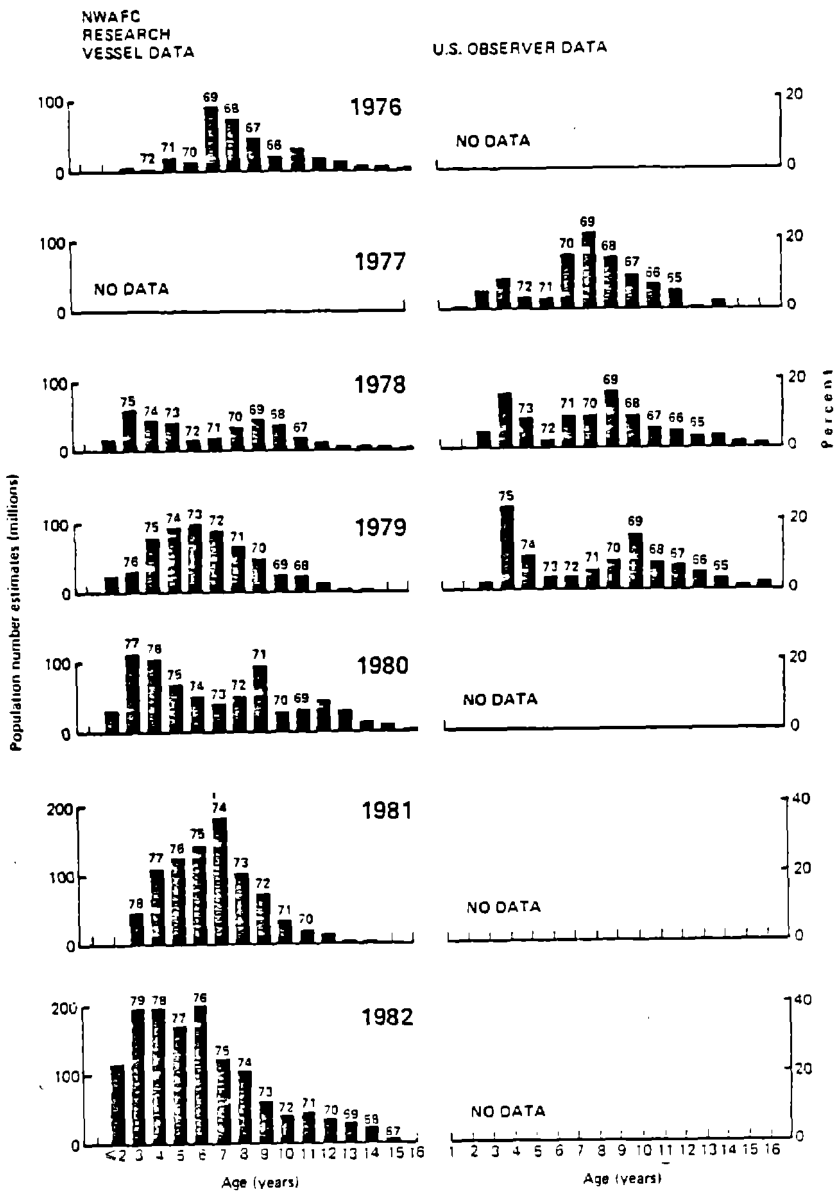

Figure 4. --Age composition of flathead sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

between the two age groups is strong for most years. The results suggest that recruitment continues reasonably strong with the possible exception of the 1983 year class showing in 1985 and the 1984 year class in 1986. This trend indicates a continuing modest increase in CPUE and biomass estimates as these age classes grow and mature.

Age data for Alaska plaice also extends only through 1982 (Fig. 5). Unlike the rock sole and flathead sole, Alaska plaice are not normally recruited until ages 4-5 at lengths generally greater than 20 cm (Fig. 6). The lack of younger age groups with length intervals more easily defined prevents the type of analysis used for rock sole and flathead sole. However, the size distribution gives no indication of higher than normal recruitment since the 1975 year class. This is reflected in CPUE and biomass estimates which have declined since 1983 and mean size which has increased nearly 5 cm between 1975 and 1984.

MAXIMUM SUSTAINABLE YIELD

The maximum sustainable yield (MSY) of the "other flatfish" complex has in previous years been estimated, following the Alverson and Pereyra (1969) yield equation, at one-half the instantaneous rate of natural mortality (traditionally estimated to be 0.23 although no documentation of the basis for this estimator has been found) multiplied by the virgin biomass. Based on the assumption that the species group was fully utilized by the fishery prior to 1975, virgin biomass was estimated to fall between 480,000 t and 697,000 t, giving an MSY estimate of 55,200-80,200 t (Bakkala and Walters 1986). However, biomass estimates derived from annual resource assessment surveys indicate that the biomass of the complex has increased dramatically and consistently since 1979 (the apparent decline in biomass in 1985 is believed to be an artifact of a change in sampling pattern), and now stands at a level more than double that of the original "virgin biomass" estimate. The MSY estimate derived from the 1975 data, therefore, appears unrealistically low for current conditions.

These earlier estimates of MSY were based on limited knowledge of the flatfish complex and some major assumptions which were difficult to evaluate. However, the estimates were required by the Fisheries Management Plan. Given the changes in stock sizes, new estimates of MSY are obviously required and our better knowledge of these resources allows us to improve the quality of these estimates. Although the new estimates still incorporate some assumptions that are difficult to substantiate, they are a first step in upgrading the quality of the estimates.

Rock Sole

The biomass estimates for rock sole have remained close to 1 million t since 1983 (Table 2). If we assume that this value approximates maximum biomass for this species, maximum production should be obtained by a fishery which would hold biomass near 500,000 t. An age structured projection model was used to estimate the catches required to obtain this biomass (Bmsy). Inputs to the model include the age structure of the latest known population (1983), estimates of recruitment to the survey at age 5 (400-700 million fish),

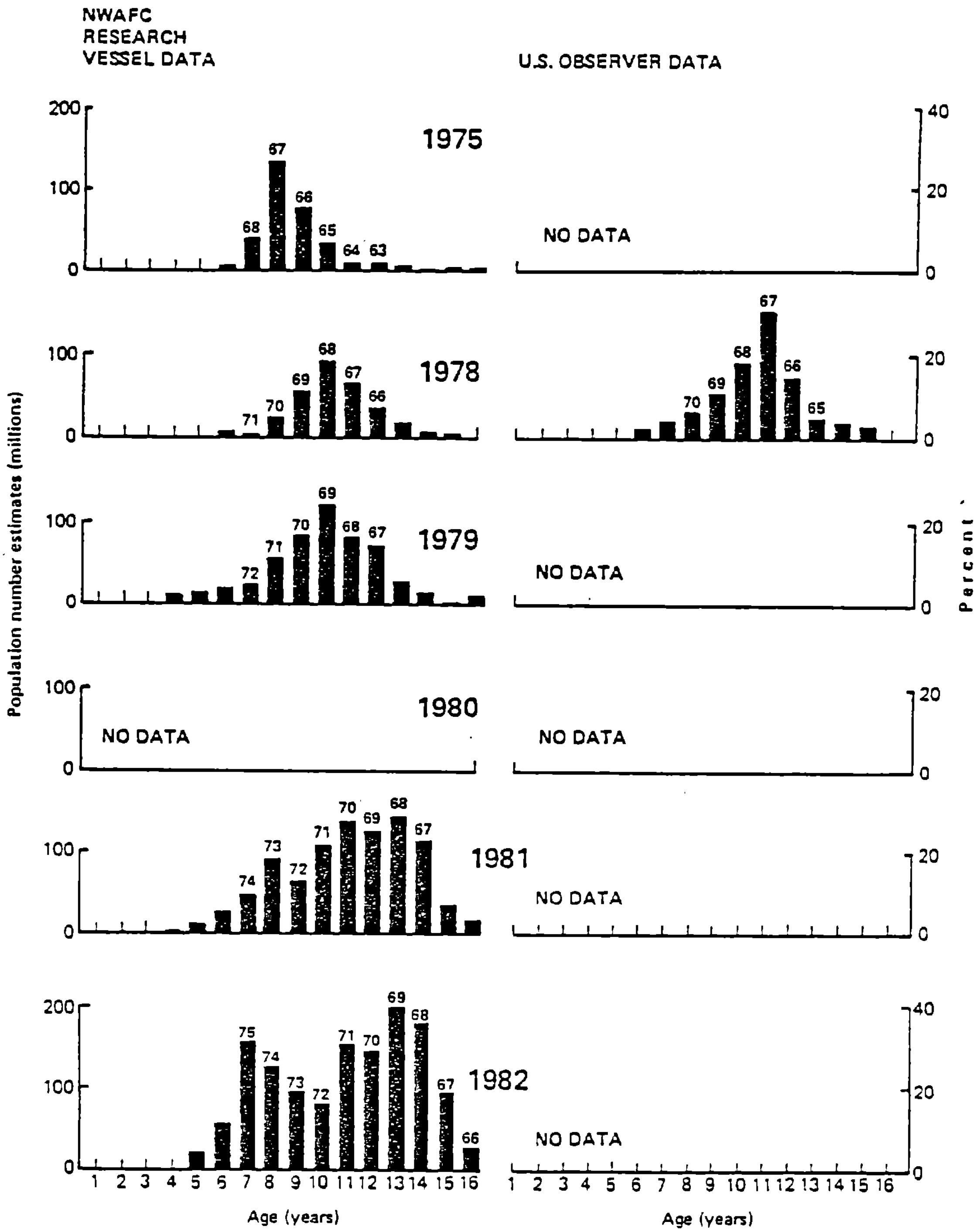

Figure 5 .--Age composition of Alaska plaice as shown by data collected on Northwest and Alaska fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in tie commercial fishery.

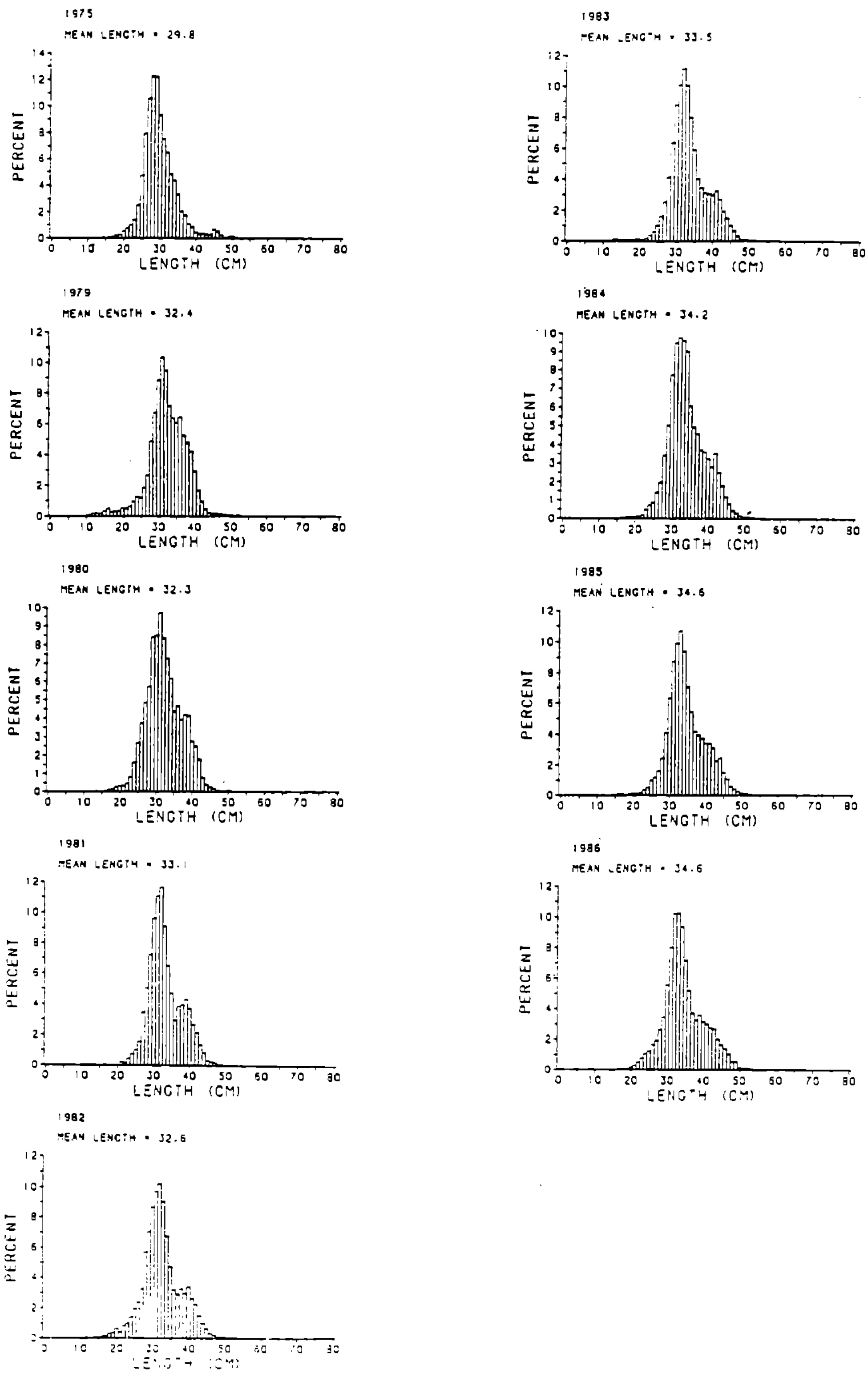

Figure 6.--Size composition of Alaska plaice from Northwest and Alaska Fisheries Center bottom trawl surveys.

an estimate of natural mortality (M = 0.23), estimates of mean weight at age, and catchability coefficients (q) for those ages from full survey recruitment (age 5) to full fishery recruitment (age 7). These latter estimates were obtained from analysis of 1985 survey and fishery size distributions and resulted in estimates of q = 0.855 for age 6 and q = 0.564 for age 5.

Over the range of recruitment values used, the model predicts that biomass will stabilize near 500,000 t with annual catches in the range of 50,000-70,000 t. MSY is, therefore, estimated to fall between 50,000 and 70,000 t as long as recruitment remains at current high levels.

Flathead Sole

Biomass estimates for flathead sole (including Bering flounder) show a steady increase of this stock from 1979 to 1984; after 1984 biomass appears to have leveled off at approximately 350,000 t. We do not currently have sufficient data for this stock to estimate MSY using the projection model described above. MSY was, therefore, estimated according to the Alverson-Pereyra yield equation, assuming a maximum biomass level of 350,000 t and an instantaneous natural mortality rate of M = 0.23, resulting in an estimated MSY of 40,250 t.

Alaska Plaice

The population of Alaska plaice appears to have declined over the last few years after reaching a peak of 734,000 t in 1984, indicating that this 1984 estimate may be a good approximation of maximum biomass for the stock. Using this value in the yield equation (at M = 0.23) gives an estimated MSY of 84,500 t.

Miscellaneous Flatfish

No meaningful estimate of MSY can be developed for this group, as both the abundance and species composition are highly variable from year to year.

ACCEPTABLE BIOLOGICAL CATCH

Rock Sole

Since the present biomass estimate for rock sole exceeds Bmsy and recruitment appears high, the recommended acceptable biological catch (ABC) is at least as high as the upper range of MSY estimates (70,000 t). Further data on expected recruitment and refinement of the age-structured projection model will provide additional information in future years.

Flathead Sole

Flathead sole in the eastern Bering Sea are also currently at a biomass level exceeding Bmsy, and ABC can be set at the MSY estimate of approximately 40,000 t. It should be noted, however, that at Bmsy this would represent an exploitation rate of over 20%, indicating that the [MSY estimate needs to be re-evaluated using other techniques such as the age-structured projection model applied to rock sole.

Alaska Plaice

Although this stock is at present declining, it is still at a level well in excess of Bmsy. ABC can therefore theoretically be set at the estimated MSY of 84,000 t. However, this gives an excessive exploitation rate and a more conservative ABC of 50,000 t, representing an exploitation rate of 10%, is recommended.

Miscellaneous Flatfish

For lack of other information, an ABC of 4,000 t (10% of the current estimated biomass) is recommended.

SABLEFISH

by

Sandra A. McDevitt

INTRODUCTION

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

Longline and trawl vessels fish for sablefish in relatively deep waters of 400-900 m. Japanese longliners began targeting on sablefish in the eastern Bering Sea in 1958. The fishery rapidly expanded and catches increased to a peak of 25,990 t in 1962 (Table 1). As fishing grounds used by longliners became preempted by expanding trawl fisheries, the longline fleet expanded to the Aleutian region and the Gulf of Alaska. Catches peaked in the Aleutian region at 3,530 t in 1972 (Table 2).

Catches declined in the eastern Bering sea and the Aleutian region after 1972 largely due to declining stock abundance. Catches since 1977 have remained at relatively stable and reduced levels because of continued low stock abundance and catch restrictions placed on the fishery. In 1985 the all-nation catch of sablefish was 2,248 t in the eastern Bering Sea, and 2,089 t in the Aleutian region. United States vessels caught 87% of the sablefish taken in the eastern Bering Sea and 94% in the Aleutians in 1985.

CONDITION OF STOCKS

Relative Abundance Estimates from the Fishery

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

Prior to 1977, Japan harvested the greatest portion of sablefish catches in U.S. waters. Japanese longline and stern trawl vessel CPUE data have been used to provide estimates of sablefish abundance trends prior to the availability of survey data (Table 3). Japanese stern trawlers generally target on other species, with only a few targeting specifically on sablefish. Estimates of relative abundance from stern trawl vessels may therefore not be representative of actual abundance trends for sablefish (Sasaki 1985).

Table 1 .--Annual sablefish catches in metric tons from the eastern Bering Sea by nation, 1956-85[a].

Year	Japan	U.S.S.R.	Republic of Korea	Taiwan	U.S.	Other[b] nations	Joint Venture	Total[c]
1956	--	--	--	--	--	--	--	--
1957	--	--	--	--	--	--	--	--
1958	6	--	--	--	--	--	--	6
1959	289	--	--	--	--	--	--	289
1960	1,861	--	--	--	--	--	--	1,861
1961	15,627	--	--	--	--	--	--	15,627
1962	25,989	--	--	--	--	--	--	25,989
1963	13,706	--	--	--	--	--	--	13,706
1964	3,545	--	--	--	--	--	--	3,545
1965	4,838	--	--	--	--	--	--	4,838
1966	9,505	--	--	--	--	--	--	9,505
1967	10,462	1,236	--	--	--	--	--	11,698
1968	10,118	4,256	--	--	--	--	--	14,374
1969	14,430	1,579	--	--	--	--	--	16,009
1970	8,863	2,874	--	--	--	--	--	11,737
1971	12,276	2,830	--	--	--	--	--	15,106
1972	10,621	2,137	--	--	--	--	--	12,758
1973	4,765	1,192	--	--	--	--	--	5,957
1974	4,181	77	--	--	--	--	--	4,258
1975	2,728	38	--	--	--	--	--	2,766
1976	2,798	29	96	--	--	--	--	2,923
1977	2,661	--	2	53	2	--	--	2,718
1978	1,006	--	182	5	--	--	--	1,192
1979	1,058	49	261	6	--	2	--	1,376
1980	1,648	--	324	30	2	168	35	2,206
1981	2,091	--	339	102	2	46	24	2,604
1982	2,315	--	506	208	148	1	6	3,184
1983	2,231	--	372	--	47	1	44	2,695
1984	1,006	--	179	--	1,518	13	76	2,793
1985	187	--	53	--	1,959	2	47	2,248

[a]Japanese catch data for 1958-70 from Forrester et al. 1978, for 1971-76 from Forrester et al. 1983; U.S.S.R. data for 1967-76 provided through U.S.-U.S.S.R. bilateral agreements; R.O.K. 1976 data provided through U.S.-R.O.K. bilateral agreements; U.S. data 1977-85 provided by U.S. state fishery agencies; 1977-85 data for ail other nations from U.S. Foreign Fisheries Observer Program. The catches provided in this table may differ from previous tables as they no longer include catches from the western Bering Sea (INPFC areas 3 and 4).

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

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

Table 2.--Annual sablefish catches in metric tons from the Aleutian Islands by nation, 1963-85[a].

Year	Japan	U.S.S.R.	Republic of Korea	U.S.	Other[b] nations	Joint Venture	Total[c]
1963	664	--	--	--	--	--	664
1964	1,541	--	--	--	--	--	1,541
1965	1,249	--	--	--	--	--	1,249
1966	1,341	--	--	--	--	--	1,341
1967	1,652	--	--	--	--	--	1,652
1968	1,673	--	--	--	--	--	1,673
1969	1,673	--	--	--	--	--	1,673
1970	1,248	--	--	--	--	--	1,248
1971	2,766	170	--	--	--	--	2,936
1972	3,262	269	--	--	--	--	3,531
1973	2,740	162	--	--	--	--	2,902
1974	2,463	14	--	--	--	--	2,477
1975	1,630	79	38	--	--	--	1,747
1976	1,558	61	40	--	--	--	1,659
1977	1,810	--	87	--	--	--	1,897
1978	798	--	23	--	--	--	821
1979	617	--	165	--	--	--	782
1980	233	--	26	3	8	4	274
1981	320	--	56	--	1	156	533
1982	715	--	92	28	1	118	955
1983	527	--	45	29	3	70	673
1984	717	--	7	47	1	272	1,043
1985	70	--	--	1,956	--	63	2,089

[a]Japanese catch data for 1963-70 from Forrester et al. 1978, for 1971-76 from Forrester et al. 1983; U.S.S.R. data for 1971-76 provided through U.S.-U.S.S.R. bilateral agreements; R.O.K. 1975-76 data provided through U.S.-R.O.K. bilateral agreements; U.S. data 1980-85 provided by U.S. state fishery agencies; 1977-85 data for all other nations from U.S. Foreign Fisheries Observer Program.

[b]Federal Republic of Germany and Taiwan.

