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Condition of Groundfish Resources of the Eastern Bering Sea and Aleutian Islands Region in 1987

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Richard G. Bakkala (editor)
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Daniel H. Ito, Grant G. Thompson, Vidar G. Wespestad, Sandra A. McDevitt, Daniel K. Kimura, Gary E. Walters, Jimmie J. Traynor, Lael L. Ronholt, Karen L. Halliday, Allen M. Shimada, and Miles S. Alton

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Northwest and Alaska Fisheries Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
7600 Sand Point Way NE, BIN C15700, Bldg. 4
Seattle, WA 98115-0070

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ABSTRACT

This report contains assessments of the condition of groundfish and squid stocks in the eastern Bering Sea and Aleutian Islands regions management area. The assessments are based on single species analyses of commercial fishery and research vessel survey data available through August 1987. Estimates of maximum sustainable yields and acceptable biological catches are presented to guide management of the 1988 fishery. Table A summarizes results of these assessments.

Pacific cod, *Gadus macrocephalus*; yellowfin sole, *Limanda aspera*; arrowtooth flounder, *Atheresthes stomias*; 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 fish than in previous years. The condition of sablefish, *Anoplopoma fimbria*, and Pacific ocean perch, *Sebastes alutus*, have improved providing somewhat higher yields than in recent past years. Recruitment and abundance of the exploitable population of Atka mackerel, *Pleurogrammus monopterygius*, has declined, resulting in a lower yield estimate than for 1987. The stock condition of Greenland turbot, *Reinhardtius hippoglossoides*, is of greatest concern. There has been a recruitment failure of age 1 Greenland turbot since 1980 and this lack of recruitment is projected to reduce the abundance of the exploitable stock into the early 1990s.

Estimates of acceptable biological catches (ABCs) for the groundfish complex increased from 2.2 million metric tons (t) for 1987 to 2.7 million t for 1988. This increase results mainly from higher yield estimates for walleye pollock, arrowtooth flounder, and "other flatfish."

The groundfish management plan for this area established an optimum yield (OY) range of 1.4-2.0 million t which cannot be exceeded without an amendment to the plan. Thus, although the ABCs indicate that the complex can be exploited at a level of 2.7 million t in 1988, no more than 2.0 million t can be taken because of the stipulated OY range.

Table A.--Estimated biomasses, maximum sustainable yields (MSY), and acceptable biological catches (ABC) in thousands of metric tons (t), and views on stock condition for groundfish in the eastern Bering Sea/Aleutian Islands region from assessments in 1987[a].

Species	Estimated biomass	MSY	ABC	Stock condition	Abundance trend
Walleye pollock	7,500	2,770	1,730		Abundance projected to decline
(Eastern Bering Sea)	(6,500)	(2,300)	(1,500)	Good	
(Aleutians)	(1,000)	(470)	(230)	Good	
Pacific cod	1,324	206	213	Excellent	Abundance remains at historic high
Yellowfin sole	2,466	150-175	216	Excellent	Abundance near historic high but expected to decline.
Greenland turbot	414	34.5-66.0	14	Fair	Abundance projected to decline
Arrowtooth flounder	491	---	109.5	Excellent	Abundance high and increasing
Other flatfish	2,256	224.5-230.5	330.5		
(Rock sole)	(1,250)	(112.5)	(163.0)	Excellent	Abundance at historic peak
(Alaska plaice)	(552)	(76.0)	(76.0)	Good	Abundance above average
(Flathead sole)	(406)	(36.0-42.0)	(87.5)	Excellent	Abundance at historic peak
(Miscellaneous flatfish)	(48)	---	(4.0)	Fair	Abundance stable at moderate level
Sablefish	152.8	6.6-11.7	10.6		
(Eastern Bering Sea)	(56.5)	(3.0-5.3)	(3.9)	Improved	Improved but below historic level
(Aleutians)	(96.3)	(3.6-6.4)	(6.7)	Improved	
Pacific ocean perch complex					
(Eastern Bering Sea)	101.1	7.4	6.0		
(Pacific ocean perch)	(64.1)	(4.8)	(3.8)	Improved	Recruitment improved and abundance increasing
(Other species in complex)	(37.0)	(2.6)	(2.2)	Unknown	Unknown
(Aleutians)	276.5	18.9	16.6		
(Pacific ocean perch)	(157.9)	(10.6)	(9.5)	Improved	Recruitment improved and abundance increasing
(Other species in complex)	(118.6)	(8.3)	(7.1)	Unknown	Unknown
Other rockfish	25.6	1.8	1.5		
(Eastern Bering Sea)	(7.1)	(0.5)	(0.4)	Unknown	Unknown
(Aleutians)	(18.5)	(1.3)	(1.1)	Unknown	Unknown
Atka mackerel	<200	38.8	21	Fair	Recruitment and exploitable stock reduced
Squid	---	>10	10	---	Unknown
Other species	618	59	59	Good	Abundance high
TOTAL GROUNDFISH	15,825	3,527.5-3,595.1[b]	2,737.7		

[a]Numbers in parentheses give estimates for individual management areas where applicable and for individual species making up a management unit species complex.
[b]Does not include estimates for arrowtooth flounder and miscellaneous flatfish.

CONTENTS

INTRODUCTION

by

Richard G. Bakkala

The current condition of groundfish and squid stocks 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 (MSYs) and acceptable biological catches (ABCs) or equilibrium yields (EYs) are presented to guide management of the 1988 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. exclusive economic zone (EEZ) 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 EEZ encompass the eastern Bering Sea region, and INPFC area 5 encompasses the Aleutian Islands region. 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.

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 ABC or 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 foreseeable economic value (Table 1). These species are only taken 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 while fishing for target species. If any species are retained, catch records must be kept.

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

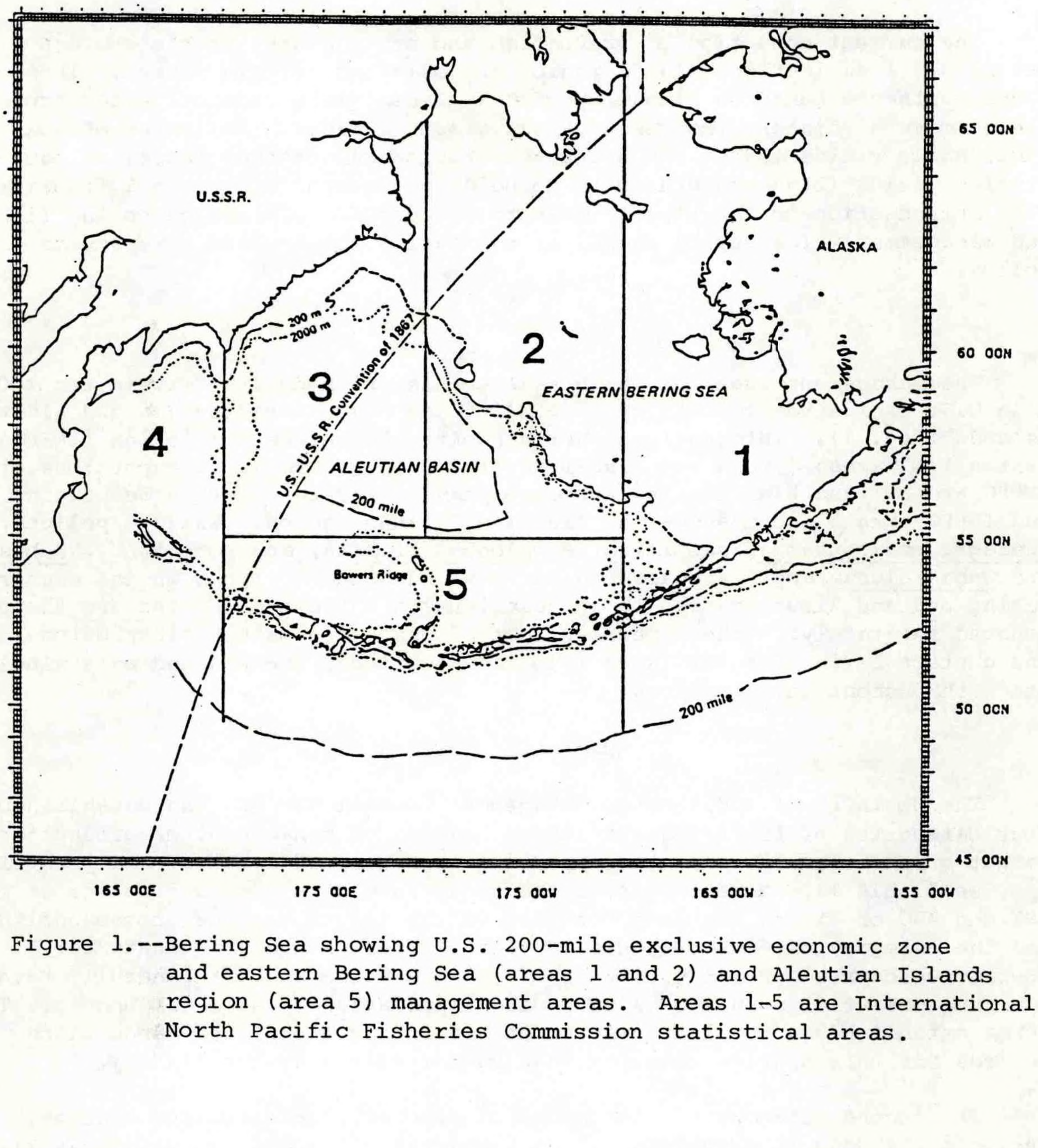


Figure 1.--Bering Sea showing U.S. 200-mile exclusive economic zone and eastern Bering Sea (areas 1 and 2) and Aleutian Islands region (area 5) management areas. Areas 1-5 are International North Pacific Fisheries Commission statistical areas.