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

Table 3.--Sablefish catch per unit effort trends in the eastern Bering Sea and Aleutian Islands region based on data from Japanese longline and trawl fisheries, 1964-84.

	Eastern Bering Sea				Aleutian Islands Region				
	Japan estimates		U. S. estimates		Japan estimates		U. S. estimates		
	Longline		Longline	Trawl	Longline		Longline		Trawl
	kg/10 hachi[a]	t/vessel day[b]	kg/10 hachi[c]	kg/h[c]	kg/10 hachi[a]	t/vessel day[b]	kg/10 hachi[c]	t/vessel day[c]	kg/h[c]
1964	93	2.4	61		141	3.1	139		
1965	105	3.0	54		183	4.1	110		
1966	166	4.5	139		233	6.3	229		
1967	216	6.2	210	151	275	7.1	277		154
1968	140	5.1	143	134	161	5.9	165		259
1969	187	6.9	189	142	183	7.1	184		318
1970	241	8.7	231	50	241	9.4	189		112
1971	185	5.6	120	76	202	9.4	165	4.5	222
1972	117	3.3	50	62	208	11.6	203	11.8	123
1973	148	6.0	47	41	204	7.7	192	4.6	115
1974	164	7.4	141	24	208	7.8	187	4.4	44
1975	130	4.9	68	13	168	6.0	98	1.8	30
1976	147	5.6	69	6	114	4.5	71		7
1977	135	5.4	73	5	108	4.0	70	1.1	3
1978	52		16	1	40		24		2
1979	48		24	1	39		26		1
1980	64		31	2	66		24		2
1981	75		35	0	96		40		<1
1982	99		47	2	138		76		<1
1983	109		49		152				
1984	83				159				

[a]Sasaki (1986). Hachi is a unit of longline gear 100 m long.
[b]Sasaki (1978).
[c]Method of Low et al. (1977).

Data from longline vessels whose effort has been directed toward sablefish may depict stock abundance trends. Japanese longline data indicate a considerable decline in CPUE for both the eastern Bering Sea and the Aleutian region (Table 3). To better illustrate the trend in abundance of sablefish as shown by Japanese longline data, the Japanese CPUE estimates in units of kg/10 hachi, from Table 3, are standardized below by setting the 1970 values to 100 units:

	Eastern Bering Sea		Aleutian Region	
Year	All nation catch (t)	Normalized CPUE	All-nation catch (t)	Normalized CPUE
1970	11,700	100	1,200	100
1971	15,100	77	2,900	83
1972	12,800	49	3,500	86
1973	6,000	61	2,900	85
1974	4,300	68	2,500	86
1975	2,800	54	1,700	70
1976	2,900	61	1,700	47
1977	2,700	56	1,900	45
1978	1,200	22	800	17
1979	1,400	20	800	16
1980	2,200	27	300	27
1981	2,600	31	500	40
1982	3,200	41	1,000	57
1983	2,700	45	700	63
1984	2,800	34	1,000	66
1985	2,200	Not Available	2,000	Not Available

The data show a general decline through 1977. In 1977 the CPUE value in the eastern Bering Sea was 56% of the 1970 level, while the value for the Aleutian region was 45% of the 1970 level. The CPUE values for 1978-84 may not be consistent with data from previous years due to changes in fishing patterns brought about by fishing regulations following enactment of the Magnuson Fishery Conservation and Management Act (MFCMA) in 1977. Even though catches after 1978 remained relatively stable at a low level, CPUE values continued to drop, reaching lows of 20 and 16% of the 1970 values in 1979 for the eastern Bering Sea and Aleutian region, respectively. The CPUE data show an upward trend beginning in 1980, which is a reflection of the recruitment to the fishery of the strong 1977 year class. In 1983, rates increased to 45% of 1970 values in the eastern Bering Sea then dropped to 34% in 1984. In 1984 rates increased to 66% of the 1970 value in the Aleutian Islands. Although the CPUE data have shown an upward trend, values are still below values of 1975 and earlier years.

Yearly changes in catch and effort data used to compute the CPUE values of Table 3 are shown in Figure 1. Catches and effort showed corresponding fluctuations through 1977 in both the eastern Bering Sea and Aleutians. In

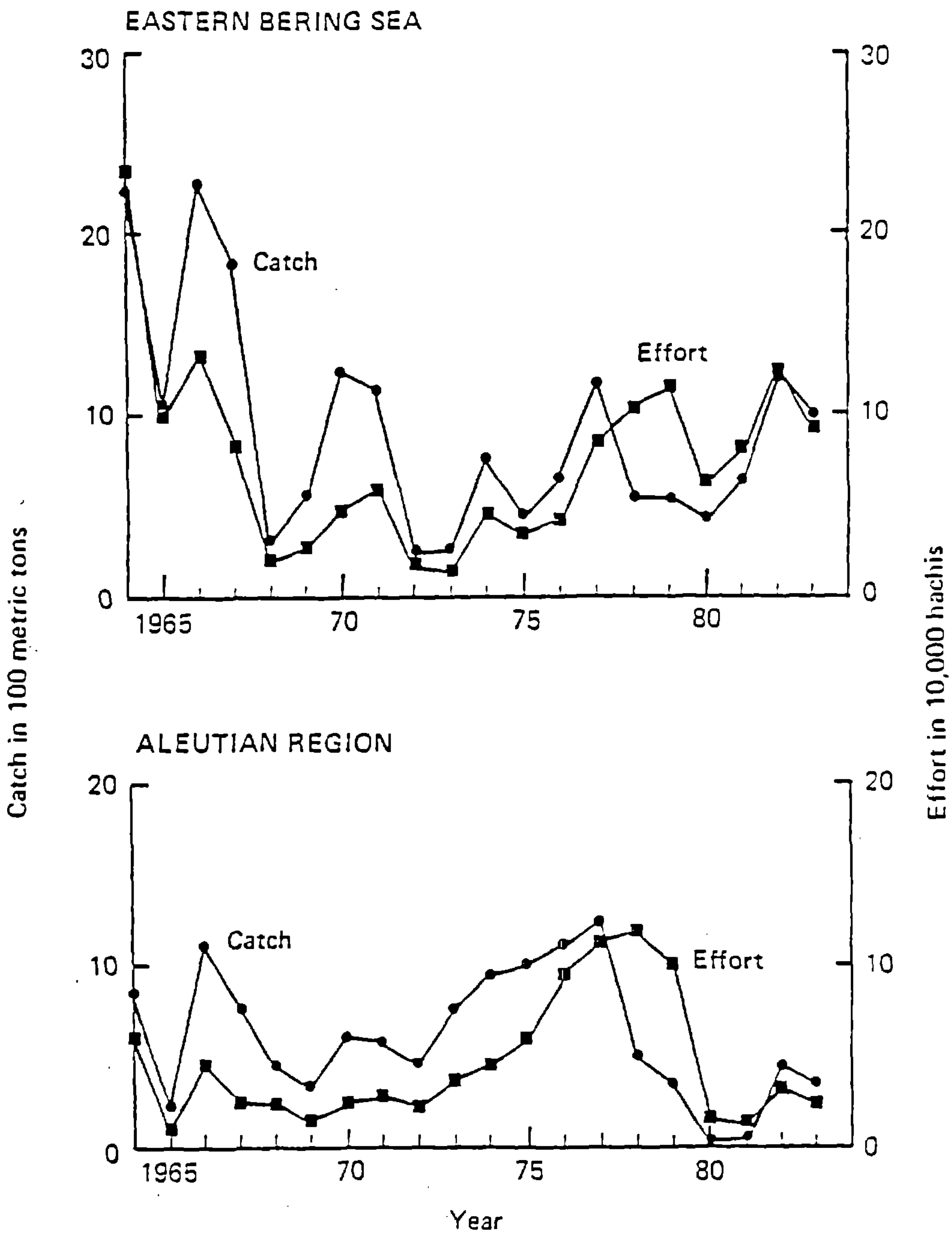

Figure 1. --Catch and effort trends of Japanese longline vessels targeting on sablefish in the eastern Bering Sea and the Aleutian, Islands region, 1964-83.

1977-78 there was a large drop in catches despite a minor increase in fishing effort. Effort continued to increase through 1979 with catches remaining at a low level, which provides further evidence that the stocks were in poor condition during those years.

Data collected by U.S. observers from Japanese longline vessels fishing at depths greater than 500 m provide another source for evaluating the condition of sablefish stocks (Table 4). Sablefish were not the dominant species in the sampled catches until 1984 in the eastern Bering Sea, but have been the dominant species in the Aleutian region since 1980. Thus, the Aleutian data may be a better indication of sablefish abundance than eastern Bering Sea data. Nevertheless, both sets of data show the same trends.

Catch per unit effort values show a general increase starting in 1981 or 1982 and continuing through 1984. The increases were 288% in the eastern Bering Sea between 1981 and 1984, and 477% in the Aleutian Islands between 1979 and 1984. Whether these data accurately reflect changes in sablefish abundance is difficult to evaluate because observer coverage increased during this time period (Table 5) and time periods fished varied between years. In addition, the average depth fished in 1984 in the eastern Bering Sea was 370 m greater than the previous year. Nevertheless, although the magnitude of the increases may be questioned, the increasing trend in abundance parallels that shown by the foreign reported CPUE data.

Abundance Estimates from Surveys

There are two series of Japan-U.S. cooperative surveys that provide biomass estimates for the exploitable population: trawl surveys and longline surveys. Trawl surveys have been conducted in the eastern Bering Sea slope region of International North Pacific Fisheries Commission (INPFC) statistical areas 1 and 2 in 1979, 1981, 1982, and 1985. Trawl surveys of the eastern Bering Sea shelf are conducted annually, but sablefish have never occurred on the shelf in large numbers until the 1977 year class appeared. Trawl surveys are conducted triennially in the Aleutian region and biomass estimates from these surveys are available for 1980 and 1983. The 1986 Aleutian survey is currently being conducted and will finish in late September. The Aleutian surveys also cover the Aleutian portion of INPFC Area 1 (north Aleutians east of 170°W) which is not included in the eastern Bering Sea slope surveys. The biomass estimates from the Aleutian Island portion of area 1 are added to the estimates from the eastern Bering Sea slope surveys to provide total biomass estimates for areas 1 and 2 combined.

Japan and the United States have conducted annual cooperative longline surveys in the Gulf of Alaska since 1978. This survey has included the Aleutian region since 1980 and the eastern Bering Sea since 1982. The longline survey catch data are stratified by 100 m depth intervals. Catch per unit of effort in units of fish per hachi are multiplied by the respective areas of each depth strata to obtain an index of relative population number (RPN). Relative population numbers by length group are calculated and then weighted by the mean body weight of fish by length category to produce indices of relative population weight (RPW). These surveys provided relative population weight indices for 1982-85 in the eastern Bering Sea and 1980-85 in the Aleutian region.

Table 4.--Japanese longline catch per unit of effort (CPUE) data for sablefish from hauls sampled by U.S. observers at depths greater than 500 m, 1977-84[a].

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

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

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

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

Table 5.--Percentage of Japanese longline catch sampled by U.S. observers in the eastern Bering Sea and the Aleutian Islands, 1977-84.

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

Sasaki (1986) has attempted to relate the longline indices of abundance. to biomass estimates from trawl surveys in the same area and year. Rose (1986), however, has found considerable length related variability between trawl and longline sablefish catch rates and felt that the relationship would vary by population depending on size composition. These findings suggest that the usefulness of a general, overall relationship is limited. Although trawl catch rates are biased and have limitations of their own, they are probably better measures of absolute abundance (based on the area swept technique) than are the longline catch rates.

Due to the uncertainties regarding absolute abundance estimates from the longline survey, the 1979-85 trawl surveys are considered to provide the most dependable estimates of biomass, but the estimates for the longline surveys are also presented and provide relative indices of abundance (Table 6.)

Eastern Bering Sea

Increases in commercial catches and abundance estimates from the fishery and research vessels all indicate that sablefish abundance has generally increased between 1980 and 1984. This increase reflects the recruitment of the unusually strong 1977 year class into the exploitable stock. This year class was first observed as age 1 juveniles in 1978 during the annual U.S. trawl survey of the eastern Bering Sea shelf (Fig. 2). Sablefish have rarely been observed on the shelf since the survey was initiated in 1971 but appeared in abundance in 1978. Subsequent surveys indicated that the 1977 year class persisted in continental shelf waters of the eastern Bering Sea through 1980. In 1981 the abundance on the shelf sharply declined, and there was a corresponding increase in abundance on the continental slope (Fig. 3). This was presumably due to the movement of these 4-year-old fish from the shelf to slope waters. Population estimates by length intervals (Fig. 3) from the 1979, 1981, and 1982 U.S.-Japan slope surveys show that population numbers on the slope quadrupled between 1979 (5.3 million fish) and 1982 (22.7 million fish).

The U.S.-Japan trawl surveys show a general increase in biomass between 1979 and 1982 in areas 1 and 2 of the eastern Bering Sea, and in the north Aleutian portion of eastern Bering Sea area 1 (Table 6). However, the 95% confidence intervals for the two estimates overlap extensively, indicating that they may not be significantly different.

The 1985 trawl survey biomass estimate shows an apparent decrease from 1982. This is contradictory to the trend shown in the longline survey (Table 6). In 1985, the biomass on the shelf increased so that overall there has been little change in biomass (t) of the shelf and slope combined since 1979 as shown below:

	Shelf	Slope	Total
1979	38,885	12,646	51,530
1981	7,740	39,435	47,175
1982	6,745	42,944	49,689
1985	15,155	34,720	49,875

Table 6.--Estimated biomass and relative population weight indices of sablefish from U.S.-Japan cooperative trawl and longline surveys.

Area	1979	1980	1981	1982	1983	1984	1985
Trawl surveys (biomass in t)							
Eastern Bering Sea (Areas 1 & 2)	12,600	--	39,400	42,900	--	--	34,720
(95% Confidence intervals)	(0-56,900)		(23,800-55,100)	(35,800-50,100)			(28,368-41,071)
Eastern Bering Sea (Area 1, N. Aleutians)	--	8,500	--	--	9,900	--	--
(95% Confidence intervals)		(0-17,500)			(400-19,300)		
Aleutian region (Area 5)	--	20,300	--	--	68,500	--	--
(95% Confidence intervals)		(8,100-32,400)			(0-143,200)		
Longline survey (relative population weight)							
Eastern Bering Sea (Areas 1 & 2)	--	--	--	33,538	26,029	38,513	55,148
Aleutian region (Area 5)	--	28,241	27,500	30,984	35,888	44,282	56,381

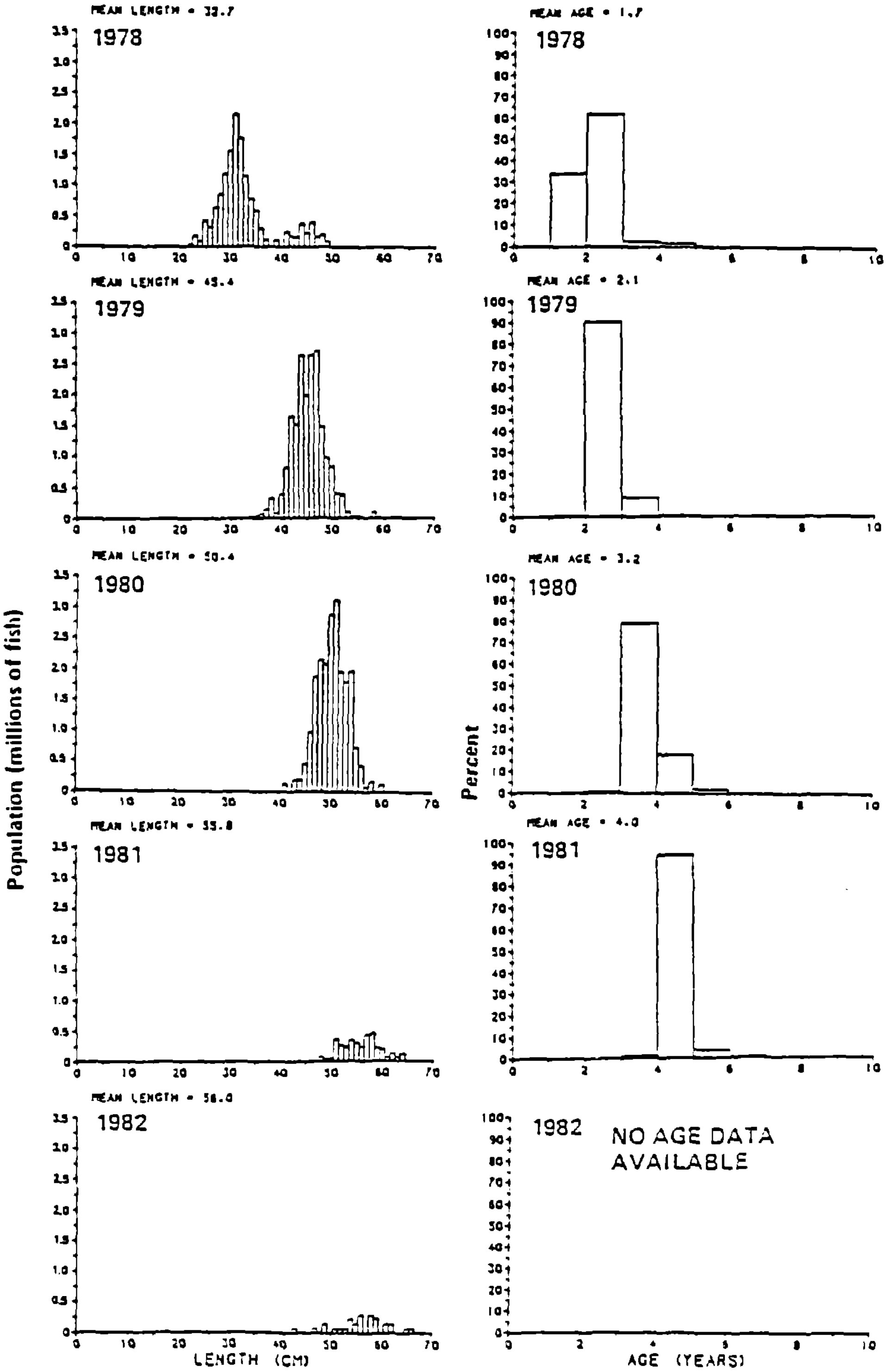

Figure 2.--Size and age composition of sablefish from the continental shelf area surveyed by U.S. research vessels, 1978-82. Age determinations for 1978 may be inaccurate due to differences in ageing structures; scales were used in 1978, and otoliths were used in subsequent years (Umeda et at. 1983).

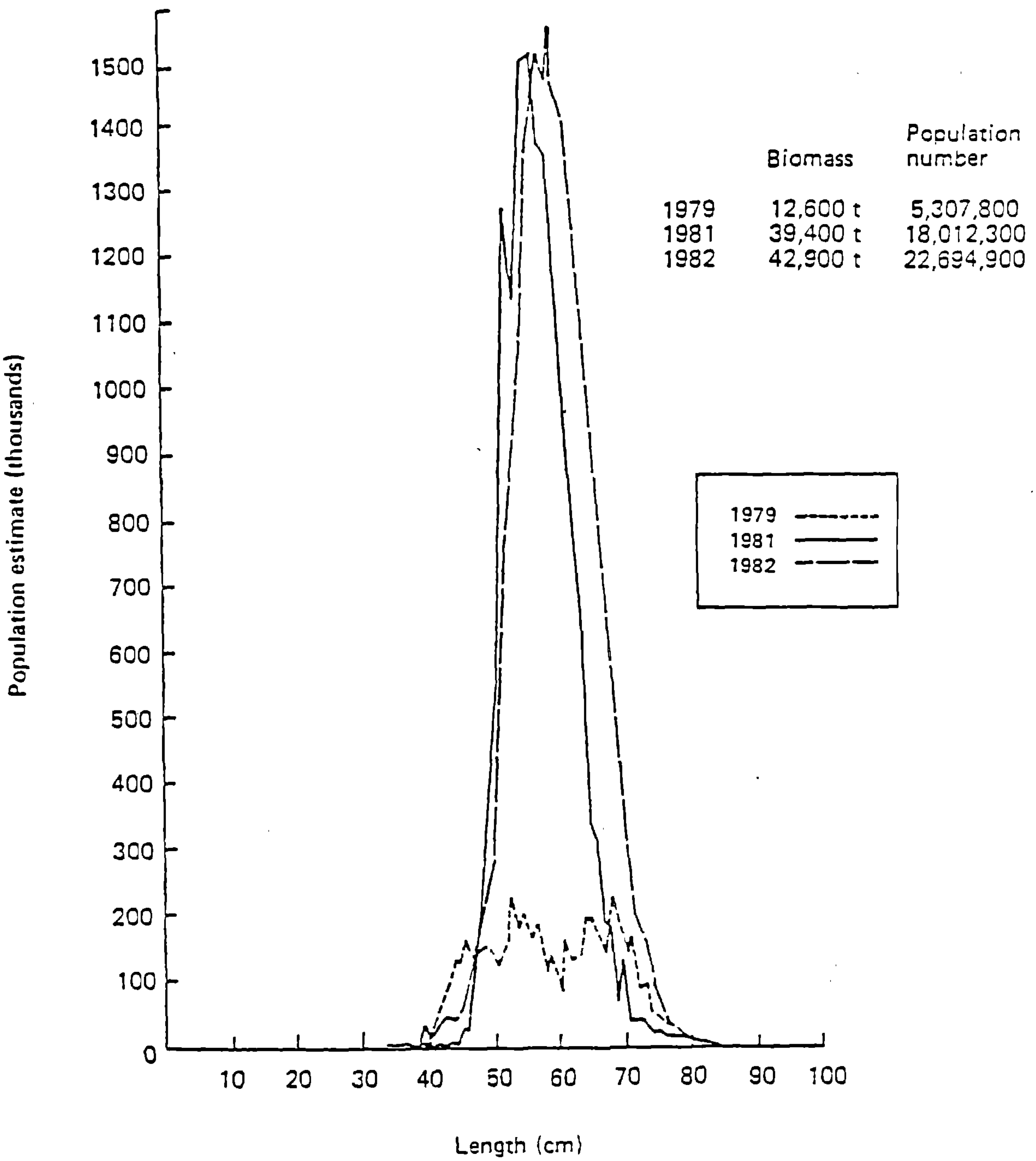

Figure 3. --Population estimates of sablefish by centimeter size interval on the continental slope of the eastern Bering Sea as shown by data from cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, 1982. Total estimated biomass and population number for the slope areas surveyed are also given.