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, lumpsuckers (Cyclopteridae)	
	Turbots	Smelts	Sandfishes (<u>Trichodon</u> sp.)	
	Other flatfishes		Rattails (Macrouridae)	
	Atka mackerel		Ronquils, searchers (Bathymasteridae)	
	Sablefish		Lancetfish (Alepisauridae)	
	Pacific ocean perch		Pricklebacks, cockscombs, warbonnets, shanny	
	Other rockfish		Prowfish (<u>Zaprora silenus</u>)	
			Hagfish (<u>Eptatretus</u> sp.)	
			Lampreys (<u>Lampetra</u> 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. Throughout much of the history of this fishery, distant water fleets from Japan, the U.S.S.R., and the Republic of Korea have predominately harvested these resources. Not until recent years have U.S. domestic and joint venture fisheries taken a significant portion of the catch.

These U.S. fisheries began operations for groundfish in 1980 and have grown rapidly since. In 1980 they took 35,000 metric tons (t) or 2.7% of the total all-nation groundfish catch. By 1985 the U.S. domestic and joint venture catches had increased to 728,700 t or 41% of the total and in 1986 it surpassed that of non-U.S. fisheries, reaching 1,252,800 t or 72% of the total. In 1987 U.S. fisheries are anticipated to take about 95% of the total 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 t in 1961. Following a decline in abundance of yellowfin sole, other species were targeted, principally walleye pollock; total catches of groundfish in the eastern Bering Sea rose to much higher levels, reaching more than 2.2 million t in 1972. Catches then declined and ranged between 1.2 and 1.3 million t in 1977-83 when the United States established jurisdiction over these resources through implementation of the Magnuson Fisheries Conservation and Management Act of 1976 and placed catch restrictions on the fishery because of declining stock abundance of walleye pollock and other species. More recently, landings have again increased reaching 1.6 million t in 1985 and 1986 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 walleye pollock, and overall catches declined to less than 100,000 t annually. Starting in 1980, catches of walleye 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.

Table 2.--Groundfish and squid catches (metric tons) in the eastern Bering Sea, 1954-86*.

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	2,654	1,678	58,373	37,162	14,393		4,926	35,902	1,169,511
1978	979,431	42,543	1,192	2,211	12,155	138,433	45,781	21,040	832	6,886	61,537	1,312,041
1979	913,881	33,761	1,376	1,718	10,048	99,017	42,919	19,724	1,985	4,286	38,767	1,167,482
1980	958,279	45,861	2,206	1,097	1,367	87,391	62,618	20,406	4,955	4,040	34,633	1,222,853
1981	973,505	51,996	2,604	1,222	1,111	97,301	66,394	23,428	3,028	4,179	35,651	1,260,419
1982	955,964	55,040	3,184	224	863	95,712	54,908	23,809	328	3,837	18,200	1,212,069
1983	982,363	83,212	2,695	221	460	108,385	53,659	30,454	141	3,455	15,465	1,280,510
1984	1,098,783	110,944	2,793	1,569	327	159,526	29,294	44,286	57	2,798	8,508	1,458,885
1985	1,178,759	132,736	2,248	784	82	227,107	21,986	71,179	4	1,610	11,503	1,648,038
1986	1,189,355	134,373	3,189	849	71	208,597	14,471	77,669	12	848	10,471	1,639,905

*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, 1962-86*

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	4,907		22,447	78,717
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	8,080	9,587	4,488	20,975	1,808	16,170	73,892
1978	6,282	3,295	821	5,286	8,737	6,548	23,418	2,085	12,436	68,908
1979	9,504	5,593	782	5,487	14,543	12,847	21,279	2,252	12,934	85,221
1980	58,156	5,788	274	4,700	1,361	8,299	15,533	2,332	13,028	109,471
1981	55,516	10,462	533	3,618	1,397	8,040	16,661	1,762	7,274	105,263
1982	57,978	11,526	955	1,021	2,792	8,732	19,546	1,201	5,167	108,909
1983	59,026	9,955	673	272	1,147	7,869	11,585	524	3,675	94,726
1984	81,834	22,216	1,043	356	292	3,275	35,998	326	1,669	147,009
1985	58,730	12,690	2,089		217	104	37,856	5	2,049	113,740
1986	46,217	6,439	3,135		217	2,296	31,978	20	1,509	91,811

*See individual species sections of this report for details of the catch statistics.