Length-frequencies show that the size composition of fish on the shelf and slope were relatively the same in 1985 (Fig. 4). Perhaps there was some movement of fish between the slope and shelf to account for the apparent increase of shelf biomass and decrease of slope biomass between 1982 and 1985.

In 1985 the total eastern Bering Sea biomass in slope waters was 44,620 t (summed mean estimates from 1985 eastern Bering Sea areas 1 and 2 and 1983 north Aleutian area 1, Table 6). This is a 115% increase over the 1979 total biomass estimate for areas 1 and 2 of 21,100 t (summed mean estimates from 1979 eastern Bering Sea areas 1 and 2 and 1980 north Aleutian area 1). The increase probably reflects recruitment of the 1977 year class; however, the extent of the increases should be viewed with caution as the numbers are associated with wide variances and overlapping 95% confidence intervals. Relative population weight indices from the Japan-U.S. longline survey in the eastern Bering Sea show a 22% decrease in relative biomass from 1982 to 1983, and an overall increase of 69% from 1982 to 1985 (Sasaki 1986, Table 6).

There is some evidence that recruitment of the 1984 year class to the fishery in the eastern Bering Sea may be fairly strong. Length-frequency data from the 1986 trawl survey of the shelf shows a dominant mode of fish on the shelf at 43 to 50 cm which may represent 2 year olds of the 1984 year class (Fig. 5). This is the first evidence of relatively large numbers of age 2 fish on the eastern Bering Sea shelf since the 1977 year class was observed in these waters. The 1985 length frequency data from the shelf also showed a small mode at about 30 cm (Fig. 4). These fish are probably 1 year olds of the 1984 year class. Based on population numbers, the 1984 year class is not nearly as strong as the 1977 year class.

Aleutian Region

Joint Japan-U.S. trawl surveys of the Aleutian Islands region were conducted in 1980 and 1983. The 1986 survey is currently being conducted and data are not yet available. These surveys were the first comprehensive assessment of Aleutian groundfish resources in which the United States has participated that encompassed areas north and south of the Aleutian chain between Attu Island and Unimak Pass. Estimates of sablefish biomass from these surveys are given in Table 6.

The trawl survey data indicated a 237% increase of sablefish biomass between 1980 and 1983. Most of the increase occurred in the central Aleutians, particularly north of the chain where biomass estimates increased nearly five times from 10,100 t in 1980 to 47,100 t in 1983 (Fig. 6). The Aleutian trawl survey biomass estimates are also characterized by overlapping 95% confidence intervals (Table 6). These increases are also believed to reflect the recruitment of the 1977 year class, but the extent of the increases is not clear. The Japan-U.S. longline surveys also showed increases in relative biomass. Relative biomass increased 200% between 1980 and 1985. The time lag of increases shown in the trawl and longline surveys may be due to the age at recruitment to the gears. Longlines tend to select the larger and hence older sablefish.

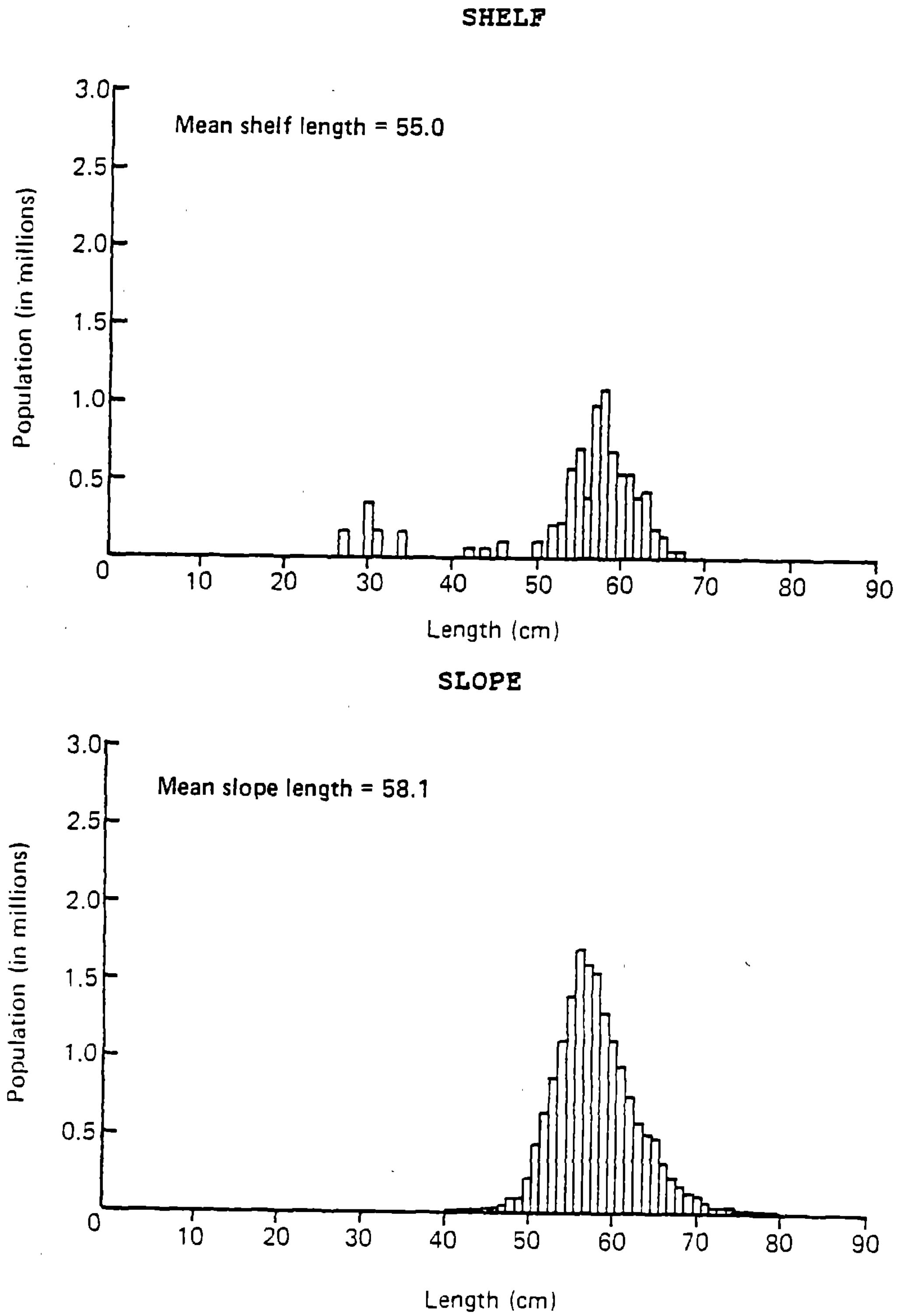

Figure 4.--Size composition of sablefish from the continental shelf and slope of the eastern Bering Sea as shown by the 1985 U.S.-Japan trawl survey.

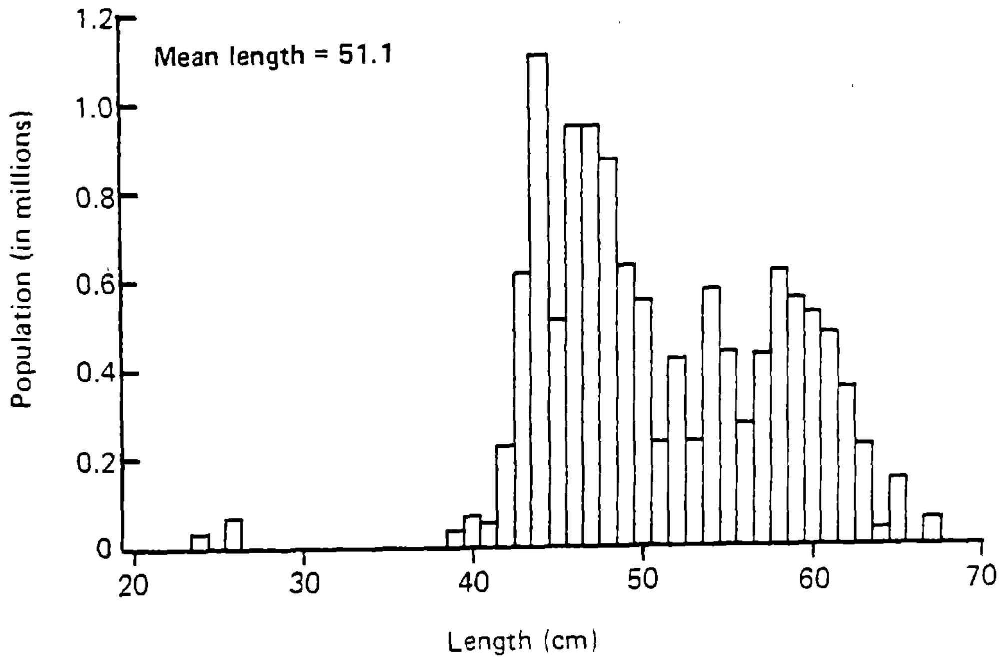

Figure 5.--Size composition of sablefish from the continental shelf of the eastern Bering Sea as shown by the 1986 U.S. trawl survey.

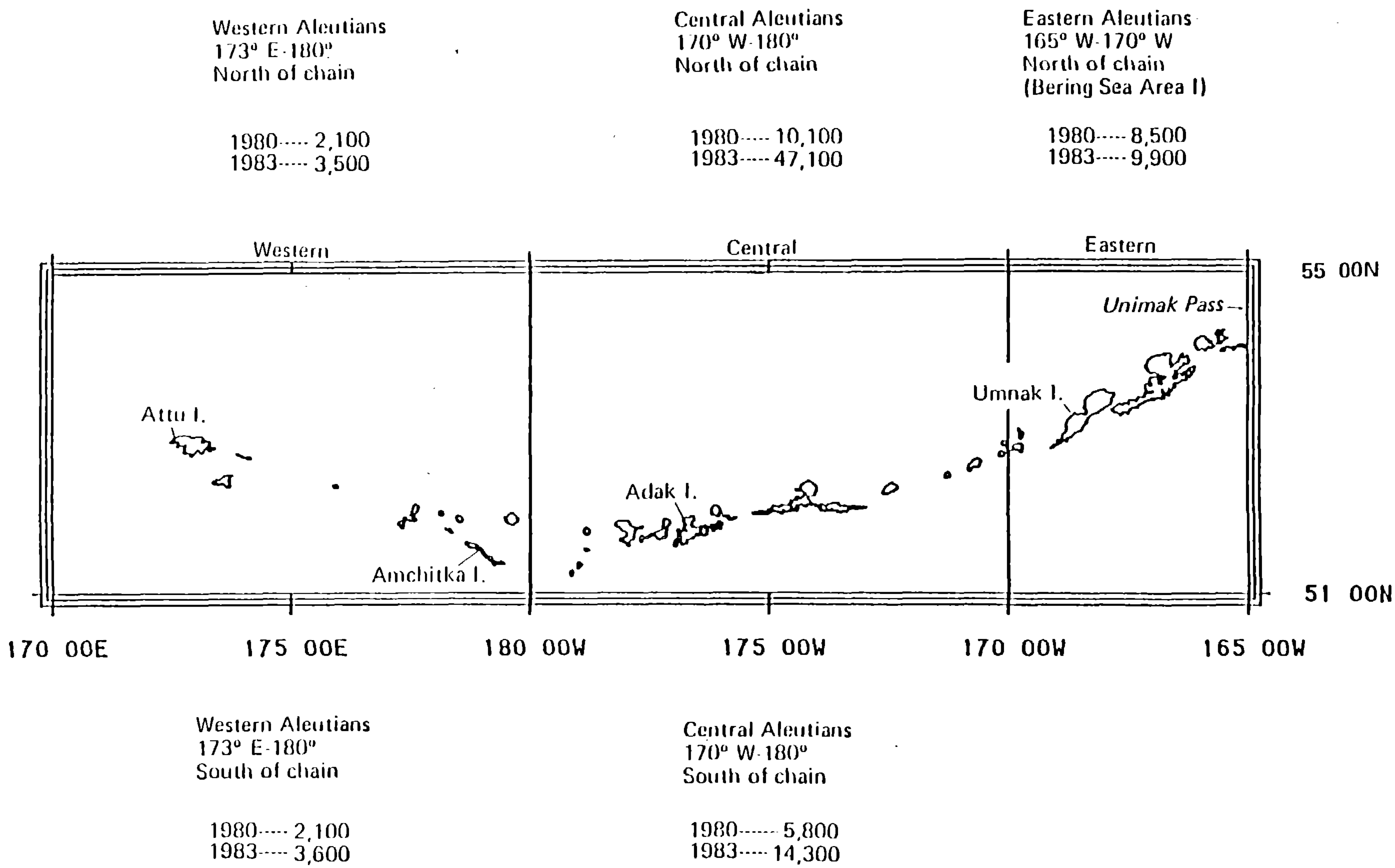

Figure 6. --Biomass estimates of sablefish in metric tons (t) in the Aleutian Islands region, by area, as shown by 1980 and 1983 U.S.-Japan cooperative trawl survey data.

STOCK REDUCTION ANALYSIS

Stock reduction analysis (SRA) (Kimura et al. 1984, Kimura 1985) using Schnute's (1985) form of the delay-difference equation was applied. In addition to catch-in-weight data, the model requires estimates of several other parameters: the instantaneous natural morality rate (M), the delay-difference growth coefficients (p,w) (Schnute 1985), the age of recruitment to the fishable biomass (k), the Cushing recruitment coefficient (r) (Kimura et al. 1984), and for the analysis presented here, current biomass.

Natural mortality has not been determined for sablefish in the eastern Bering Sea region. A value of 0.1 was used for the SRA analysis based on estimates for sablefish of 0.1 off the west coast of Canada (McFarlane et al. 1985) and 0.112 in the Gulf of Alaska (Funk and Bracken 1984). Delay-difference growth coefficients were estimated from age data collected in 1980 by U.S. observers in the eastern Bering Sea (P = 0.813, W = 0.655). The age at recruitment was 4 years based on data of Umeda et al. (1983). The Cushing recruitment coefficient (r) describes the strength of the stock-recruitment relationship. When r=0, recruitment is constant and the population is highly resilient. When r=1, recruitment is proportional to biomass and when the population is reduced it is incapable of rebuilding. For a value of r=1, there is no sustainable level of fishing. Values of r from 0.00 to 0.50 were used in the SRA analysis. The estimate of present biomass was 113,000 t (combined biomass from Japan-U.S. trawl surveys in the eastern Bering Sea and Aleutian Islands). The SRA analysis was run assuming that the stock was close to its unexploited state in 1959 and using the catch data from Tables 1 and 2.

Solutions to the SRA equations are given in Table 7. They suggest that virgin biomass was within the range of 190,500 to 243,000 t and that the biomass that produces maximum sustainable yield (MSY) is within the range of 72,100 t to 86,100 t. The analysis also indicates that MSY for the eastern Bering Sea-Aleutian regions lie in the range of 4,639-7,800 t. Catches in this region have averaged over 3,000 t since 1977 (Tables 1 and 2).

According to the SRA analysis, present biomass is above the biomass which produces MSY. This relatively good condition can be attributed to recruitment of the strong 1977 year class. It should be noted that the SRA equations are dependent on the type of recruitment used, which may not accurately represent the sablefish stock-recruitment relationship. Strong year classes which cannot be incorporated into the Cushing recruitment model can significantly increase yields over a short term.

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 MSY at 50,300 t for the Bering Sea to California region. This estimate is derived from a general production model. The MSY estimate has been apportioned to regions according to historical catches: Bering Sea, 25%; Aleutian region, 4%; Gulf of Alaska, 47%; and the British

Table 7.--Estimates of virgin biomass, maximum sustainable yield (MSY) and biomass producing MSY based on stock reduction analysis (Kimura et al. 1984 and Kimura 1985).

Cushing recruitment coefficient (r)	Virgin biomass (B_1)	Ratio present biomass to virgin biomass	MSY	Biomass producing MSY
0.0	190,500	0.594	7,802	86,077
0.25	217,000	0.521	6,820	75,245
0.50	243,000	0.465	4,639	72,069

Columbia-Washington region, 25% (Low and Wespestad 1979). Therefore, MSY was estimated at 13,000 t in the Bering Sea and 2,100 t in the Aleutian region. Current CPUE and biomass trends indicate that MSY is probably overestimated in the Bering Sea and underestimated in the Aleutian Islands region by this method. The 13,000 t estimate for the Bering Sea includes areas 3 and 4 of the western Bering Sea. Therefore, MSY for the eastern Bering Sea alone was less than 13,000 t.

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

The MSY estimates from the SRA analysis range from 4,640 to 7,800 t for the eastern Bering Sea-Aleutian regions combined. This MSY was apportioned to the eastern Bering Sea and Aleutian Islands regions based on percentages of the RPW values in each region from the longline surveys. The MSY thus ranges from 2,230 to 3,740 t for the eastern Bering Sea region, and from 2,410 to 4,060 t for the Aleutian region.

ACCEPTABLE BIOLOGICAL CATCH

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

Low exploitation rates and the recruitment of the strong 1977 year class have improved stock conditions in both regions during 1981-85 from the low levels of abundance during 1977-80. Exploitation rates of 3.8 and 1.3% appear very conservative for sablefish. Sasaki (1985) has suggested a sustainable exploitation rate of 5% which was applied to recent biomass estimates to calculate an ABC of 2,600 t in the eastern Bering Sea and 3,400 t in the Aleutian region for 1985.

The SRA analysis suggests that current biomass levels may be somewhat above that which produces MSY. The MSY values derived from SRA ranged from 2,230 to 3,740 t in the eastern Bering Sea and from 2,410 to 4,060 t in the Aleutian region. Based on the improved condition of the stock, the ABC is estimated to equal the upper end of the MSY range or 3,700 t in the eastern Bering Sea and 4,000 t in the Aleutian region.

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PACIFIC OCEAN PERCH

by

Daniel H. Ito

INTRODUCTION

Pacific ocean perch, Sebastes alutus, are found in commercial quantities along the outer continental shelf and upper slope regions of the North Pacific Ocean and Bering Sea. Chikuni (1975) concluded that in the Bering Sea-Aleutian Islands region (the geographic area covered in this series of reports) there are two stocks--the eastern Bering Sea stock and the Aleutian stock (Fig. 1). Chikuni delineated these stocks on the basis of areal differences in growth rate and length-weight, age-length, and length-fecundity relationships of adult fish. Although biochemical genetic analyses by Wishard and Gunderson (1981) suggested that the species is not made up of discrete, sharply differentiated subpopulations, the two stocks described by Chikuni (1975) have been maintained in the management regime of the North Pacific Fisheries Management Council (NPFMC).

Pacific ocean perch were highly sought after by Japanese and Soviet fleets and supported major trawl fisheries throughout the 1960's. These fisheries began in the eastern Bering Sea region around 1960 and expanded into the Aleutian region in 1962. Catches peaked at 47,000 metric tons (t) in the eastern Bering Sea in 1961 and at 109,000 t in the Aleutian region in 1965 (Table 1). Catches have since declined sharply. In 1985 catches were but a small fraction of the peak levels: 825 and 513 t in the eastern Bering Sea and Aleutian regions, respectively.

It is highly probable that prior to the implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) in 1977 the reported catches of Pacific ocean perch included other species of rockfish--particularly northern rockfish, S. polyspinis; rougheye rockfish, S. aleutianus; shortraker rockfish, S. borealis; and sharpchin rockfish, S. zacentrus. These four species are similar in color and physical characteristics to S. alutus.

Even with MFCMA, however, the reporting requirements have not always been consistent. In 1977 and 1978 the category "Pacific ocean perch" included only S. alutus; all other members of the rockfish genera Sebastes and Sebastolobus were included in the category "other fish." In 1979 the NPFMC revamped its strategy for managing rockfish in the Bering Sea-Aleutian region. The four alutus-like species mentioned above (northern, rougheye, shortraker, and sharpchin rockfish) were grouped with S. alutus in the so-called "Pacific ocean perch complex." Other members of the genera Sebastes and Sebastolobus remained in the "other fish" category in 1979 but from 1980 on have been placed in a separate category "other rockfish."

Of the five species making up the Pacific ocean perch complex, S. alutus has been the most widely studied with respect to its distribution and biology. Accordingly, the analyses here deal almost exclusively with S. alutus, and the other four species of the complex are primarily dealt with in the other rockfish section of this report.