Fishery Restrictions

Prior to implementation of U.S. extended jurisdiction and establishment of the 200-mile EEZ, a number of restrictions in the form of 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 the INPFC to minimize the impact of groundfish fisheries on the traditional North American setline fishery for Pacific halibut, *Hippoglossus stenolepis*. A number of these restrictions were retained by the NPFMC following implementation of extended jurisdiction in 1977.

Time-area restrictions applicable to non-U.S. groundfish fisheries in the two management areas are illustrated in Figure 2. Figure 3 illustrates regulatory areas implemented in 1986 and amended in 1987 in which incidental catch limits have been established for Pacific halibut; red king crab, *Paralithodes camtschatica*; and bairdi Tanner crab, *Chionoecetes bairdi*. No U.S. joint venture or non-U.S. trawling is allowed in the area between 160° and 162°W long. and south of 58°N lat.; longline fishing is allowed in this zone and a U.S domestic trawl fishery for Pacific cod may be allowed in a southern portion of the zone under certain circumstances and until a by-catch of 12,000 red king crab has been taken. In zone 1, U.S. domestic and joint venture trawl fisheries in 1987 are limited to a by-catch of 135,000 red king crab or 80,000 bairdi Tanner crab and in zone 2 to 326,000 bairdi Tanner crab. The U.S. joint venture fisheries is further limited to a by-catch of 828,000 Pacific halibut in zone 1. For non-U.S. fisheries in 1987 there was a limit of 64,000 bairdi Tanner crab for combined zones 1 and 2. Non-U.S. fisheries are also prohibited from fishing in zone 1 if U.S. domestic and joint venture fisheries reach their limit of red king crab in this zone.

Optimum Yields

Optimum yields (OY) estimated by the NPFMC since implementation of extended jurisdiction in 1977 are given in Table 4. The OY is the amount of fish that will provide the greatest overall benefit to the United States. This concept takes into account the maximum harvest that will permit a species to sustain itself, and includes consideration of relevant economic, social, or ecological factors. The management plan for eastern Bering Sea and Aleutians groundfish established an OY range of 1.4-2.0 million t which cannot be exceeded without an amendment to the plan. The overall OY for all species combined has steadily increased from 1.4 million t in 1977 to 2.0 million t in 1984 and has remained at the upper limit of the OY range through 1987. Species accounting for the major part of this increase have been walleye pollock, yellowfin sole, and Pacific cod.

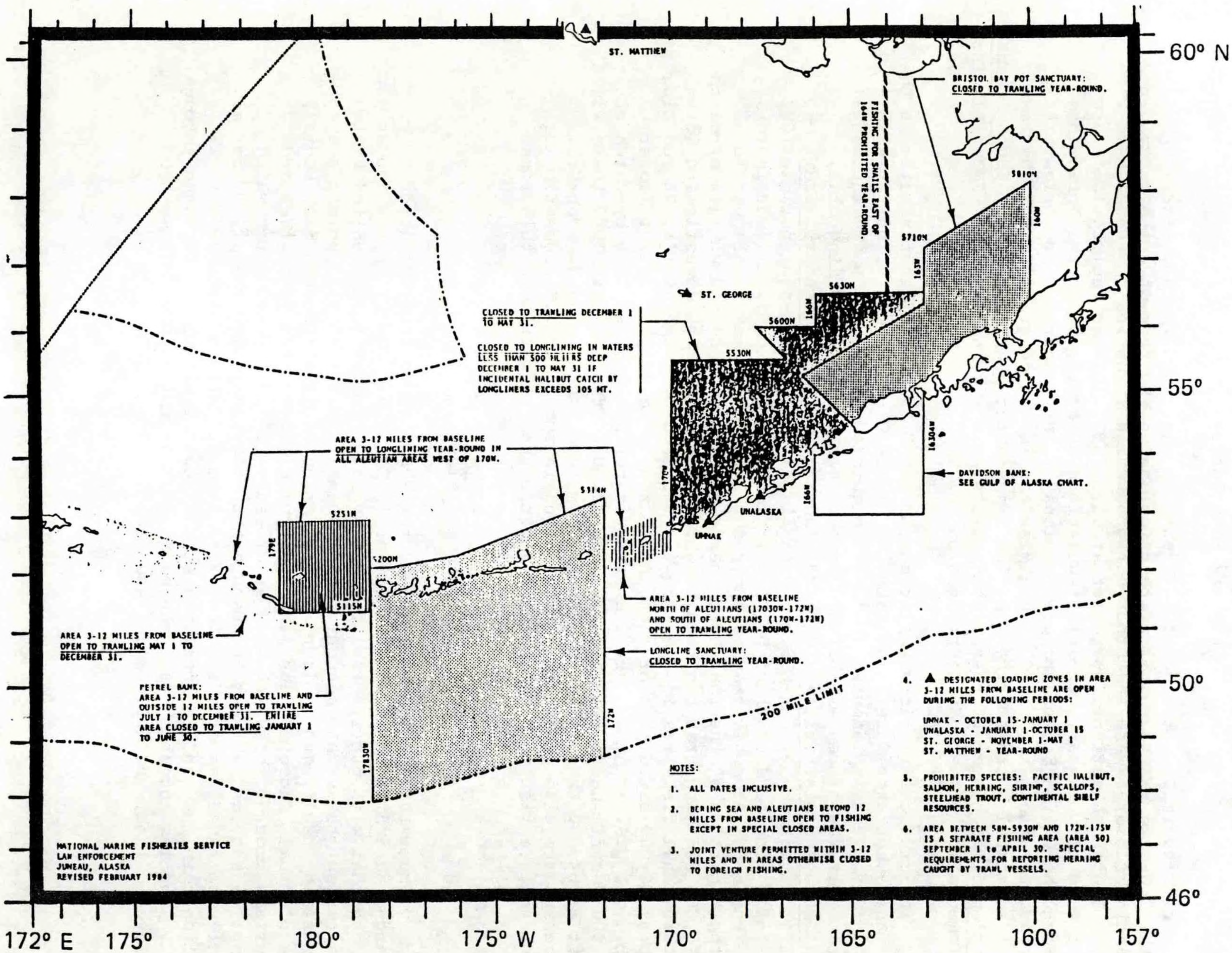


Figure 2.--Time-area restrictions applicable to non-U.S. groundfish fisheries in the eastern Bering Sea and Aleutian Islands regions.