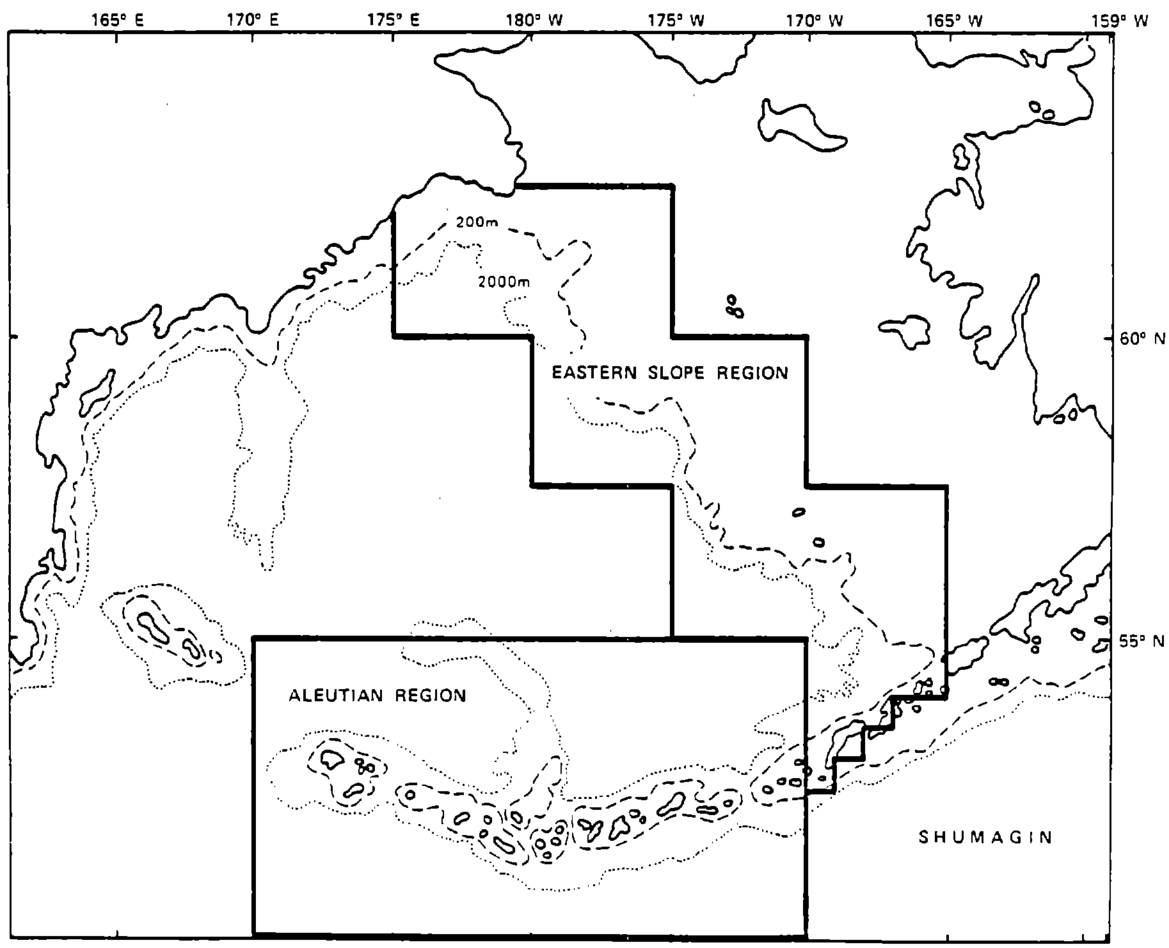

Figure 1 .--The Bering Sea with the two stock areas (regions) for Pacific ocean perch delineated.

Table 1.--Catch (thousands of t) of Pacific ocean perch (*Sabastes alutus*)[a] from the eastern Bering Sea and Aleutian Islands regions, by fishery category, 1960-85[b].

Year	Eastern Bering Sea				Aleutian Islands				Regions Combined			
	Japan	USSR	Others[c]	Total	Japan	USSR	Others[c]	Total	Japan	USSR	Others[c]	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	0.1	1.7	5.3	Tr	0.2	5.5	6.9	Tr	0.3	7.2
1980	---	---	---	1.1	---	---	---	4.7	---	---	---	5.8
1981	---	---	---	1.2	---	---	---	3.6	---	---	---	4.8
1982	---	---	---	0.2	---	---	---	1.0	---	---	---	1.2
1983	---	---	---	0.2	---	---	---	0.3	---	---	---	0.5
1984	---	---	---	0.3	---	---	---	0.6	---	---	---	0.9
1985	---	---	---	0.8	---	---	---	0.5	---	---	---	1.3

[a]The 1960-76 catches probably contain rockfish other than S. *alutus*, the 1977-78 catches are S. *alutus* only, and the 1979-85 catches contain the five species Pacific ocean perch complex (see text).

[b]Catch data may differ from earlier status of stocks reports. The data used here, however, is believed to be the most reliable presently available.

[c]Republic of Korea, Taiwan, Poland, Federal Republic of Germany, Canada, joint venture, and U.S. domestic.

Sources: 1960-70: Forrester et al. (1978); 1971-76: Forrester et al. (1983); 1977-84 foreign and joint venture: Berger et al. (1906); 1977-85 U.S. domestic: Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. Fifth Avenue, Portland, OR 97201.

Tr: Trace less than 50 L.

CONDITION OF STOCKS

Eastern Bering Sea Region

Relative Abundance

Ito (1986) examined catch per unit effort (CPUE) data from the Japanese commercial trawl fisheries (1963-84) and found that by the late 1970's, CPUE values had dropped in excess of 90% from those of the early 1960's. Since the late 1970's, these values have declined to (and remain at) at historically low levels. The CPUE data in more recent years, however, may not be a good index of stock abundance because most of the Japanese trawl effort in the eastern Bering Sea is now directed to species other than Pacific ocean perch.

Estimates of Absolute Abundance

Trawl Surveys--Data from the 1979, 1981, 1982, and 1985 cooperative trawl surveys by the Northwest and Alaska Fisheries Center (NWAFC) and the Fisheries Agency of Japan provide biomass estimates for Pacific ocean perch in the eastern Bering Sea. These surveys were conducted both on the continental shelf and the continental slope, but almost all catches of Pacific ocean perch were taken by Japanese research trawlers fishing on the slope at depths greater than 100 fathoms. For this reason, only data collected by Japanese vessels were employed to calculate S. alutus abundance estimates.

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 2). In 1985, this estimate jumped to 32,392 t; however, this sixfold increase from 1982 to 1985 appears unreasonable. The 95% confidence interval about the 1985 point estimate is extremely wide (Fig. 2) and points to the problems of sampling this species. Schools of Pacific ocean perch may be randomly distributed and not adequately sampled by systematic trawl surveys, thereby resulting in highly variable estimates. Another reason for the observed increase in the 1985 estimate may result from an attempt in 1985 to trawl rougher bottom (where Pacific ocean perch may be more concentrated) than in previous years.

The surveys conducted in 1979, 1981, 1982, and 1985 did not sample the Aleutian Islands (long. 165°W to 170°W) portion of the eastern Bering Sea management area. This area, however, was sampled during the 1980 and 1983 U.S.-Japan trawl surveys of the Aleutian Islands which provided biomass estimates of about 7,000 t and 95,000 t, respectively. Because of the wide variances of these latter estimates, a conservative approach was taken in estimating biomass for the entire eastern Bering Sea region by using the 1980 point estimate from the Aleutian Islands segment and the average of the 1979-85 estimates from the eastern Bering Sea slope. Using this approach, S. alutus biomass in the eastern Bering Sea at depths greater than 100 fathoms was estimated at 20,044 t.

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

Table 2.--Estimated population numbers and biomass of *Sebastes alutus* in the eastern Bering Sea slope region (>100 fm) as shown by data from cooperative U.S.-Japan trawl surveys in 1979-85, using Japanese data only.

Year	Mean Estimates[a] Population numbers (millions)	Biomass (t)	95% Confidence intervals for biomass estimates (t)
1979	6.322	4,459	0 - 9,217
1981	14.317	9,821	5,567 - 14,074
1982	7.781	5,505	3,074 - 7,937
1985	64.133	32,392	9,390 - 55,394

[a]These estimates do not represent the entire eastern Bering Sea region. The Aleutian Islands portion (165°W to 170°W long.) of this area was not covered by the 1979-85 U.S.-Japan cooperative trawl surveys (see text).

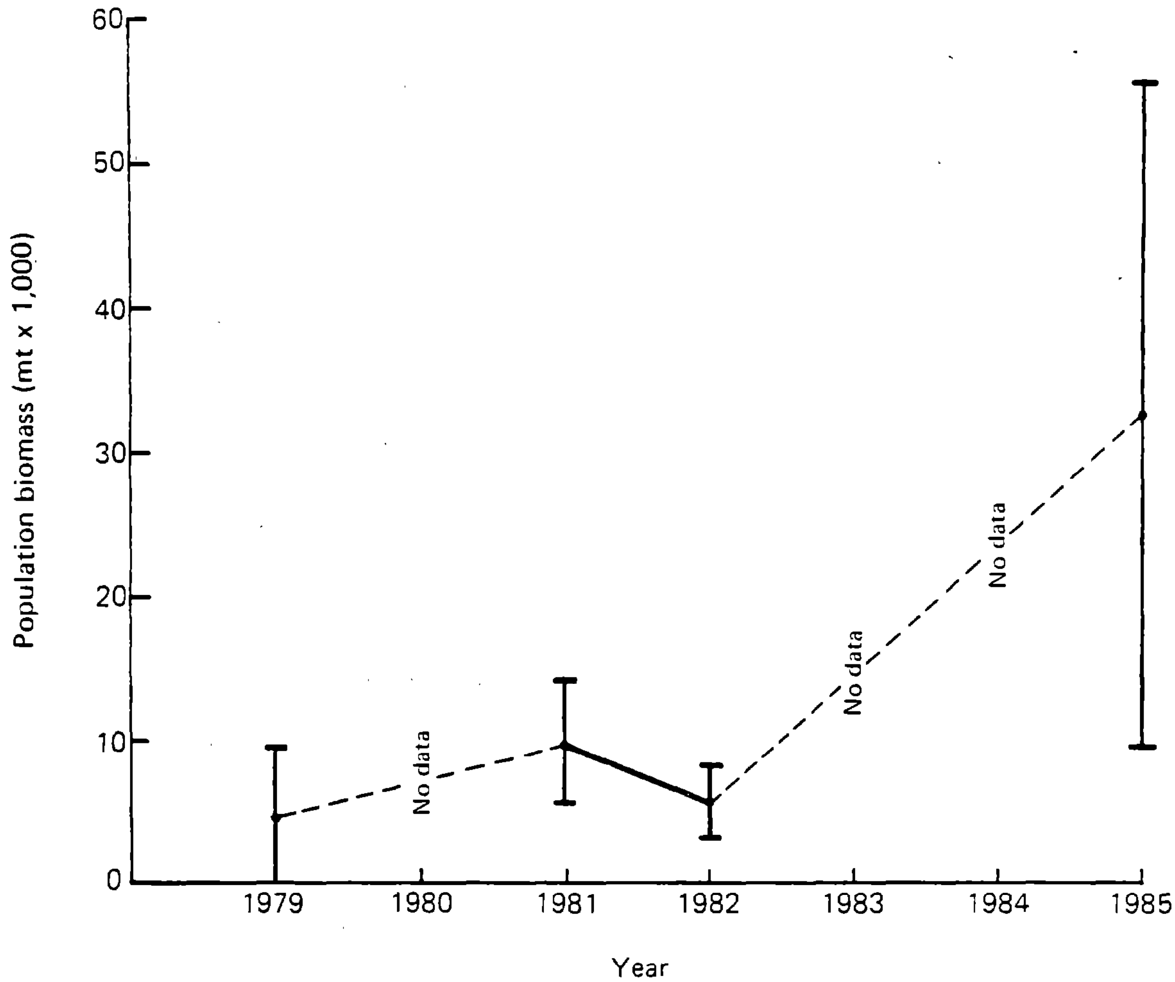

Figure 2.--Biomass estimates and 95% confidence intervals for Sebastes alutus along the continental slope of the eastern Bering Sea as shown by U.S.-Japan cooperative bottom trawl surveys, using Japanese data only.

difficult, particularly with effort data from the eastern Bering Sea. Reduced quotas, 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. Ito (1982) applied cohort analysis to catch-at-age data from the eastern Bering Sea fishery based on the equations of Pope (1972). Catch and age data (1963-79) were derived from Chikuni (19751, 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. 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).

<u>Virtual Population Analysis (VPA)</u>--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 years. 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 (Fig. 4), like those from cohort analysis, indicated a long-term decreasing trend in biomass for the eastern Bering Sea stock. Depending on the initial F-value chosen, this stock declined 60.4-98.8% during the 16-year period from 1963 to 1979. Regardless of the F-value used, however, the resulting biomass trends converged back toward a level of

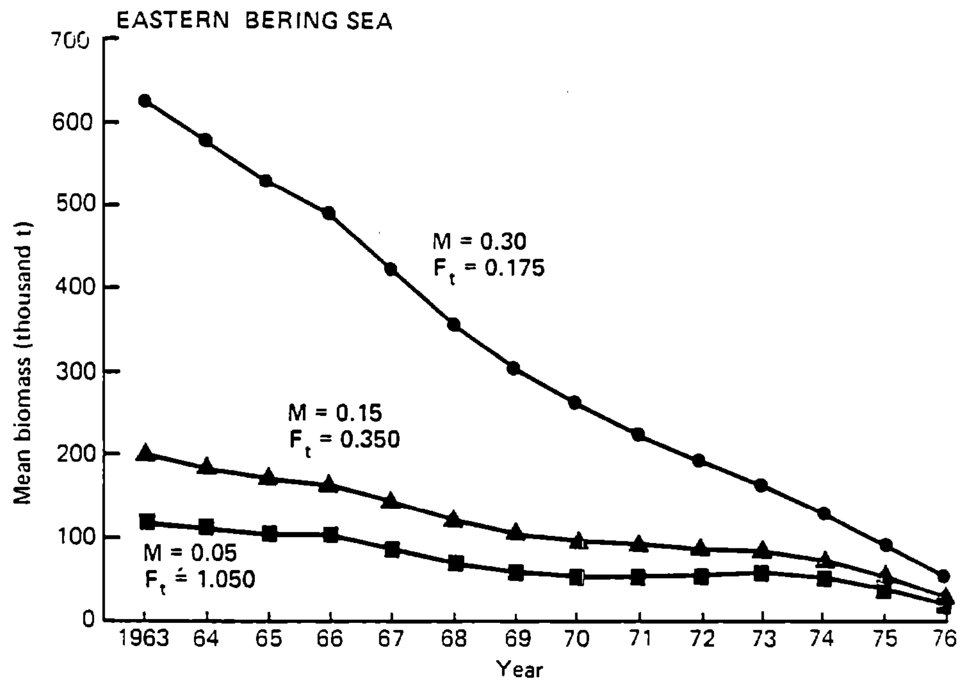

Figure 3.--Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by cohort analyses using various estimates of natural (M) and terminal fishing mortalities (F_t).

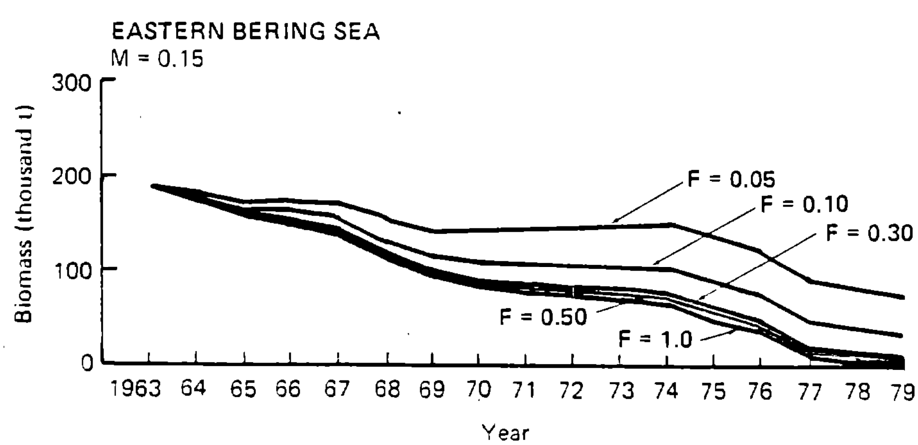

Figure 4.--Trends in abundance for Pacific ocean perch from the eastern Bering Sea region estimated by virtual population analyses using various estimates of fishing mortalities (F).

about 188,000 t. This convergence point is probably a good estimate of virgin biomass assuming, of course, that M = 0.15 and the catch-at-age data are accurate.

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

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

where M = natural mortality rate and B_o = the virgin (unexploited) biomass of the exploitable stock. The B_o estimate was calculated by assuming knife-edge recruitment at 9 years and summing the age-specific biomass estimates from ages 9 to 20 years 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 ageing studies indicate that Pacific ocean perch may be much older than previously thought (Beamish 1979; Archibald et al. 1981; Chilton and Beamish 1982).

Stock Reduction Analysis (SRA)--Kimura and Tagart (1982) developed a biomass-based method of stock assessment (SRA) that links the exponential form of the catch equations when age data are insufficient or unavailable. Essentially, given n years of catch data (in biomass) and an estimate of M, SRA provides estimates of B(1) (the initial population biomass); P (the ratio of final biomass to initial biomass); and R (recruitment biomass), consistent with the catch history and expected levels of recruitment. Independent estimates of any of these factors (from say, modeling, hydro-acoustic surveys, analysis of CPUE, etc.) 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 (Kimura et al. 1984) are required. The age at recruitment was assumed to be k = 9 years and natural mortality M = 0.05 (Archibald et al. 1981). Growth data from Archibald et al. (1983) was used to estimate a Brody growth coefficient of P = 0.38. These parameter values are consistent with the older ages derived from sectioned and break/burned otoliths.

Balsiger et al. (1985) carried out the SRA under a variety of model parameters. The results from each parameter set provided a historical trace of the fishable biomass (Fig. 5). with the exception of the constant recruit-ment scenario, the results indicated that the stock has maintained itself at a fairly low but constant level since the early 1970's. Under the constant recruitment condition (i.e., r = 0.0, where r is a parameter in the recruitment model), biomass appears to have increased since 1977. Although this suggests that the stock is rebuilding, the reader should keep in mind that a constant

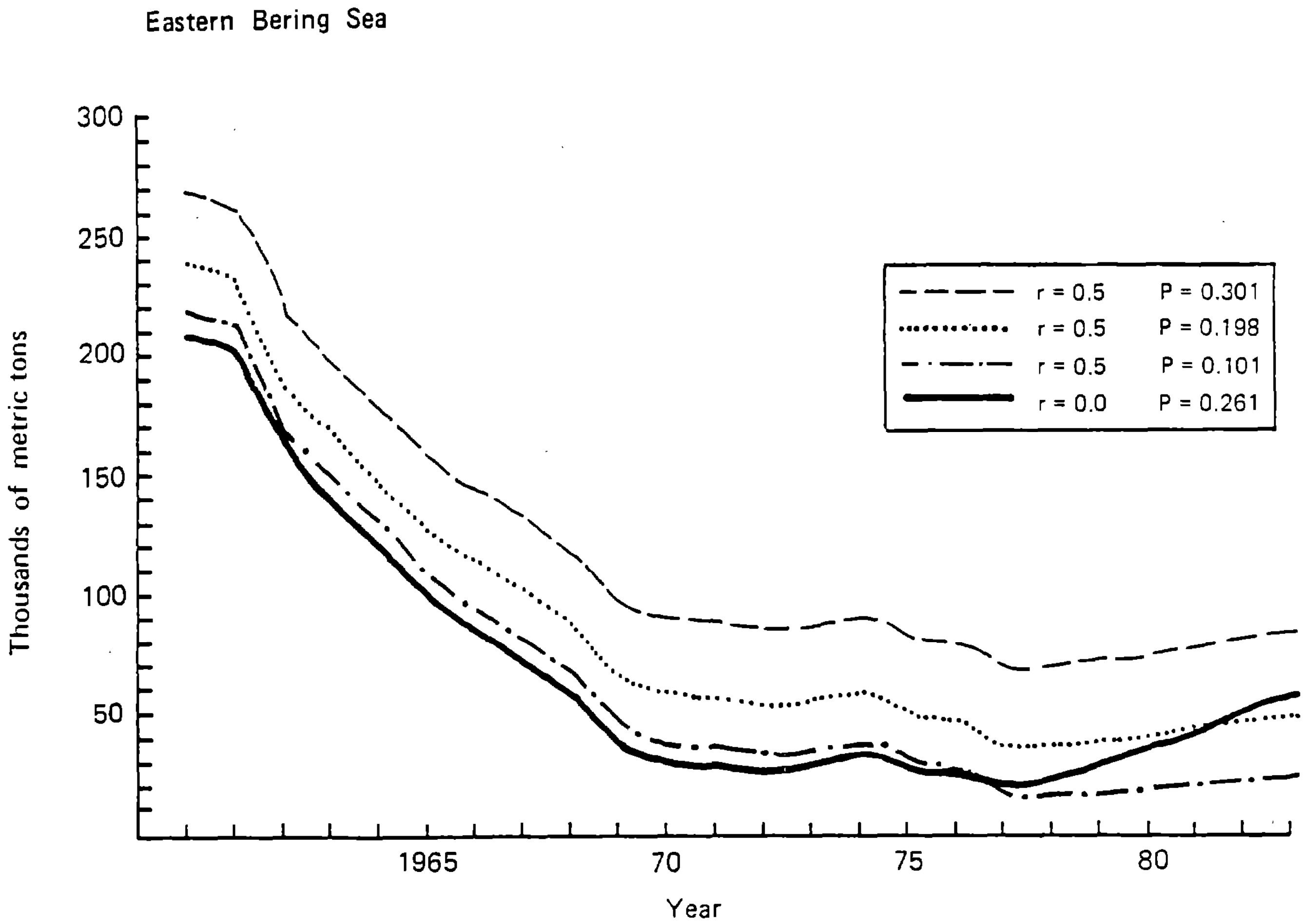

Figure 5.--Estimated population biomass for Pacific ocean perch from the eastern Bering Sea region (assuming M = 0.05 P = 0.38) over time for various stock reduction analysis fit's (from Balsiger et al. 1985).

recruitment scenario reflects the most optimistic view. That is, recruitment to the fishable biomass will be the same year after year regardless of the population size.

The results also indicated that the virgin fishable biomass in the eastern Bering Sea was between 210,000 and 270,000 t. This is not a statistical interval, but an interval consistent with various model parameter scenarios. A range of MSY estimates were also calculated using the formulas described in Kimura et al. (1984). The high estimate of MSY was obtained by assuming a P value of about 0.25 with constant recruitment (i.e., r = 0.0). This estimate amounted to 4,984 t. A low estimate of MSY was calculated by assuming a P value of about 0.20 with moderate recruitment (i.e., r = 0.5). The MSY estimate in this case totaled 2,840 t. One property of SRA relevant here is that if r = 1.0, no sustainable yield is possible regardless of the value of P.