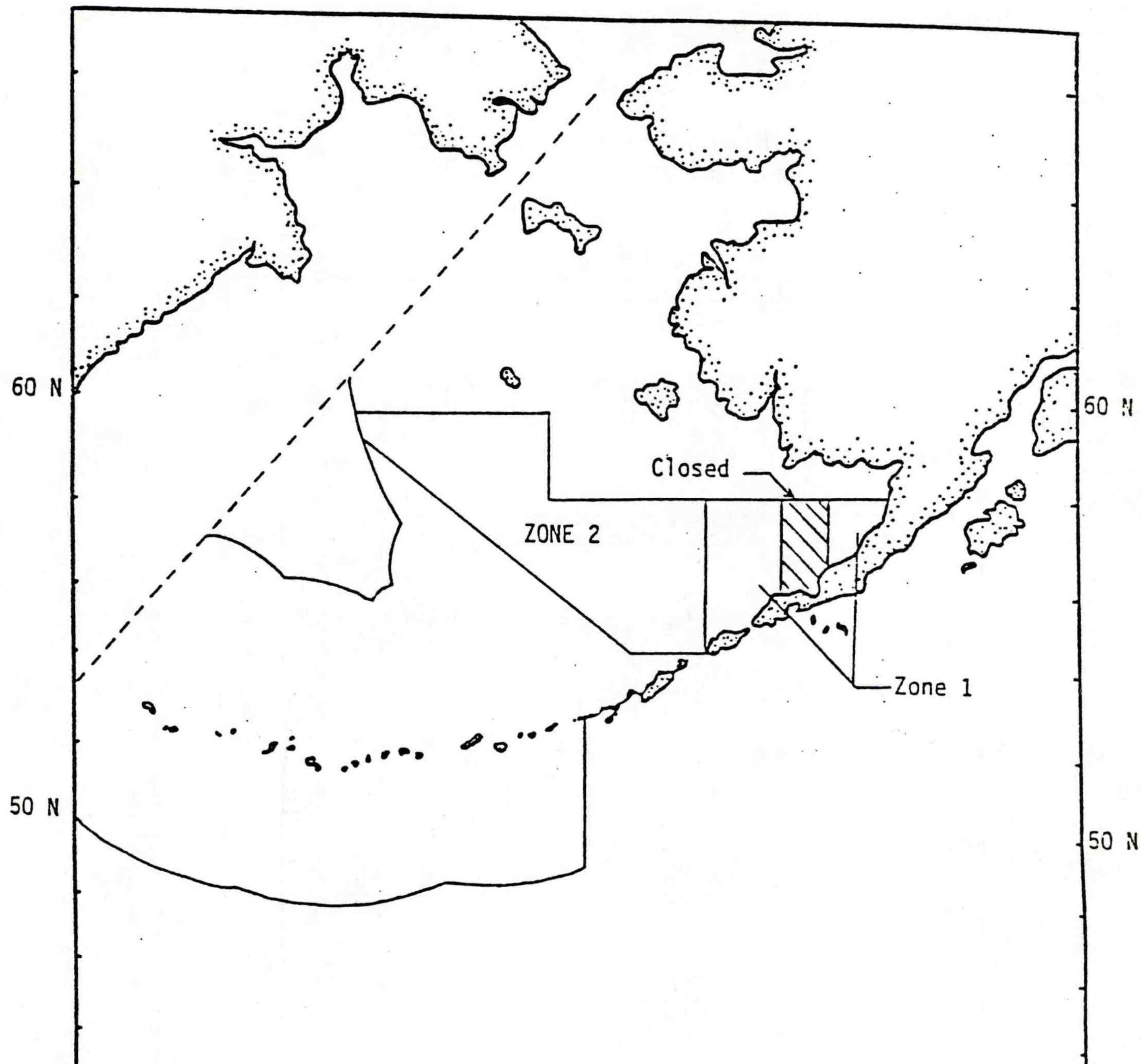


Figure 3.--Regulatory areas for controlling by-catches of red king crab and bairdi Tanner crab in commercial trawl fisheries.

Table 4.--Optimum yields (t) for groundfish of the eastern Bering Sea and Aleutian Islands region 1977-87.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
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	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	209,500	187,000
Greenland turbot	-	-	-	90,000	90,000	90,000	90,000	59,610	42,000	33,000	20,000
Arrowtooth flounder[b]	-	-	-	-	-	-	-	-	-	20,000	9,795
Other flounders[c]	100,000	159,000	159,000	61,000	61,000	61,000	61,000	111,490	109,900	124,200	148,300
Pacific cod	58,000	70,500	70,500	70,700	78,700	78,700	120,000	210,000	220,000	229,000	280,000
Sablefish	5,000	3,000	3,000	3,500	3,500	3,500	3,500	3,740	2,625	2,250	3,700
Pacific ocean perch	6,500	6,500	6,500	3,250	3,250	3,250	3,250	1,780	1,000	825	2,850
Other rockfish	-	-	-	7,727	7,727	7,727	7,727	1,550	1,120	825	450
Herring	21,000	18,670	18,670	-[d]	-	-	-	-	-	-	
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	5,000	500
										27,800	15,000
Aleutians[a]											
Walleye pollock	-	-	-	100,000	100,000	100,000	100,000	100,000	100,000	100,000	88,000
Sablefish	2,400	1,500	1,500	1,500	1,500	1,500	1,500	1,600	1,875	4,200	4,000
Pacific ocean perch	15,000	15,000	15,000	7,500	7,500	7,500	7,500	2,700	3,800	6,800	8,175
Other rockfish	-	-	-	-	-	-	-	5,500	5,500	5,800	1,430
Atka mackerel	-	24,800	24,800	24,800	24,800	24,800	24,800	23,130	37,700	30,800	30,800
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	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, Greenland turbot and arrowtooth flounder , other flounders, Pacific cod and squid.

[b]Combined with Greenland turbot until 1986.

[c]Includes Greenland turbot and arrowtooth flounder until 1980.

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

WALLEYE POLLOCK

by

Vidar G. Wespestad and Jimmie J. Traynor

INTRODUCTION

Walleye pollock (Theragra chalcogramma) is the most abundant fish species in the northeastern Pacific Ocean, composing 80% of the total catch of groundfish species (Bakkala et al. 1986b). Walleye pollock range completely across the Pacific Rim, from Washington State to the Sea of Japan. Large stocks of pollock also occur in waters off Asia, as indicated by catches in the 4-6 million metric ton (t) range for 1980-85 (Food and Agriculture Organization 1987); however, abundance data are not available for these stocks.

Pollock is a semidemersal species which is primarily pelagic during the first few years of life and then becomes increasingly demersal in behavior as it ages. The species is found in greatest abundance along the outer continental shelf between the 100-m and 300-m depth contours. Pollock has also been found to occur pelagically at low density in the deep waters of the Aleutian Basin (Okada and Yamaguchi 1985).

Several studies have attempted to delineate the stock structure of pollock (Grant and Utter 1980), yet unit stocks are still poorly understood and several hypotheses have been proposed (Bakkala et al. 1986b). For management purposes two stocks are recognized: eastern Bering Sea and Aleutian Islands.

COMMERCIAL UTILIZATION

Japanese trawlers harvested pollock at low levels in the eastern Bering Sea from 1954 to 1963 and began directed pollock fisheries in 1964. Commercial catches increased rapidly during the late 1960s and reached a peak in 1970-75 when catches ranged from 1.3 to 1.9 million t annually (Fig. 1). Following the peak catch of 1.9 million t in 1972, pollock catches were steadily reduced through bilateral agreements. Since 1977, when the United States established exclusive management jursisdiction, quotas ranging from 950,000 t to 1.2 million t have been in effect and catches have ranged from 914,000 t to 1.2 million t. In 1980, U.S. vessels began harvesting pollock, and by 1986 U.S. harvests in the Bering Sea had grown to 71% of the 1.2 million t quota (Table 1).

Catches in the Aleutian Islands area have historically been much less than the harvest in the eastern Bering Sea. However, since 1980 the catch in this area has increased (Table 2). Part of the growth has been due to the development of off-shelf fisheries in the Bowers Ridge area. Additionally, increasing catches of pollock are reported from the international zone in the

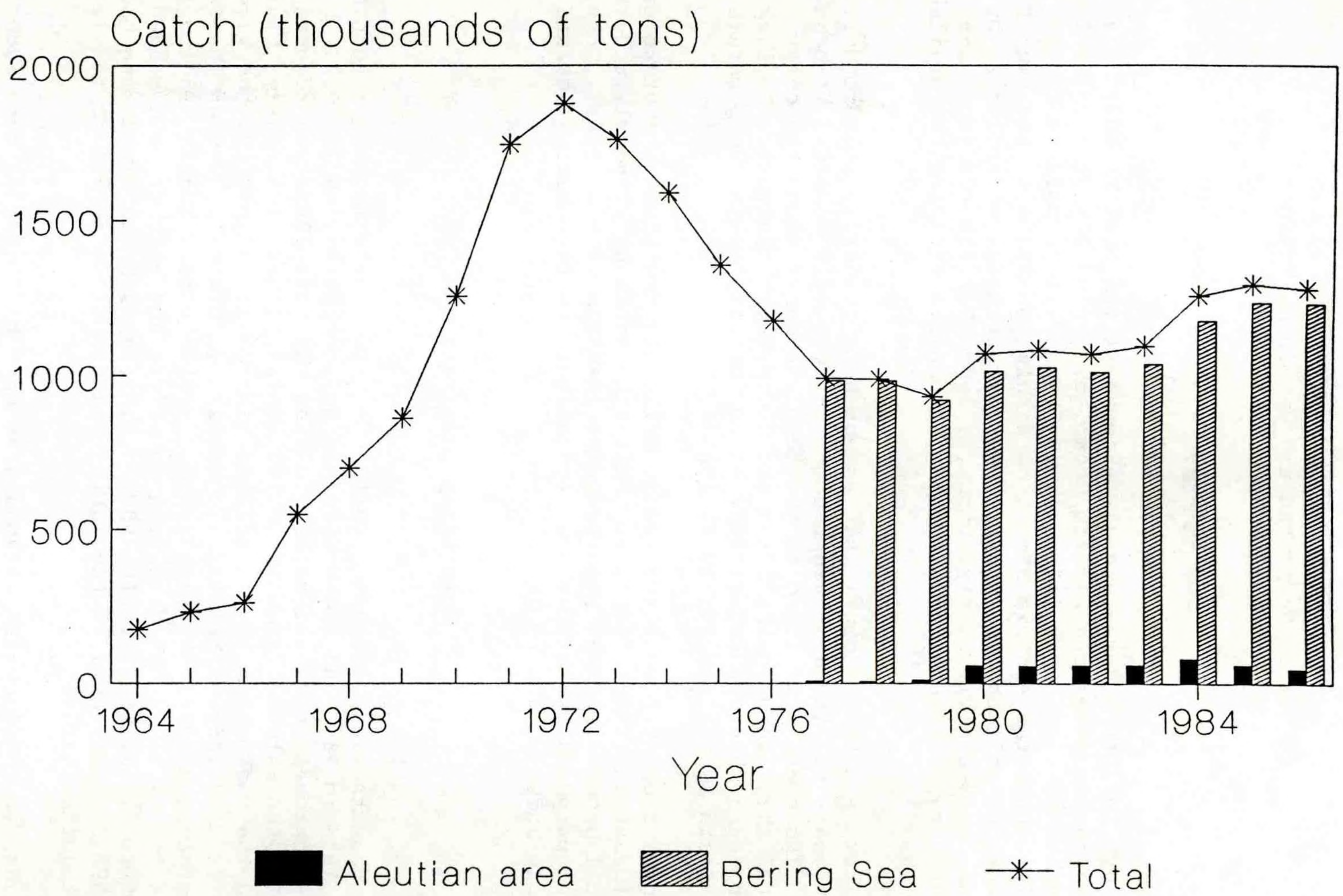


Figure 1.--Walleye pollock catch in the eastern Bering Sea and Aleutian Region, 1964-86.