Length and Age Composition

Length data collected 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, 1982, and 1985 were 36.3, 34.0, 35.0 and 32.3 cm, respectively. The 1981 and 1982 length distributions indicated the possible recruitment of a relatively strong year class and recent length data from the 1985 survey supports this (Fig. 6). Ito (1986) indirectly estimated the age of the incoming modes in 1981 and 1982 at 6 and 7 years, respectively. These ages correspond with the 1975 year class. However, this year class cannot be verified until the otoliths from the surveys are read.

Aleutian Islands Region

Relative Abundance

Ito (1986) examined CPUE data from Japanese trawl fisheries operating in the Aleutian Islands region. His analyses indicated that Pacific ocean perch abundance dropped precipitously throughout the 1960's and 1970's. For example, CPUE by vessel classes 4 and 7, which have historically accounted for the majority of Pacific ocean perch catch by stern trawlers, dropped in excess of 90% from 1969 to 1979. More recent CPUE data, however, may not be a good index of stock abundance because much of the trawl effort is now directed to species other than Pacific ocean perch.

Estimates of Absolute Abundance

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

The exploitable biomass of Pacific ocean perch in the Aleutian Islands region (long. 170°E to 170°W) was estimated at about 107,800 t in 1980 and 119,920 t in 1983. Overlapping confidence intervals between the two estimates indicate that this increase was not significant. As in the case of the eastern Bering Sea, the actual Pacific ocean perch biomass is questionable because of the large variances in the trawl estimates.

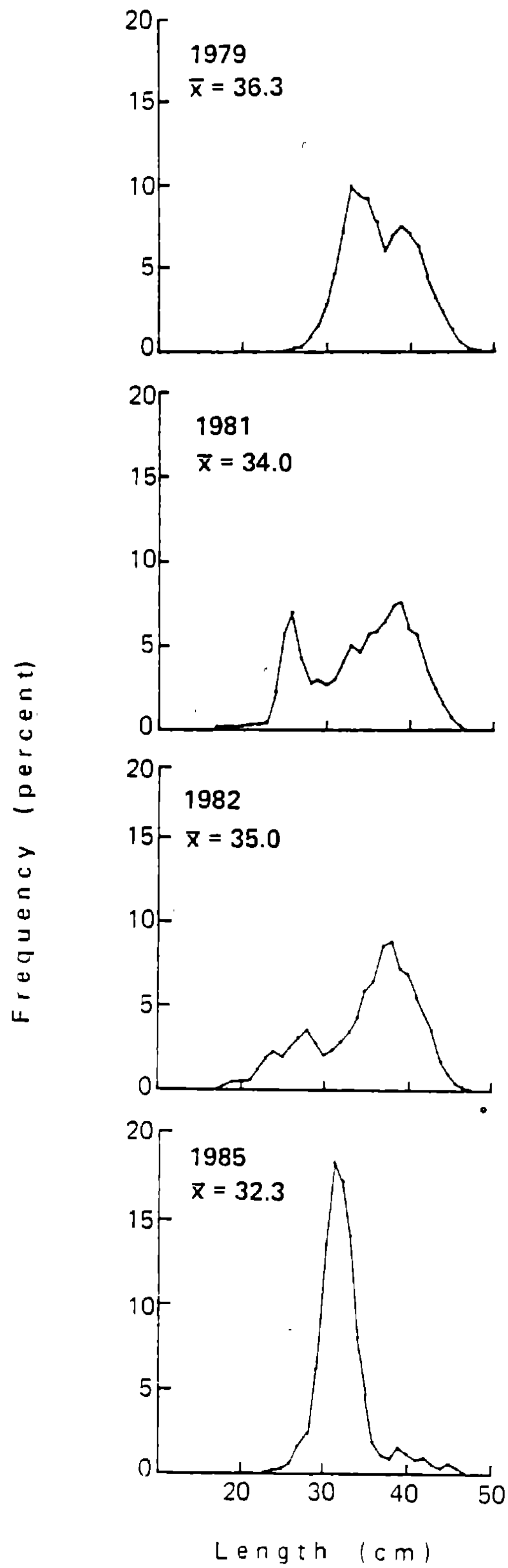

Figure 6.--Size composition of Pacific ocean perch in the eastern Bering Sea as shown by data collected during the cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, 1982, and 1985.

Cohort Analysis--Ito (1982) applied cohort analysis to catch-at-age data from the Aleutian Islands Pacific ocean perch stock. As with the Bering Sea cohort analysis, the catch-at-age data (1964-79) used in the cohort analysis for the Aleutian stock were derived from Chikuni (1975), foreign reported catches, and U.S. observer databases. Matural 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, a reduction of about 91%.

Because of the uncertainty regarding the true values of the input parameters, Ito (1982) further 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).

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.

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. 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 years, 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.

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

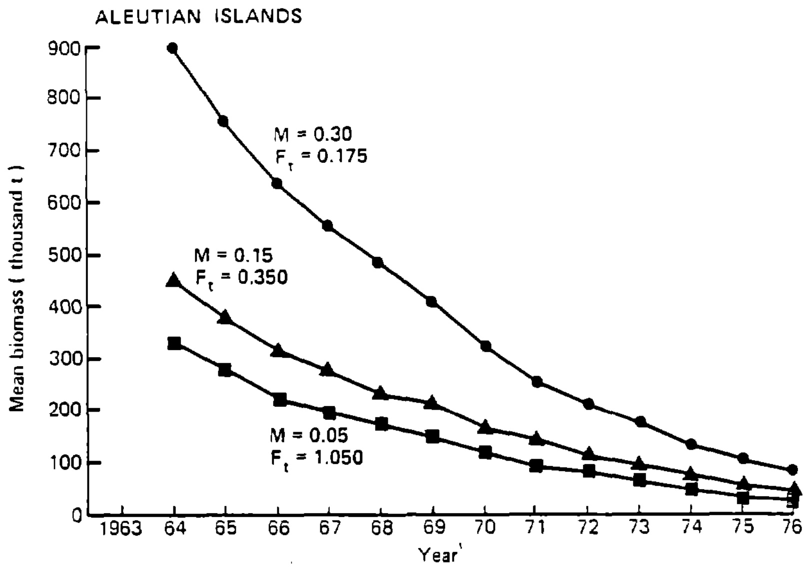

Figure 7.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by cohort analysis using various estimates of natural (M) and fishing mortalities (F_t).

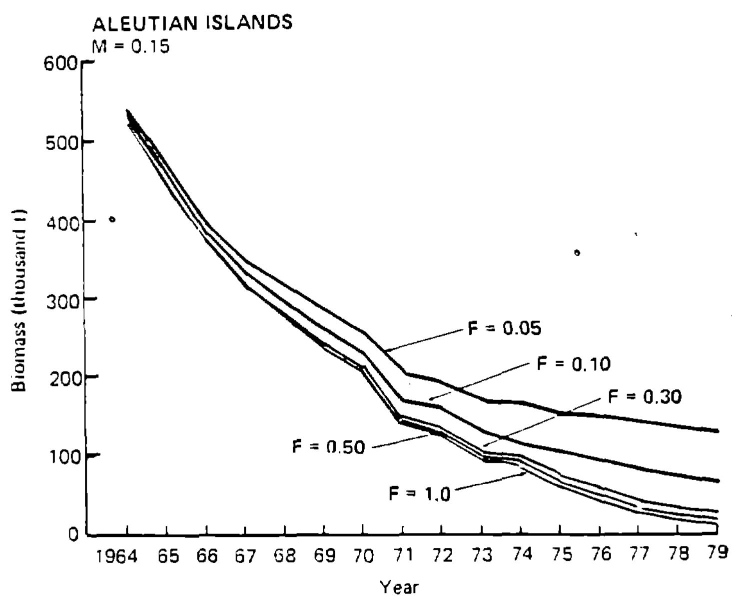

Figure 8.--Trends in abundance for Pacific ocean perch from the Aleutian region estimated by virtual population analysis using various estimates of fishing mortalities (F).

Similiar to results from SRA for the eastern Bering Sea stock, the Aleutian stock appears to have maintained itself at a fairly low but constant level since the early 1970's. (Fig. 9). Under the constant recruitment scenario (i.e., $r = 0.0$), however, biomass appears to have increased since 1977. Again the reader is reminded that a constant recruitment situation reflects the most optimistic view. Estimates of virgin biomass ranged from 500,000 to 620,000 t.

Estimates of MSY were calculated in a similar manner as those for the eastern Bering Sea stock. The SRA results indicated a range of MSY values from 6,627 to 11,864 t. It should be noted again, however, that if recruitment is proportional to biomass (i.e., $r = 1.0$), no sustainable yield is possible regardless of the value of P.

Length and Age Composition

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

Pacific ocean perch caught by these trawlers ranged in length from 16 to 50 cm. The average size increased from 30.8 cm in 1977 to 33.2 cm in 1981 and then decreased sharply to 30.1 cm in 1982 (Fig. 10). The commercial fishery appears to be dependent on a wide range of ages, 4 to 20 years. From 1978 to 1980, the average age in the catch decreased from 11.0 to 9.2 years.

Based on length data collected from the 1980 and 1983 Aleutian Islands surveys, it appears that one or more strong year classes have entered the population (Fig. 11). The mean size has dropped from 32.4 cm in 1980 to 30.2 cm in 1983, with a corresponding shift in the dominant mode from 34 cm in 1980 to 28 cm in 1983.

Otoliths collected during the 1983 survey were read using the more recent break and burn ageing technique. The resulting ages, which ranged from 1 to 98 years, were used to develop an age-length key to estimate the percent of total population by age (Fig. 12). The mean age in the population was estimated at 13.7 years. Of particular significance is the presence of the strong 1976 year class. This year class at age 7 comprised greater than 26% of the total population. The 1975 and 1977 year classes appear relatively strong as well. The combination of the 1975, 1976 and 1977 year classes made up over 56% of the total population in the Aleutian Islands region in 1983.

Condition of Stocks Summary

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

Two major types of assessments were employed in this study--relative and absolute abundance assessment techniques. Relative abundance indices were calculated from commercial fishery catch and effort statistics. These indices

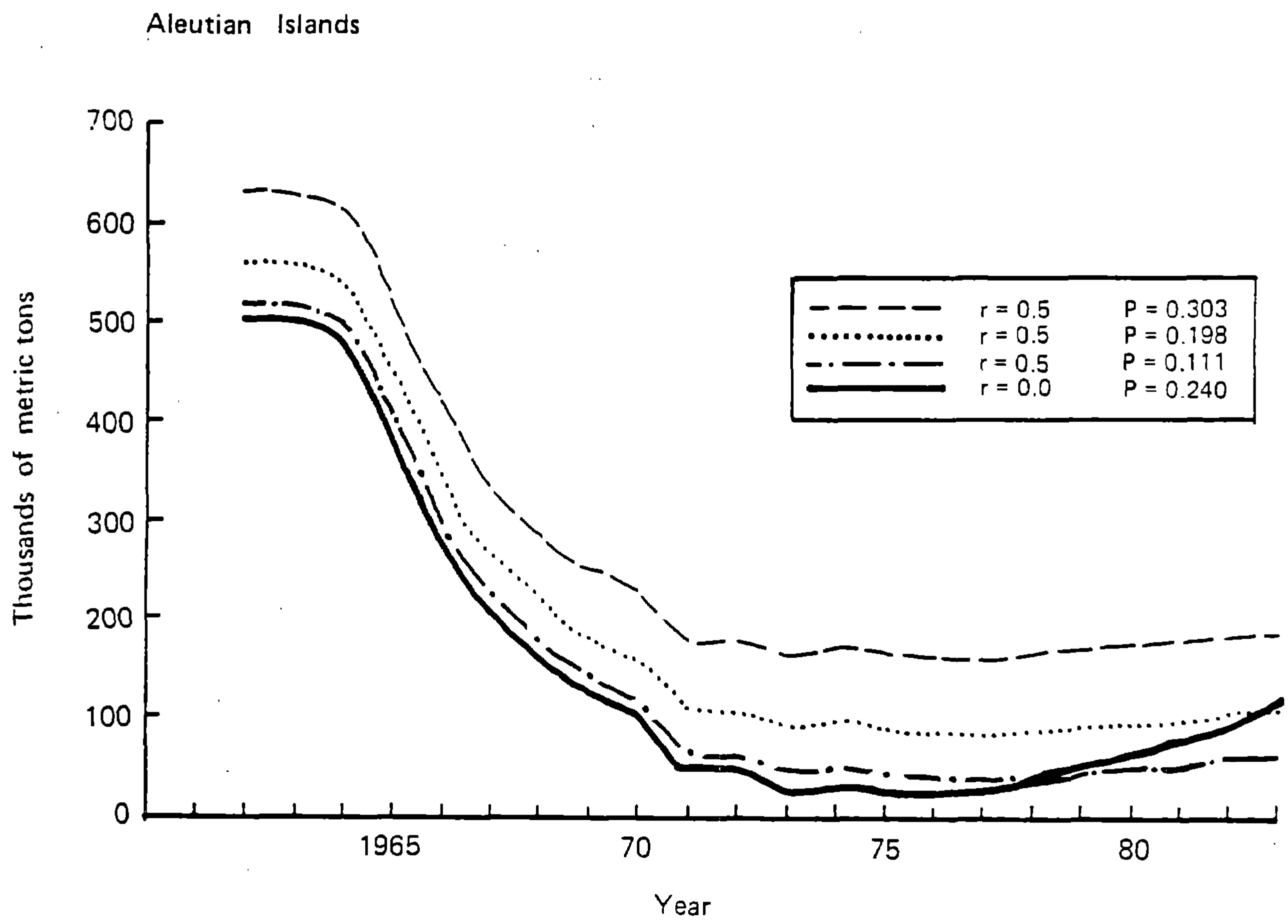

Figure 9.--Estimated population biomass for Pacific ocean perch from the Aleutian region (assuming M = 0.05 and P = 0.38) over time for various stock reduction analysis fits (from Balsiger et al. 1985).

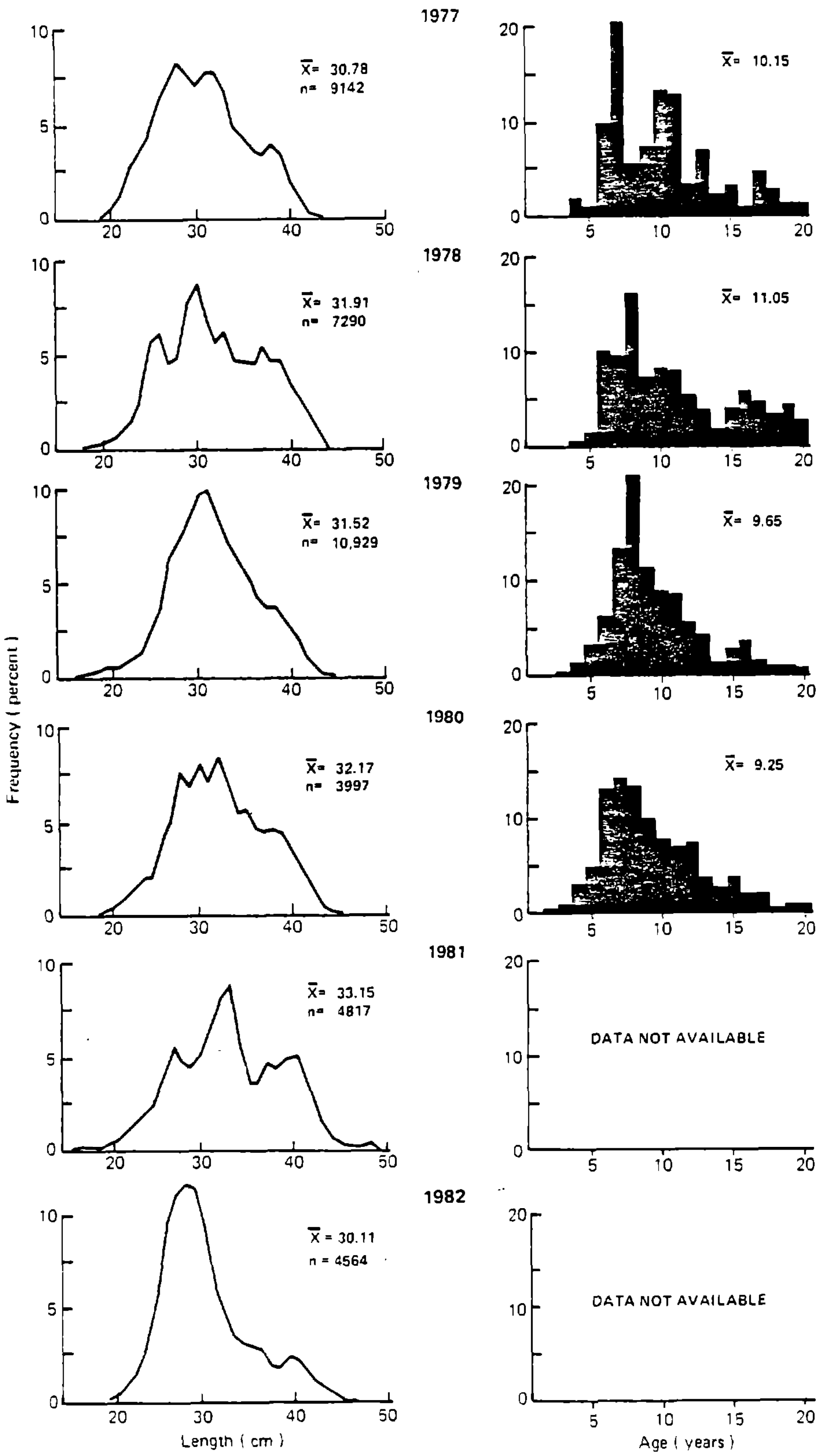

Figure 10.--Length and age composition of Pacific ocean perch in the Aleutian region as shown by data taken by U.S. observers from catches aboard Japanese small stern trawlers, 1977-82.

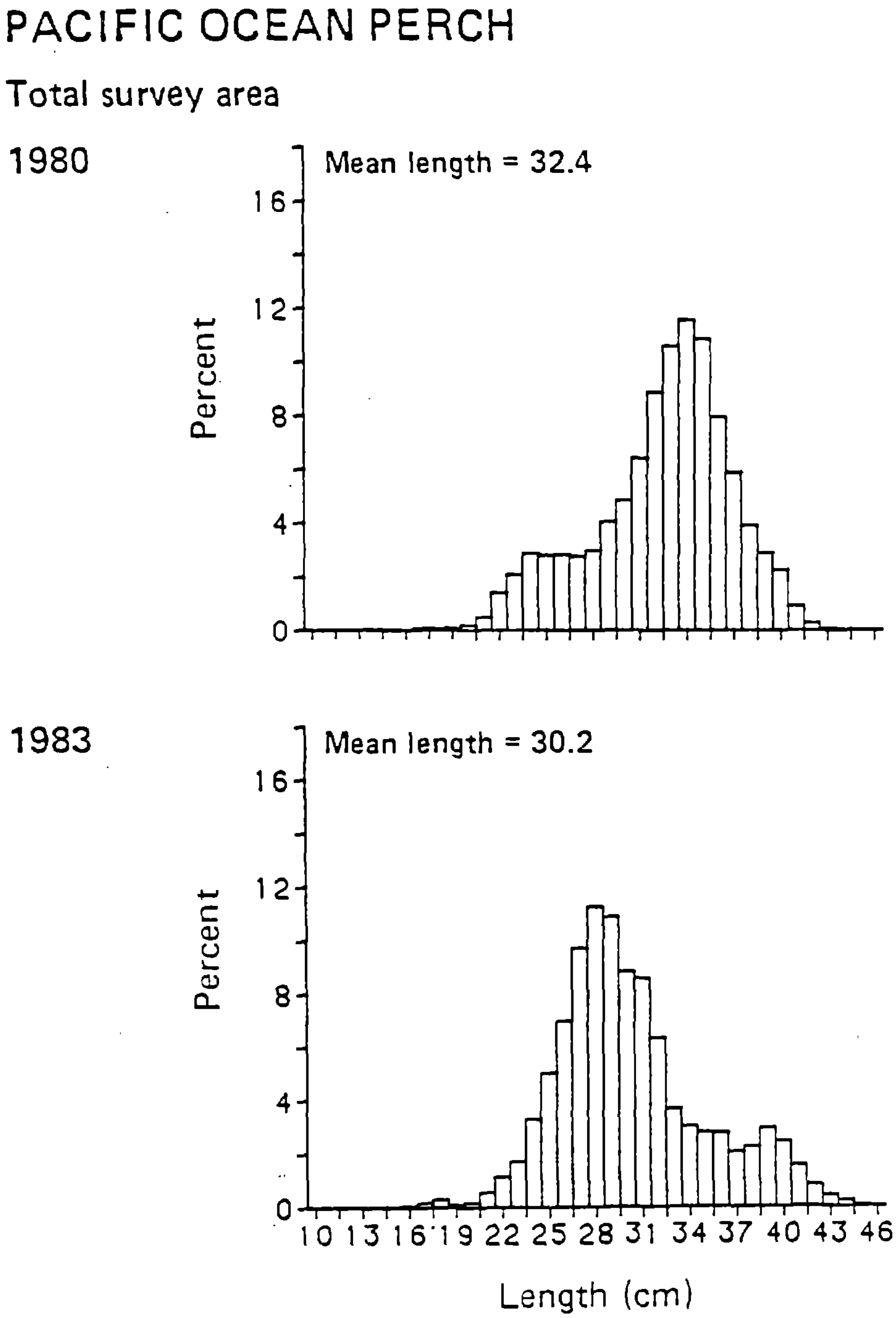

Figure 11. --Size composition of Pacific ocean perch in the Aleutian Islands as shown by data collected during the cooperative U.S.-Japan demersal trawl surveys in 1980 and 1983.

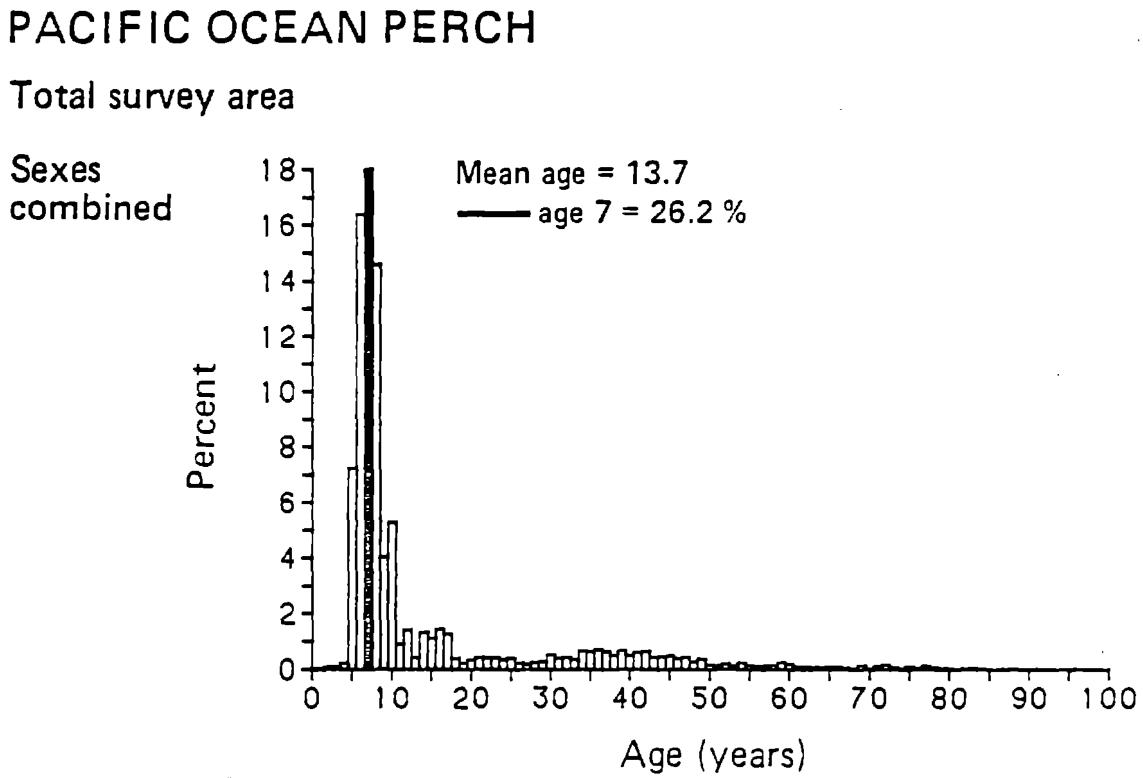

Figure 12.--Age composition of the Pacific ocean perch population in the Aleutian Islands as shown by data collected during the cooperative U.S. -Japan demersal trawl surveys in 1993.

indicated that Pacific ocean perch stocks in both the eastern Bering Sea and the Aleutian Islands regions underwent sizable reductions throughout the 1960's and late 1970's. As previously mentioned, the use of CPUE data in more recent years may not be a good index of stock abundance, as most of the effort is now directed to species other than Pacific ocean perch.

Trawl surveys, cohort analysis, virtual population analysis, and stock reduction analysis provided estimates of absolute abundance. The results from each assessment method show that both stocks are at low levels of abundance relative to earlier years. Reductions in biomass of 60 to 98% from levels present in the early 1960's were indicated by cohort, virtual population, and stock reduction analyses. Recent information from the 1985 eastern Bering Sea and the 1983 Aleutian Islands surveys, however, indicate increased recruitment to both stocks. This is indeed an encouraging sign and may indicate that the stocks are now in the process of rebuilding.

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-year 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 3).

The MSY estimates from VPA were based on a natural mortality of 0.15, which is compatible with maximum ages (about 30 years) obtained from surface readings of scales and otoliths. However, recent ageing techniques using sectioned or broken and burned otoliths suggest longevity may be as much as 90 years. To be consistent with this greater age range, MSY estimates from SRA were based on a natural mortality value of 0.05. The MSY estimates from SRA were 2,840-4,984 t for the eastern Bering Sea and 6,627-11,864 t for the Aleutian Islands regions. The combined MSY estimates from SRA of 9,467-16,848 t for the eastern Bering Sea and Aleutian Islands regions compare well with estimates of Low (1974) of 12,000-17,000 t (Table 3).

EQUILIBRIUM YIELD

Balsiger et al. (1985) modified the SRA model to project future biomass by incorporating the Deriso (1980) delay-difference equation. This model was used to estimate equilibrium yield (EY) by examining levels of fishing mortality (F) that would stabilize the population at its current level. By assuming that the S. alutus stock had declined to between 10 and 30% of virgin biomass and that a moderate stock-recruitment relationship prevailed, current biomass was estimated to range between 22,000 and 81,000 t for the eastern Bering Sea stock and between 58,000 and 191,000 t for the Aleutian stock, ranges that

Table 3.--Maximum sustainable yield (MSY) estimates for *S. alutus* 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)

[a]VPA = Virtual population analysis.
[b]SRA = Stock reduction analysis.

encompass the latest trawl biomass estimates. By projecting the current estimates of biomass into the future using the modified SRA model, a fishing mortality of about F = 0.05 was estimated to stabilize future biomass. Calculating the exploitation rate corresponding to this value of F (exploitation rate = $F(1.0 - \exp(-F-M)/(F+M)) = 0.0476$) and then multiplying this exploitation rate by the estimates of current biomass resulted in estimates of EY of between 1,047 and 3,854 t for the eastern Bering Sea stock and between 2,760 and 9,088 t for the Aleutian Islands stock. Using mean values, the S. alutus EY values are 2,450 t in the eastern Bering Sea and 5,924 t in the Aleutian Islands regions.

In practice, Pacific ocean perch is managed as a complex comprised of five species--Pacific ocean perch (S. alutus), northern rockfish (S. polyspinus), rougheye rockfish (S. aleutianus), shortraker rockfish (S. borealis), and sharpchin rockfish (S. zacentrus). The EY values for the four species (other than S. alutus) were-derived from biomass estimates (refer to the section on "other rockfish" in this report). The 1979-85 trawl surveys show that their biomasses total 13,248 t in the eastern Bering Sea and 49,742 t in the Aleutian Islands regions. Assuming that these estimates are underestimated by 50% (because of the off-bottom components of the stocks and other trawl inefficiencies for sampling rockfish), the EY for this group was estimated at 1,362 t for the eastern Bering Sea and 4,974 t in the Aleutians (5% of biomass). Therefore, the combined EY for the Pacific ocean perch complex (of five species) totaled 3,812 t in the eastern Bering Sea and 10,898 t in the Aleutians.

ALLOWABLE BIOLOGICAL CATCH

The North Pacific Fishery Management Council has previously set catch levels below EY (ranging from 50 to 75% of EY) to promote rebuilding of the stocks. An allowable biological catch (ABC) consistent with the Council's previous actions, would result in ABC values ranging from 1,906 to 2,859 t for the eastern Bering Sea and 5,449-8,174 t for the Aleutian Islands. The midpoint of these ranges are 2,382 t for the eastern Bering Sea and 6,812 t for the Aleutian Islands. It is recommended that the Council's practice of setting catch levels below EY continue in order to accelerate the rebuilding process. There appears to be strong recruitment entering the population in both regions, which may indicate the onset of rebuilding. By keeping catches below EY, these strong year classes will have an opportunity to increase in biomass and contribute to future yields. The estimates of EY and ABC for the Pacific ocean perch complex are summarized below:

Region	EY	ABC
Eastern Bering Sea	3,812 t	2,382 t
Aleutian Islands	10,898 t	6,812 t

OTHER ROCKFISH

by

Daniel H. Ito

INTRODUCTION

From 1960 until the implementation of the Magnuson Fisheries Conservation and Management Act (MFCMA) in 1977, rockfish (genera Sebastes and Sebastolobus) were the objects of intense foreign fisheries in the Bering Sea-Aleutian Islands region. Toward the end of that period, however, catches had declined sharply. The catch in 1976 (on the eve of MFCMA) was roughly only one-quarter the catch in peak year 1965. Catches were variously reported as a single category--Pacific ocean perch, Sebastes alutus (which was far and away the most abundant species) or as two categories: 1) Pacific ocean perch and 2) other rockfish. It is highly probable that under either system, the reported catches of Pacific ocean perch included other species of rockfish--particularly northern rockfish, Sebastes polyspinis; rougheye rockfish, Sebastes aleutianus; shortaker rockfish, Sebastes borealis; and sharpchin rockfish, Sebastes zacentrus. These four species are similar in color and physical characteristics to S. alutus.

It has only been since the implementation of MFCMA, and the accompanying placement of the U.S. observers aboard foreign fishing vessels, that catch and effort data have become available for individual species of rockfish, thus making it possible for the North Pacific Fisheries Management Council (NPFMC) to manage species or groups of species separately.

Even with MFCMA, however, the management regime has not been consistent. In 1977 and 1978 the category "Pacific ocean perch" included only S. alutus; all other rockfish were included in the category "other fish" (not to be confused with the category "other rockfish"). In 1979 the four S. alutus-like species mentioned above (northern, rougheye, shortraker, and sharpchin rockfish) were grouped with S. alutus in the so-tailed "Pacific ocean perch complex'" or "POP complex." other members of the genera Sebastes and Sebastolobus remained in the "other fish" category in 1979, but beginning with 1980 have been placed in a separate category "other rockfish."

Equilibrium yield (EY), the criterion used by MFCMA for managing other rockfish, was set at 9,000 metric tons (t) in 1985--1,200 t in the eastern Bering Sea region and 7,800 t in the Aleutian region. It is the objective of the present inquiry to evaluate current information bearing on the EY estimate. Examination of the catch data and the development of biomass estimates (which lay the groundwork for estimating EY) will be done in concert with one or more species of the Pacific ocean perch complex. Abundance information developed here on the Pacific ocean perch complex has been utilized in the status of stocks report on the Pacific ocean perch complex section of this report.

COMMERCIAL CATCHES

The methods of sampling and estimating commercial catches of rockfish from the U.S. foreign fisheries observer data have been described by Nelson et al. (1980, 1981a, 1981b, 1982, 1983a). U.S. observers have identified 32 species of rockfish in groundfish catches from the eastern Bering Sea and Aleutian Islands region (Table 1). Although all observers were trained in species identification and instructed in the use of fish identification keys, errors in the identification of some rockfish species may have occurred.

The 1977-85 estimated catches of all rockfish from the eastern Bering Sea and Aleutian Islands regions are listed in Tables 2 and 3, respectively. These catches were separated into two major rockfish categories, Pacific ocean perch complex and "other rockfish." Catches of "other rockfish," separated by individual species, are presented in Tables 4 and 5 for the eastern Bering Sea and Aleutian Islands regions, respectively.

Total rockfish catches by foreign and joint venture fisheries in the eastern Bering Sea since 1977 peaked at 14,366 metric tons (t) in 1978 (Table 2). Catches since then have decreased and reached an all time low of 149 t in 1985. The "other rockfish" catches follow this trend, peaking in 1978 at about 2,600 t and then dropping to an all time low of 38 t in 1985. The average catch of "other rockfish" during the period of observer coverage was 714 t and averaged only about 17% of the total rockfish catch during this period.

Shortspine thornyheads, <u>Sebastolobus alascanus</u>, have consistently dominated the "other rockfish" catches in the eastern Bering Sea (Table 4). This species alone has comprised over 80% of the "other rockfish" catch from 1977 to 1985. Darkblotched rockfish, <u>Sebastes crameri</u>; dusky rockfish, <u>Sebastes ciliatus</u>; and redstripe rockfish, <u>Sebastes proriger</u>, have also made up significant portions of the "other rockfish" catch during the past 9 years.

With the exception of 1978, total rockfish catches from the Aleutian Islands region (Table 3) have exceeded those from the eastern Bering Sea. Harvests of all rockfish from the Aleutian region since 1977 peaked in 1979 at 20,030 t and then declined to a historic low of 432 t in 1985. The catches of "other rockfish" averaged 1,383 t during the period from 1977 to 1985. As in the eastern Bering Sea, shortspine thornyheads have usually dominated catches of "other rockfish," but darkblotched, dusky, and redstripe rockfish have also made up significant portions of the "other rockfish" catch during some years of observer coverage (Table 5).

BIOMASS ESTIMATES

Data from the 1979-85 cooperative U.S.-Japan trawl surveys provide biomass estimates for "other rockfish" in the eastern Bering Sea and Aleutian Islands region. The surveys in the eastern Bering Sea were conducted both on the continental shelf and the continental slope, but almost all catches of "other rockfish" were taken by Japanese research trawlers fishing on the slope at depths greater than 200 m. For this reason, only data collected by Japanese research vessels were employed to calculate "other rockfish" abundance estimates.

Table 1.--The common and scientific names of rockfish identified by U.S. observers in the foreign and joint venture catches in the eastern Bering Sea and Aleutian Islands regions.

Common name	Scientific name
PACIFIC OCEAN PERCH COMPLEX	
Pacific ocean perch	*Sebastes alutus*
Northern rockfish	*Sebastes polyspinis*
Rougheye rockfish	*Sebastes aleutianus*
Sharpchin rockfish	*Sebastes zacentrus*
Shortraker rockfish	*Sebastes borealis*
OTHER ROCKFISH	
Longspine thornyhead rockfish	*Sebastolobus altivelis*
Shortspine thornyhead rockfish	*Sebastolobus alascanus*
Aurora rockfish	*Sebastes aurora*
Black rockfish	*Sebastes melanops*
Blackgill rockfish	*Sebastes melanostomus*
Blue rockfish	*Sebastes mystinus*
Bocaccio	*Sebastes paucispinis*
Canary rockfish	*Sebastes pinniger*
Chilipepper	*Sebastes goodei*
Copper rockfish	*Sebastes caurinus*
Darkblotched rockfish	*Sebastes crameri*
Dusky rockfish	*Sebastes ciliatus*
Greenstriped rockfish	*Sebastes elongatus*
Harlequin rockfish	*Sebastes variegatus*
Pygmy rockfish	*Sebastes wilsoni*
Redbanded rockfish	*Sebastes babcocki*
Redstripe rockfish	*Sebastes proriger*
Rosethorn rockfish	*Sebastes helvomaculatus*
Silvergray rockfish	*Sebastes brevispinis*
Splitnose rockfish	*Sebastes diploproa*
Stripetail rockfish	*Sebastes saxicola*
Tiger rockfish	*Sebastes nigrocinctus*
Vermilion rockfish	*Sebastes miniatus*
Widow rockfish	*Sebastes entomelas*
Yelloweye rockfish	*Sebastes ruberrimus*
Yellowmouth rockfish	*Sebastes reedi*
Yellowtail rockfish	*Sebastes flavidus*

Table 2.--Estimated catches (t) of rockfish from the eastern Bering Sea as determined by U.S. observers aboard foreign and joint venture fishing vessels, 1977-85.

	1977	1978	1979	1980	1981	1982	1983	1984	1985
Foreign									
POP[a] complex:	4,021	11,759	9,707	1,946	2,000	788	332	339	77
Pacific ocean perch	2,654	2,211	1,718	1,050	1,221	212	116	156	35
Northern rockfish	322	119	126	58	31	68	10	19	5
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99	16
Sharpchin rockfish	--	--	6	3	4	4	tr[b]	0	0
Shortraker rockfish	1	8,792	2,726	652	444	354	148	65	21
Other rockfish	311	2,607	2,059	456	332	262	212	123	37
Subtotal	4,332	14,366	11,766	2,402	2,332	1,050	544	462	114
Joint venture									
POP complex:	--	--	--	59	1	17	121	147	34
Pacific ocean perch	--	--	--	47	1	3	97	134	32
Northern rockfish	--	--	--	11	0	2	24	13	2
Rougheye rockfish	--	--	--	tr	0	tr	tr	tr	tr
Sharpchin rockfish	--	--	--	1	0	0	0	0	0
Shortraker rockfish	--	--	--	0	0	12	tr	tr	tr
Other rockfish	--	--	--	3	0	6	8	8	1
Subtotal	--	--	--	62	1	28	129	155	35
Combined									
POP complex:	4,021	11,759	9,707	2,005	2,001	805	453	486	111
Pacific ocean perch	2,654	2,211	1,718	1,097	1,222	215	213	290	67
Northern rockfish	322	119	126	69	31	70	34	32	7
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99	16
Sharpchin rockfish	--	--	6	4	4	4	tr	0	0
Shortraker rockfish	1	8,792	2,726	652	444	366	148	65	21
Other rockfish	311	2,607	2,059	459	332	273	220	131	38
Grand Total	4,332	14,366	11,766	2,464	2,333	1,078	673	617	149

[a]POP = Pacific ocean perch.
[b]tr = trace quantities.

Table 3.--Estimated catches (t) of rockfish from the Aleutian Islands region as determined by U.S. observers aboard foreign and joint venture fishing vessels, 1977-85.

	1977	1978	1979	1980	1981	1982	1983	1984	1985
Foreign									
POP[a] complex:	14,625	13,102	15,513	5,645	4,684	1,690	371	414	2
Pacific ocean perch	8,080	5,286	5,487	4,700	3,618	1,012	272	356	tr
Northern rockfish	5,311	3,782	997	374	138	193	28	12	tr
Rougheye rockfish	1,128	2,938	4,538	469	477	159	22	19	tr
Sharpchin rockfish	3	1	73	tr[b]	tr	14	1	0	0
Shortraker rockfish	103	1,095	4,418	102	451	312	48	27	1
Other rockfish	3,042	921	4,517	416	328	2,114	1,041	42	2
Subtotal	17,667	14,023	20,030	6,061	5,012	3,804	1,412	456	4
Joint venture									
POP complex:	--	--	--	tr	7	2	11	451	420
Pacific ocean perch	--	--	--	tr	4	2	8	273	215
Northern rockfish	--	--	--	0	2	0	tr	173	196
Rougheye rockfish	--	--	--	0	1	0	2	5	9
Sharpchin rockfish	--	--	--	0	0	0	tr	0	0
Shortraker rockfish	--	--	--	0	0	0	1	tr	tr
Other rockfish	--	--	--	0	0	0	4	14	8
Subtotal	--	--	--	tr	7	2	15	465	428
Combined									
POP complex:	14,625	13,102	15,513	5,645	4,691	1,692	382	865	422
Pacific ocean perch	8,080	5,286	5,487	4,700	3,622	1,014	280	629	215
Northern rockfish	5,311	3,782	997	374	140	193	28	185	196
Rougheye rockfish	1,128	2,938	4,538	469	478	159	24	24	9
Sharpchin rockfish	3	1	73	tr	tr	14	1	0	0
Shortraker rockfish	103	1,095	4,418	102	451	312	49	27	1
Other rockfish	3,042	921	4,517	416	328	2,114	1,045	56	10
Grand Total	17,667	14,023	20,030	6,061	5,019	3,806	1,427	921	432

[a]POP = Pacific ocean perch.
[b]tr = trace quantities.

Table 4.--Catches (t) of "other rockfish" in the eastern Bering Sea groundfish fishery, 1977-85[a].

Common name	Foreign fishery									Joint venture fishery					
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1980	1981	1982	1983	1984	1985
Black rockfish		0.7	12.2	0.1											
Blackgill rockfish					0.4	0.9	1.6	2.1					1.0		
Blue rockfish	1.2	8.9	0.2												
Darkblotched rockfish	2.4	39.4	62.8	33.0	55.1	7.2	9.3	1.0	0.7						tr
Dusky rockfish	3.1	56.5	92.4	18.9	13.7	13.9	4.8	18.1	6.5	1.2	tr	1.3	6.6	5.1	0.5
Harlequin rockfish		2.2		10.1	50.0	2.4									
Longspine thornyhead		0.4	16.2	0.3	3.3	1.0	0.4	2.6							
Redbanded rockfish		1.8	12.8	3.3	1.3										
Redstripe rockfish		65.6	78.9	0.2	8.5	8.5	3.0	2.7	0.3			4.6		1.2	0.1
Shortspine thornyhead	292.2	2,288.8	1,585.6	389.2	195.9	219.4	178.4	91.4	28.6			4.9	0.3	0.4	0.3
Silvergray rockfish		0.8													
Splitnose rockfish						4.8	10.6								
Misc. rockfish	12.0	149.3	247.3	1.3	3.1	3.7	3.9	3.5	0.8	1.4		tr[b]	0.5	1.7	0.3
Total	310.9	2,614.4	2,108.4	456.4	331.3	261.8	212.0	121.4	36.9	2.6	tr	10.8	8.4	8.4	1.2

[a]Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a; Berger et al. 1984, 1985b, 1986.
[b]tr = trace amounts.

Table 5.--Catches (t) of "other rockfish" in the Aleutian Islands groundfish fishery, 1977-85[a].

Common name	Foreign fishery									Joint venture fishery					
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1980	1981	1982	1983	1984	1985
Black rockfish		1.6	2.3												
Blackgill rockfish						4.8	3.8	0.7							
Darkblotched rockfish	0.4	42.2	1,641.8	86.3	7.0	7.6	1.7	0.1	0.9						
Dusky rockfish	2,932.9	11.3	54.8	2.8	10.6	3.8	1.0	2.6	0.3		tr[b]		0.9	8.3	8.2
Harlequin rockfish	1.0	8.1	51.6	60.8	8.4	0.4									
Longspine thornyhead		0.2	2.2			2.1	0.7	0.4							
Redbanded rockfish		81.8	40.0	6.8	tr										
Redstripe rockfish		127.0	997.1	51.3	5.1	2.2	2.2	0.8	tr				3.4	0.8	0.1
Shortspine thornyhead	89.1	546.8	1,709.6	210.7	276.3	2,089.1	982.6	36.5	0.9	tr					
Silvergray rockfish			1.0												
Splitnose rockfish						3.3	44.0								
Misc. rockfish	19.1	102.0	16.2	2.0	20.8	0.7	5.0	1.1	tr		tr			5.0	0.2
Total	3,042.5	921.0	4,516.6	420.7	328.2	2,114.0	1,041.0	42.2	2.1	tr	tr	0.0	4.3	14.1	8.5

[a]Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a; Berger et al. 1984, 1985b, 1986.
[b]tr = trace amounts.

Survey results indicate that the biomass of "other rockfish" in the eastern Bering Sea increased from 3,251 t in 1979 to 4,975 t in 1981 and then declined slightly to 4,381 t in 1982. In 1985, this estimate amounted to 5,127 t. These abundance estimates should be viewed with caution, however, because of their relatively low degree of precision. The 1980 and 1983 cooperative U.S.-Japan surveys of the Aleutian region indicated an average of about 1,300 t of "other rockfish" in the Aleutian Islands portion of International North Pacific Fisheries Commission (INPFC) area 1 (the north side of the Aleutians between long. 165°W and 170°W). Thus, an overall estimate for the eastern Bering Sea region, based on the mean of the 1980 and 1983 Aleutian estimates and the mean of the 1979-85 eastern Bering Sea survey data, is 5,733 t.

The estimated biomass for the Pacific ocean perch complex (excluding S. alutus) in this region amounted to about 13,621 t.

Biomass estimates of "other rockfish" from the 1980 and 1983 U.S.-Japan cooperative trawl surveys of the Aleutian Islands region indicate a decrease from 22,300 t in 1980 to 15,900 t in 1983. These estimates, however, were characterized by relatively wide variances, and the 95% confidence intervals overlapped extensively, indicating that the point estimates may not be significantly different. Nevertheless, the mean of these trawl estimates (19,100 t) indicates a much larger stock size than that found in the eastern Bering Sea. Biomass for the Pacific ocean perch complex (excluding S. alutus) in the Aleutian region was estimated at about 49,742 t.

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

MAXIMUM SUSTAINABLE YIELD

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

EQUILIBRIUM YIELD

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

The biomass of the "other rockfish" stock in the eastern Bering Sea was estimated at about 5,733 t; for the Pacific ocean perch complex (excluding S. alutus) the estimate was about 13,621 t. The 1980 and 1983 biomass estimates for "other rockfish" in the Aleutian region averaged about 19,100 t and for the Pacific ocean perch complex (excluding S. alutus), about 49,742 t. Using the assumption that these estimates represent-about one-half the actual biomass, EY values were 573 t in the eastern Bering Sea and 1,900 t in the Aleutian Islands region for "other rockfish." For the Pacific ocean perch complex (excluding S. alutus), EY was estimated at 1,362 t for the eastern Bering Sea and 4,974 t for the Aleutian region.

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ATKA MACKEREL

by

Lael L. Ronholt and Daniel K. Kimura

INTRODUCTION

Atka mackerel, *Pleurogrammus monopterygius,* are found from the east coast of the Kamchatka Peninsula, throughout the Komandorskiye and Aleutian Islands, north to the Pribilof Islands in the eastern Bering Sea, and eastward through the Gulf of Alaska to southeast Alaska. Commercial catches in the Bering Sea area occur in both the eastern Bering Sea and Aleutians, the largest landings coming from the Aleutian region which, from 1978 to 1985, produced 88.6% of the total Bering Sea landings (Table 1). Based on the 1983 cooperative U.S.-Japan groundfish resource assessment survey, Atka mackerel is the third most abundant species in the Aleutian Islands region after walleye pollock, *Theragra chalcogramma,* and grenadiers (rattails, family Macrouridae).

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

CATCH STATISTICS

The total annual landings of Atka mackerel in the Bering Sea and Aleutian region increased during the 1970's, reaching an initial peak of 24,250 metric tons (t) in 1978 (Table 2). From 1979 to 1982 catches gradually declined and then dropped sharply to 11,726 t in 1983. The decline in Atka mackerel landings from 1980 to 1983 was due to changes in interests by fishing nations, rather than changes in stock abundance. In 1984 and 1985 Atka mackerel catches reached record high levels of 36,054 t and 37,861 t. Although significant landings came from the eastern Bering Sea area during 1978-81, the vast majority of the catches have been from the Aleutian Islands region (Table 1).

During the 1970's, Atka mackerel landings were made almost exclusively by the U.S.S.R. (Table 2). In the early 1970's, catches by the Soviet fleet were made primarily west of long. 180°. During 1978 and 1979, the Soviet fleet moved progressively eastward (Table 3), making significant catches in the central and eastern portions of the Aleutian region. In addition to the

Table 1 .--Atka mackerel catches in metric tons by International North Pacific Fisheries Commission areas in the Bering Sea and Aleutian Islands regions, 1978-85.

Year	Eastern Bering Sea (I)	(II)	Central Bering Sea (III)	Aleutians (V)	Total
1978	422	410	0	23,418	24,250
1979	1,653	332	0	21,279	23,264
1980	4,235	462	0	15,793	20,490
1981	2,307	721	0	16,661	19,689
1982	155	173	0	19,546	19,874
1983	21	95	0	11,610	11,726
1984	23	18	0	36,013	36,054
1985	4	1	0	37,856	37,861

Source: U.S. Foreign Fisheries Observer Program, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way N.E., BIN C15700, Bldg. 4, Seattle, WA 98115.

Table 2.--Atka mackerel catches in metric tons by nation, in the eastern Bering Sea and Aleutian Islands regions, 1970-85.

Year	U.S.S.R.	Japan	R.O.K.[a]	W. Germany	Poland	U.S.J.V.[b]	Total
1970	949	--	--	--	--	--	949
1971	--	--	--	--	--	--	--
1972	5,907	--	--	--	--	--	5,907
1973	1,712	--	--	--	--	--	1,712
1974	1,377	--	--	--	--	--	1,377
1975	13,326	--	--	--	--	--	13,326
1976	13,126	--	--	--	--	--	13,126
1977	20,975	--	--	--	--	--	20,975
1978	22,622	1,531	97	--	--	--	24,250
1979	20,277	1,656	1,329	--	2	--	23,264
1980	937	1,719	17,483	42	44	265	20,490
1981	0	5,615	12,385	38	18	1,633	19,689
1982	0	888	6,385	126	--	12,475	19,874
1983	0	280	910	24	--	10,512	11,726
1984	0	103	8	--	tr[c]	35,943	36,054
1985	0	2	tr		tr	37,859	37,861

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

Table 3.--Annual catches in metric tons (t) of Atka mackerel by 1° of longitude in the Aleutian region between long. 170°E and 170°W.[a]

Year	East longitude										West longitude										Total
	170°	171°	172°	173°	174°	175°	176°	177°	178°	179°	179°	178°	177°	176°	175°	174°	173°	172°	171°	170°	
1977	81	143	112	141	385	13,058	3,789	327	195	111	557	34	0	393	0	0	2	10	34	290	19,662
1978	426	0	0	0	400	11,684	275	0	41	34	6,703	0	0	0	955	0	0	21	1,509	0	22,048
1979	58	34	6,694	4,236	30	121	111	18	65	67	770	20	8	1	1,919	1	42	4,972	1,941	42	21,150
1980	125	26	110	35	95	171	107	56	121	296	185	119	26	52	41	98	449	10,867	2,635	748	16,363
1981	268	68	104	84	180	490	250	163	210	459	283	108	35	10	60	69	303	7,968	1,874	820	13,523
1982	53	28	37	26	33	74	86	42	31	35	92	49	0	0	7	34	66	5,147	7,346	230	13,416
1983	15	4	21	3	13	32	17	17	18	26	159	5	4	2	0	1	2,753	5,492	737	83	9,402
1984	0	0	11	1	tr	0	0	1	167	215	4,951	235	16	9	0	204	2,507	23,892	361	tr	32,570
1985	0	0	103	0	0	0	0	0	2,988	5,509	6,462	0	tr	0	0	0	541	17,356	332	5	33,296

[a]These data based on non-U.S. and U.S. joint venture landings when U.S. foreign fisheries observers were aboard the vessels.
[b]tr = trace quantity.

Soviet Union, significant catches have been made by Japan (1978-81) and the Republic of Korea (1980-82). However, the joint venture fisheries which began in 1980 have steadily grown and, in 1984 and 1985, accounted for virtually all landings (Table 2).

Since 1980, the major catches of Atka mackerel (75-96%) have occurred east of long. 180° primarily between long. 171° and 174°W in the Aleutian Islands region (Table 3). In 1984, and 1985, the joint venture fisheries landed the majority of their total catches from a single 0.5° latitude by 1° longitude block bounded by lat. 52°30' N and 53°N and long. 172°W and 173°W (73% in 1984, 52% in 1985).

SURVEY BIOMASS ESTIMATES

Because Atka mackerel occur in large localized concentrations and are poor acoustic targets, they are difficult to survey either hydroacoustically or with trawls. Although survey data (Table 4) show a marked building of stocks from 1974-75 through 1983, it is difficult to know if this increase is real or the result of changes or improvements in survey techniques. For example, the joint U.S.-Japan trawl surveys showed a large increase in biomass between 1980 and 1983, but most of this increase can be attributed to fish in the 1-100 m depth range that appeared only in 1983 (Table 5). Nevertheless, the most recent survey results indicate that Atka mackerel stocks in the Aleutian region are presently healthy, if not at a historically high biomass level. The biomass estimate from the 1983 U.S.-Japan survey, which was 306,778 t for the Aleutian region, is a key statistic from which we shall estimate maximum sustainable yield (MSY) values.

BIOLOGICAL STATISTICS

Biological statistics for Atka mackerel in the Aleutian region are available from Levada (1979b), the U.S. Foreign Fisheries Observer Program's sampling of commercial catches (1977-85), U.S.-Japan cooperative trawl surveys for 1980 and 1983, a Soviet trawl survey in 1982, and a U.S.-U.S.S.R. cooperative trawl survey in 1984. Because catches were small in other regions, the statistics we present are from only the Aleutian region.

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

Length-Frequencies

Length-frequencies from commercial catches (Fig. 1) are available from Levada (1979b) and the U.S. Foreign Fisheries Observer Program. In 1980 and 1981, the U.S. Observer sample sizes were small, so commercial samples taken by the Republic of Korea (R.O.K.) were also used. Generally, sample sizes appeared to be large enough, and the length-frequencies consistent enough, to, be meaningful. These length-frequency data showed a gradual increase in the size of fish taken in the commercial fishery (Fig. 1). In 1975 nearly all sampled fish were under 30 cm, but by 1979 nearly all were over 30 cm. Mean

Table 4.--Survey biomass estimates in metric tons for Atka mackerel in the Aleutian Islands region.

Nation	Year	Type	Biomass estimates	95% Confidence interval
1. U.S.S.R.	1974-75	Hydroacoustic	35,000-110,000	--
2. U.S.S.R.	1980	Hydroacoustic	180,000-200,000	--
3. Joint U.S.-Japan	1980	Trawl	129,500	--
4. Joint U.S.-Japan	1983	Trawl	306,778	124,029-489,554

Table 5.--Estimated biomass in metric tons (t) and average size by area and depth for Atka mackerel in the Aleutian Islands region from the cooperative U.S.-Japan groundfish surveys in 1980 and 1983.

		Southwest[a]		Northwest[b]		Southeast[c]		Northeast[d]		All areas	
Depth (m)	Year	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)	Estimated biomass (t)	Mean size (cm)
1-100	1980	182	-	0	-	0	-	13,581	31.4	13,763	31.4
	1983	15,321	34.0	41,235	34.0	65,814	38.3	18,182	34.9	140,552	35.7
101-200	1980	90,218	35.3	4,788	35.4	10,642	32.3	8,965	30.3	114,613	34.4
	1983	120,990	32.5	5,571	33.0	853	40.2	34,983	38.7	162,397	33.3
All depths	1980	90,880	35.3	5,102	35.2	10,746	32.2	22,784	30.9	129,512	34.0
	1983	138,788	32.9	46,840	34.2	66,869	38.7	54,281	37.3	306,778	34.3

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

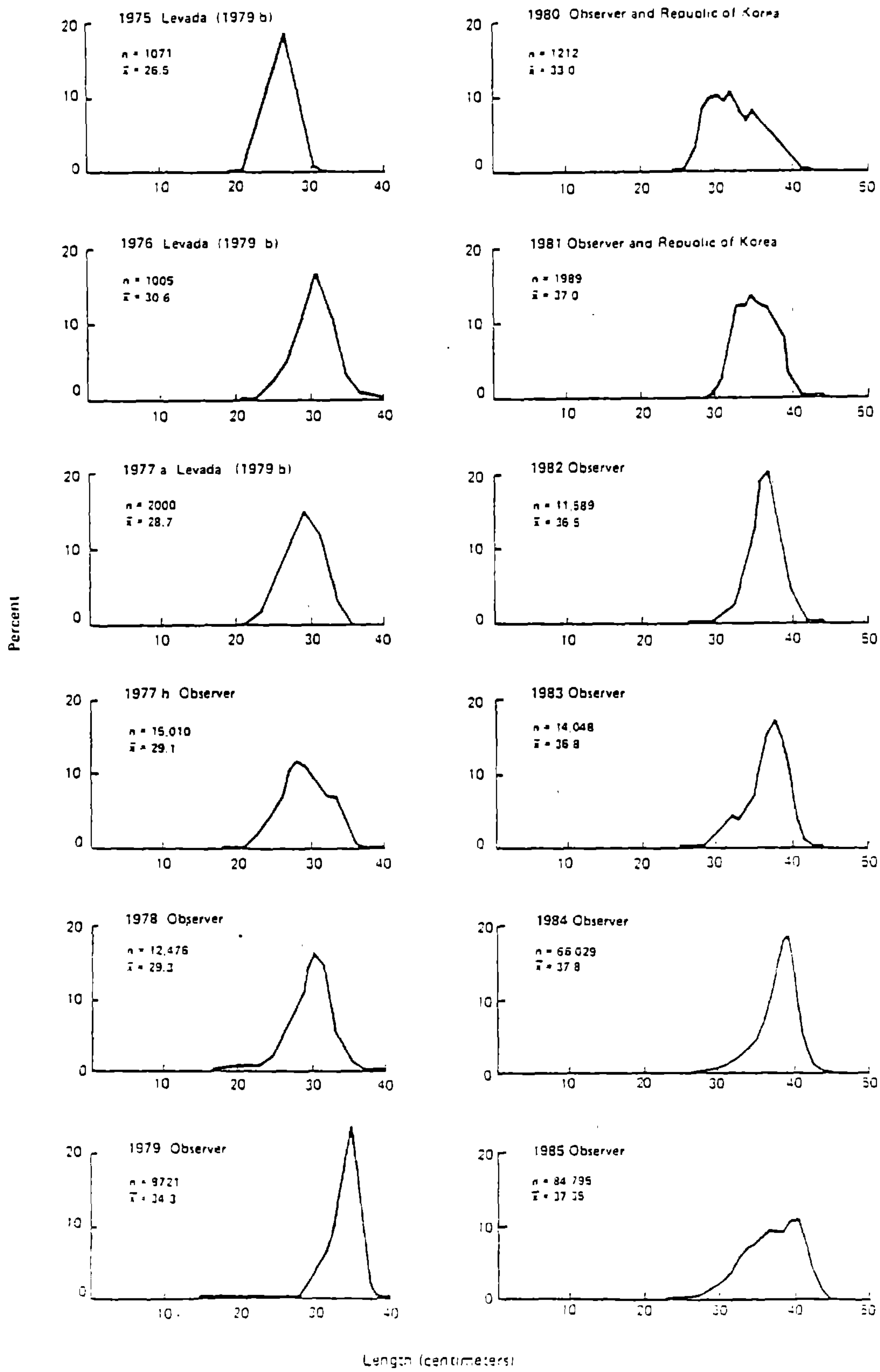

Figure 1 .--Length frequency data from Levada (1979b) and the U.S. Foreign Fisheries Observer program for Atka mackerel in the Aleutian Islands region.

size increased from 33.0 cm in 1980 to 37.8 cm in 1984, and 37.4 cm in 1985. This increase in size indicates that increasingly older fish were being taken in the fishery, and possibly that the catches were being dominated by a few year classes.

An interpretation of the length frequencies of Atka mackerel is made difficult by the apparent geographic stratification of the stock by size. During the 1980 U.S.-Japan trawl survey, fish in the western Aleutian Islands averaged 35.2-35.3 cm, and fish in the eastern Aleutians averaged 30.9-32.2 cm (Fig. 2). Thus in 1980, the largest fish were found in the west and most of the recruitment occurred in the east.

The 1983 U.S.-Japan trawl survey, however, shows a very different situation (Fig. 2), indicating the dynamic nature of these stocks. In the southeast, the length frequencies show a narrow band of large fish averaging 38.7 cm. These large fish were also present in the northeast, but a mode of smaller fish in the 34 cm range was also evident. In the southwest, a large number of younger fish less than 30 cm in size were apparent, with fewer of the over 35 cm fish that were abundant in the east. And finally, fish under 30 cm were available in the northwest, but fish in the 34 cm range were most abundant; Thus in 1983, the largest fish were found in the east, with most of the recruitment appearing in the west.

The U.S.-U.S.S.R. trawl survey during the summer of 1984 showed a continuing change in the size composition within the Aleutian Islands. In the southwest subarea, although mean size was the same as in 1983, the size range of the individuals narrowed considerably. There appeared to be little recruitment, and either a mortality or migration of older fish. In the southeast and northwest subareas, the size compositions narrowed in range and shifted to the right, indicating growth, but no recruitment. In the northeast subarea, however, an increase in size of the older fish can be seen, along with a substantial recruitment of fish in the 22-30 cm size range.

Age Distributions

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

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

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

In the Aleutian Islands region, Atka mackerel is a summer-fall spawning fish which apparently does not lay down an otolith annulus in the first year. Adding 1 year 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.

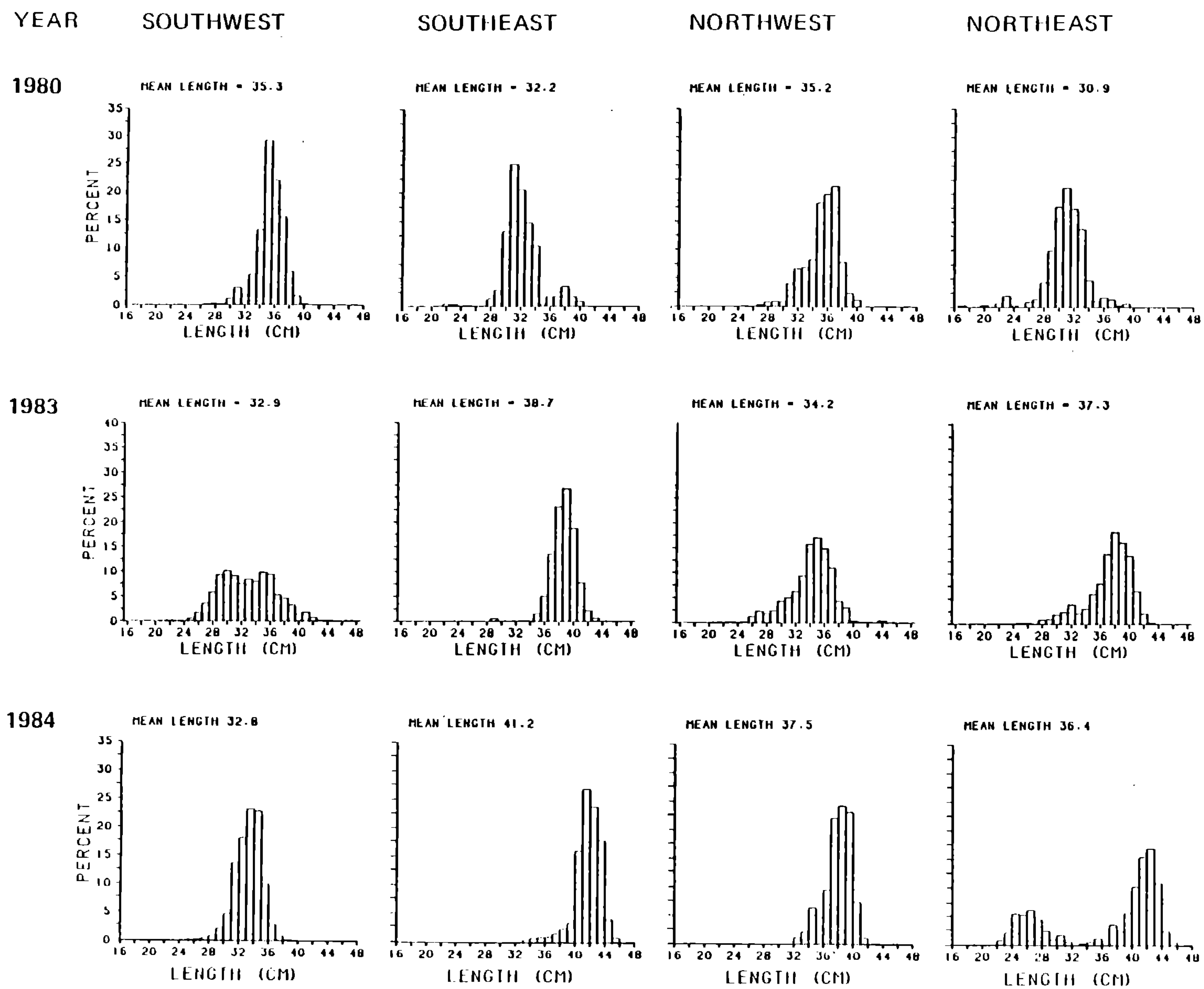

Figure 2.--Size composition of Atka mackerel in the Aleutian Islands from the cooperative U.S.-Japan groundfish surveys of 1980 and 1983, and the U.S.-U.S.S.R. cooperative survey of 1984.

Age frequencies were obtained for Atka mackerel in the Aleutian region from both observer (1977-79, 1984, and 1985) and survey (1980, 1982, and 1983) data (Fig. 3). 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.

It is important to note that 6-year-olds never appeared in abundance until 1983. This abundance of older fish in 1983 also seems to appear in the length-frequencies (Fig. 1). The 1977 year-class has continued to appear strong in 1984 as 7-year-olds, and in 1985 as 8-year-olds. This phenomenon led us to believe that there was a possibility of a sharp decline in abundance as this strong year class left the fishery. However, 1985 catches appeared strong and the 1985 age distribution does not appear to be so dependent on a single strong year class.

Von Bertalanffy Growth

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

Nonlinear least squares was used to fit the von Bertalanffy growth curve to average length-at-age for the 1977-83 age data (Fig. 4). The resulting parameter estimates were

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

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

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

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

provides an adequate description of growth for Atka mackerel in the Aleutians region (Fig. 4).

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 (l) was measured in centimeters and weight (w) was measured in decagrams. The average weight-at-length data used was collected from foreign fisheries observer data (1977-79) in the Aleutian region. The resulting parameter estimates were

males: $a = 0.000144$ $b = 3.581$
females: $a = 0.000471$ $b = 3.227$.

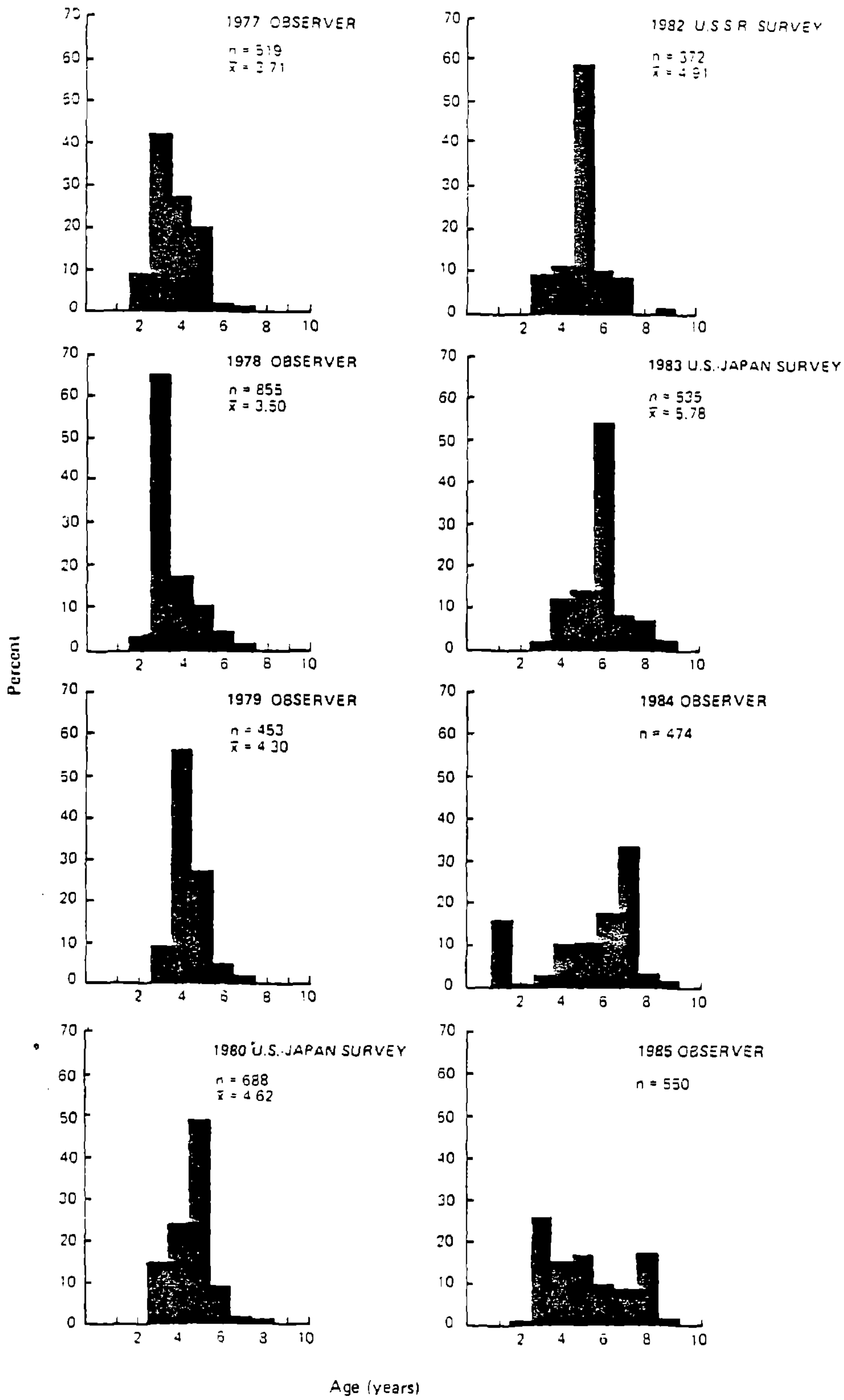

Figure 3.--Estimated age frequency of commercial catches of Atka mackerel in the Aleutian Islands region, sampled by the U.S. Foreign Fisheries Observer Program (1977-79, and 1984) and during bottom trawl surveys (1980, 1982, and 1983). Ages were determined by the Northwest and Alaska Fisheries Center Ageing Unit.

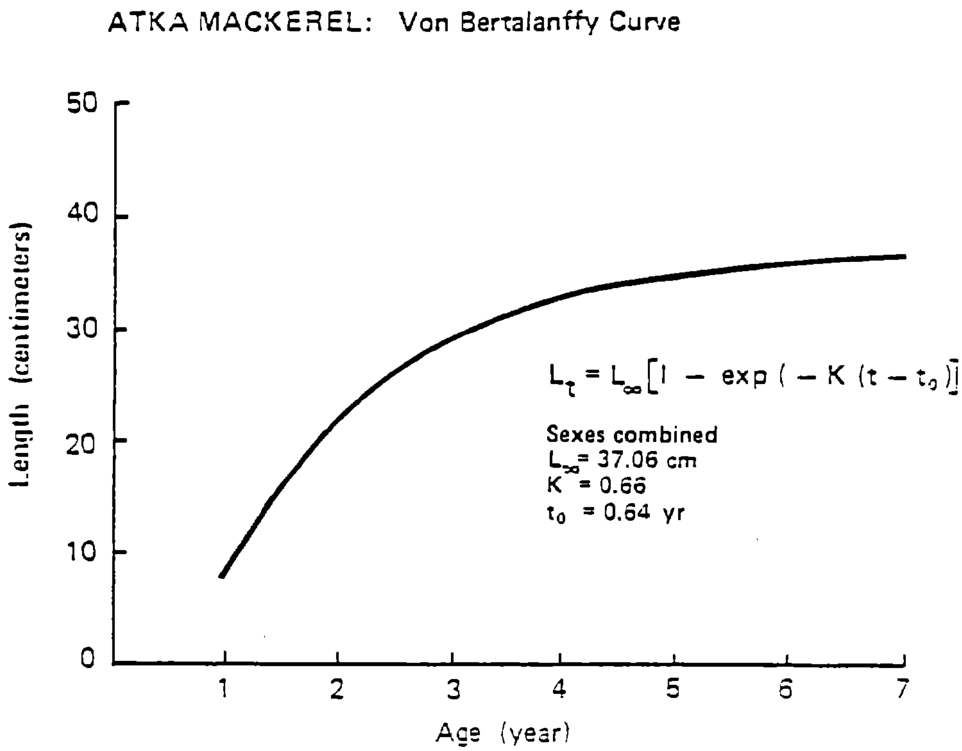

Figure 4.--Estimated von Bertalanffy growth curve (sexes combined) for Atka mackerel in the Aleutian Islands region.

Using a likelihood ratio test, these curves were found to be significantly different ($\alpha = 0.001$), with a chi-square value of 41.919 with df = 2. Nevertheless, the fitted curves (Pig. 5) were quite similar, and the combined curve,

sexes combined: a = 0.000270 b = 3.393,

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

Natural Mortality 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 M based on the Alverson and Carney (1975) formula,

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

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

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

For Atka mackerel, the estimation of K also 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.

Given these uncertainties, we found a wide range of possible estimates for M (Table 6). 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 $t_m = 12$ years, is too high for the Aleutian stock. Using our Aleutians age information, we feel M = 0.18 based on K = 0.66, $t_{mb} = 0.38\ t_m$, and $t_m = 10$ years is more realistic. Nevertheless, there is obviously room for considerable error in this estimate.

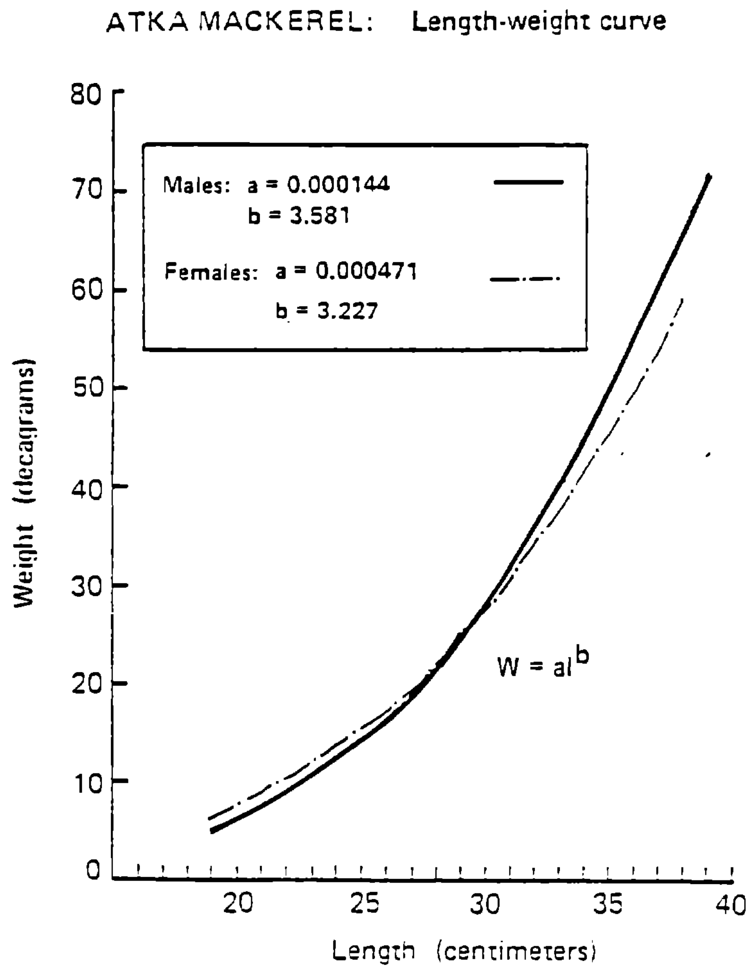

Figure 5.--Estimated length-weight relationship for male and female Atka mackerel in the Aleutian Islands region.

Table 6.--Estimates of the instantaneous natural mortality rate (M) for Atka mackerel in the Aleutian Islands region based on the method of Alverson and Carney (1975).

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

ESTIMATES OF MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) was estimated for Atka mackerel stocks in the Aleutian region using stock reduction analysis (SRA) (Kimura and Tagart 1982; Kimura et al. 1984). In the assessment presented here, SRA was used to estimate the average recruitment level from 1974 to 1983. For this analysis, we require annual commercial catches in weight, survey biomass estimates at two points in time, and an estimate of M. Catch data were used from the years 1974-82 (Tables 1 and 2), and all catches from the years 1974-77 were assumed to be from the Aleutian Islands region.

Given the commercial catches, an estimate of M (Table 6), and an initial population biomass at the beginning of 1974 of 100,000 t (Table 4), 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 (Kimura 1986), which reduces the standing biomass to about one-half the unfished biomass level.

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) (Kimura et al. 1984) 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.

Table 7 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 4).

Using the best available information concerning Atka mackerel stocks in the Aleutian region, MSY is estimated to be 38,734 t (assuming M = 0.20 and a 1983 survey biomass estimate of 300,000 t). Intervals around this MSY estimate can be considered by varying either 1983 survey biomass estimates, natural mortality rate estimates, or both. Varying the 1983 survey biomass estimates in the 100,000 to 500,000 t range affects MSY estimates considerably more than varying M between 0.10 and 0.30 (the probable range for both parameters) (Table 8). 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 years when recruitment appeared to be unusually strong. For this reason, long-term MSY may have been overestimated.

Table 7.--Estimates of recruitment, equilibrium biomass (assuming F = 0 and F = M) and maximum sustainable yield for Atka mackerel in the Aleutian Islands region. All biomass estimates are in metric tons.

Presumed natural mortality rate (M)	Presumed intial biomass 1974	Presumed final biomass 1983	SRA P-value	SRA[a] 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	187,130	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

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

Table 8.--Intervals around the estimated MSY of Atka mackerel in the Aleutian Islands region (summarized from Table 7).

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

[a]Low, medium, and high estimates of 1983 biomass are 100,000 t, 300,000 t, and 500,000 t (Table 4).

[b]Low, medium, and high estimates of M are 0.10, 0.20, and 0.30 (Table 6).

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

EQUILIBRIUM YIELD

Without more recent survey information concerning the biomass of Atka mackerel, there is not sufficient information to indicate that catches should be lowered below the estimated MSY value of 38,734 t. Nevertheless, the length data (Fig. 1) and age data (Fig. 3) show that Atka mackerel populations are undergoing a transition period in which large year classes have apparently left the fishery. We can only wait to see what impact, if any, this transition will have on our estimates of sustainable yield,

The present estimates of yield are based on biomass estimates from the joint U.S.-Japan trawl surveys in 1980 and 1983. These surveys, which sampled the entire Aleutian Islands region, indicated that the majority of the total biomass, 74.1% and 60.5%, respectively, were located west of 180° longitude. Catches by the fisheries, during this time period, however, have been mainly from a 3° longitudinal strip east of 180° (long. 171°-174°W). If the yield in the Aleutian region were apportioned according to the results of the 1983 survey, 23,434 t would be assigned west of 180°, and 15,300 t east of 180°. It is probably desirable to reduce fishing pressure in the 3° longitudinal band in the eastern Aleutian region where all of the large catches have occurred.

SQUID

by

Richard G. Bakkala

INTRODUCTION

Assessment data are not available for squid because of their mainly pelagic distribution over deep water. Little information is available on distribution, abundance, and biology of squid stocks in the eastern Bering Sea and Aleutian Islands regions, with the exception of that provided by Bubblitz 1981, Mercer 1981, Fiscus and Mercer 1982, and Wilson and Corham 1982. Squid are generally taken incidentally or are temporarily targeted by trawl fisheries when large concentrations are encountered. *Berryteuthis magister* and *Onychoteuthis borealijaponica* are the major components of squid catches. B. *magister* predominates in catches made in the eastern Bering Sea, whereas O. *borealijaponica* 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 have declined steadily to 1,600 t in 1985 (Table 1). The distribution of catches shows that the major fishing ground is on the continental slope of the eastern Bering Sea where squid have been mainly taken by the landbased dragnet fishery, surimi factory trawlers, and frozen fish factory trawlers. In this region, catch per unit of effort (CPUE) values standardized over the three vessel types (Okada 1985) have shown some fluctuations but have generally been relatively stable as shown below:

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

MAXIMUM SUSTAINABLE YIELD

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

ACCEPTABLE BIOLOGICAL CATCH

Catches of 10,000 t are believed to be sustainable. The level of recent catches indicate that there is currently only minor targeting on squid.

Table 1.--Catches of squid in metric tons (t) by nation in the Aleutian Islands region and eastern Bering Sea 1977-85.[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
1984	325		1	326	2,614	110	74	2,798	3,124
1985	1		4	5	1,469	15	126	1,610	1,615

[a]Catches in 1977-79 from data submitted to the United States by fishing nations; 1980-84 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986.
[b]Republic of Korea.
[c]Taiwan, Federal Republic of Germany, Poland, and U.S. joint ventures.

OTHER SPECIES

by

Richard G. Bakkala

INTRODUCTION

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

The "other species" category consists of five groups of species: sculpins, sharks, skates, smelts, and octopuses. Numerous species of sculpins occur in the Bering Sea. Cooperative U.S.-Japan surveys identified 34 species in the eastern Bering Sea in 1979, and 22 species in the Aleutian Islands region in 1980 (Bakkala et al. 1985b; Ronholt et al. 1985). During these same surveys, 15 species of skates were identified. However, there probably has been some misidentification of skates because of inadequate taxonomic keys and the number of species may be fewer than 15. Species that have been consistently identified during these surveys are the Alaska skate, _Bathyraja parmifera_; big skate, _Raja binoculata_; longnose skate, _R. rhina_; starry skate, _R. stellulata_; and Aleutian skate, _R. aleutica_. Species of smelt occurring in the regions are capelin, _Mallotus villosus_; rainbow smelt, _Osmerus mordax_; and eulachon, _Thaleichthys pacificus_. Sharks are rarely taken during demersal trawl surveys in the Bering Sea; the species normally caught is spiny dogfish, _Squalus acanthias_, but one occurrence of Pacific sleeper shark, _Somniosus pacificus_, has also been recorded. Two species of octopuses have been recorded, with _Octopus dofleini_ the principal species and _Opisthoteuthis californiana_ appearing intermittently in catches.

COMMERCIAL CATCHES AND ABUNDANCE ESTIMATES

Reported catches in the "other fish" category reached a peak of 133,340 metric tons (t) in 1972, when total catches of all species of groundfish reached a maximum of 2.3 million t, but have since substantially declined and were only 13,600 t in 1985 (Table 1). The proportion of "other species" in total groundfish catches was similar in the 2 years, however, representing 6% in 1972 and 8% in 1985. 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).

Table 1 .--All-nation catches of other fish in metric tons, 1964-85.[a]

Year	Aleutian Islands 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	49,953
1981	7,274	35,551	42,825
1982	5,167	18,200	23,367
1983	3,193	11,062	14,255
1984	1,669	8,508	10,177
1985	2,049	11,503	13,552

[a]Data for 1964-80 from catches reported to the United States by fishing nations; 1981-85 data from French et al. 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986.

Data from NWAFC surveys of the eastern Bering Sea in 1975 and 1979-86 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.

Survey abundance estimates for the "other species" complex have shown some general trends but have been irregular at times. Biomass estimates for the complex as a whole apparently increased between 1975 and 1982 reaching an initial peak of 533,100 t at the end of this period (Table 2). The 1981 biomass value did not fit this trend, however. The survey estimates declined after 1982 to 334,250 t in 1985, but the 1986 estimate was the highest yet observed at 573,100 t. These periodic wide fluctuations in abundance estimates may be caused by changes in availability of certain species to the survey trawls. The major contributor to this variability in estimates is the sculpins, although large fluctuations in abundance estimates for skates were also observed between 1984 and 1986 (Table 2). Some of the species of sculpins, such as the butterfly sculpin, Hemilepidotus papilio, have relatively large biomasses and are distributed on the northern fringes of the survey area. Changes in the north-south distribution of this species can substantially alter the annual biomass estimates for the sculpin complex. For example, the biomass estimate for butterfly sculpin was 54,000 t in 1985 and 159,000 t in 1986 which accounts for most of the increase in the overall biomass of the sculpin complex between 1985 and 1986.

It should be pointed out that smelts may be poorly sampled by demersal trawls because species of this family primarily inhabit pelagic waters. The abundance of this family-is, therefore, assumed to be substantially under-estimated.

Estimates indicate that the "other species" group may be from 7 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 1982 may have been somewhere between a level that produces MSY and the level of the virgin population size. Using 1) the assumption that the combined biomass estimates from the 1982 eastern Bering Sea and 1980 Aleutian surveys approximated virgin biomass and 2) a natural mortality coefficient of 0.2, the Alverson and Pereyra (1969) yield equation would indicate that MSY (i.e., MSY = 0.5 x 0.2 x 589,800 t) is 59,000 t.

Table 2.--Biomass estimates (in metric tons) of other species from Northwest and Alaska Fisheries Center demersal trawl surveys in 1975 and 1979-85.[a]

		Species Group					
Area	Year	Sculpins	Skates	Smelts	Sharks	Octopuses	Total
Eastern Bering Sea	1975	109,800	31,800	19,200	0	5,800	166,600
	1979	296,100	74,400	10,400	400	40,300	421,600
	1980	294,400	123,100	13,000	0	20,400	450,900
	1981	201,400	127,400	5,700	0	10,800	345,300
	1982	336,100	173,200	10,700	0	13,100	533,100
	1983	289,700	166,000	5,800	400	10,400	472,300
	1984	242,900	190,500	10,500	0	2,600	446,500
	1985	174,700	154,000	2,700	50	2,800	334,250
	1986	302,100	258,000	12,500	0	500	573,100
Aleutian Islands Region	1980	39,400	13,700	0	800	2,800	56,700
	1983	20,500	12,100	0	0	200	32,800

[a]The biomass estimates for the eastern Bering Sea are from the survey area shown in Figure 1 of the section of this report on walleye pollock. The 1979, 1981, 1982, and 1985 data include estimates from continental slope waters (200-1,000 m), but other years' data do not. Slope estimates were usually 5% or less of the shelf estimates.

ACCEPTABLE BIOLOGICAL CATCH

Based on the combined biomass estimates (605,900 t) from the 1986 eastern Bering Sea and 1983 Aleutian Islands surveys, the MSY of 59,100 t would represent an exploitation rate of 10%. Due to the uncertainties in the assumptions for estimating MSY, and the wide fluctuations in recent biomass estimates, it is recommended that the acceptable biological catch (ABC) for the "other species" category be set at 36,700 t. This estimate is based on the more conservative 1985 eastern Bering Sea and 1983 Aleutian Islands biomass value and a 10% exploitation rate. Although conservative, the EY estimate is well above current catch levels.

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