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]	Other non-U.S. Fisheries[d]	U.S. joint ventures[e]	U.S. Domestic[f]	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
1986	256,178		76,313		3,616		1,043	804,842	47,363	1,189,355

[a]Catch data for 1964-79 as reported by fishing nations (except 1967-76 R.O.K. catches which were based on U.S. surveillance reports). Non-U.S. and joint venture catch data for 1980-86 from U.S. observer estimates as reported by French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986, 1987a. 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]Portugal and People's Republic of China.
[e]Joint ventures between U.S. fishing vessels and R.O.K., Japanese, Polish, F.R.G., and U.S.S.R. processors.
[f]Fish caught and processed by U.S. operations.

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	U.S. joint ventures	U.S. Domestic	Others[b]	Total
1977	5,667	1,618	325				15	7,625
1978	5,025	1,193	64					6,282
1979	8,047	1,412	45					9,504
1980	46,052	1	6,256	5,806			41	58,156
1981	37,980		11,074	5,593			869	55,516
1982	33,379		8,117		1,983		14,499	57,978
1983	29,485		13,420		2,547		13,574	59,026
1984	38,598		12,027	5,171	6,694	3,891	15,453	81,834
1985	35,628		5,872	9,364	7,283	583		58,730
1986	6,245		5,319	3,215	30,261	777	400	46,217

[a]Catch data for 1977-79 as reported by fishing nations and for 1980-86 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986, 1987a. 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, Republic of China (Taiwan), and People's Republic of China.

central Bering Sea. Some of this off-shelf catch may derive from the Aleutian Islands stock, such as the harvest just outside the U.S. exclusive economic zone (EEZ) near Bowers Ridge. The catch outside the U.S. EEZ has not been officially reported and is not included in Table 2.

CONDITION OF STOCKS

Three methods of assessment have been used to evaluate the status and condition of exploited stocks: bottom-trawl research surveys, combination hydroacoustic/midwater-trawl research surveys, and analysis of commercial fisheries statistics through the application of catch per unit effort (CPUE) and age-structured assessment models.

Research Vessel Survey Assessments

Fishery research surveys have been an important source of data for pollock assessment. Surveys were initially designed to assess the abundance of commercial crab species and the gear used was low-opening bottom trawls (Bakkala et al. 1985a). Indices of abundance or biomass estimates were made by the area swept method (Baranov 1918; Alverson and Pereyra 1969), assuming a trawl catch efficiency that ranged from 0.5 to 1.0.

Annual trawl surveys instituted in the early 1970s focused on crab and only surveyed a portion of the pollock range until 1975 when the survey was expanded to encompass most of the range of pollock. Since 1979, the U.S. survey has been conducted annually in the expanded area with vessels fishing standard groundfish bottom trawls (Bakkala et al. 1985b). All abundance estimates obtained from bottom trawl surveys reported here are for a standardized area (Fig. 2) and may differ slightly from abundance estimates reported prior to 1986 (Bakkala et al. 1987b).

In 1979 a hydroacoustic survey of the midwater biomass was conducted in conjunction with the bottom trawl survey. These hydroacoustic/bottom trawl surveys have been repeated triennially (Traynor and Nelson 1985). The incorporation of hydroacoustic techniques into the Bering Sea groundfish survey provided an assessment of both the bottom and midwater component of the pollock resource (Table 3, Fig. 3). The 1979 survey-based estimate of the eastern Bering Sea pollock stock was 10.5 million t, much higher than previously estimated using bottom trawl survey information alone. The 1979 hydroacoustic survey estimated that more than twice as much biomass, 7.5 million t, occupied the pelagic zone than the bottom; bottom trawl surveys estimated 3.0 million t in the same year. In 1982, 39% of the pollock were estimated to be on bottom; in 1985, 49% were on bottom.

Survey efforts have not been as extensive in the Aleutian Islands area as in the eastern Bering Sea. Bottom trawl surveys have been conducted in 1980, 1983, and 1986. Estimated biomass from these surveys were 371,237 t in 1980, 826,810 t in 1983, and 619,445 t in 1986. These estimates do not include midwater pollock and represent only a portion of the biomass. The population in this area is likely in excess of 1 million t if the on-bottom/off-bottom distribution is similar to that in the eastern Bering Sea.

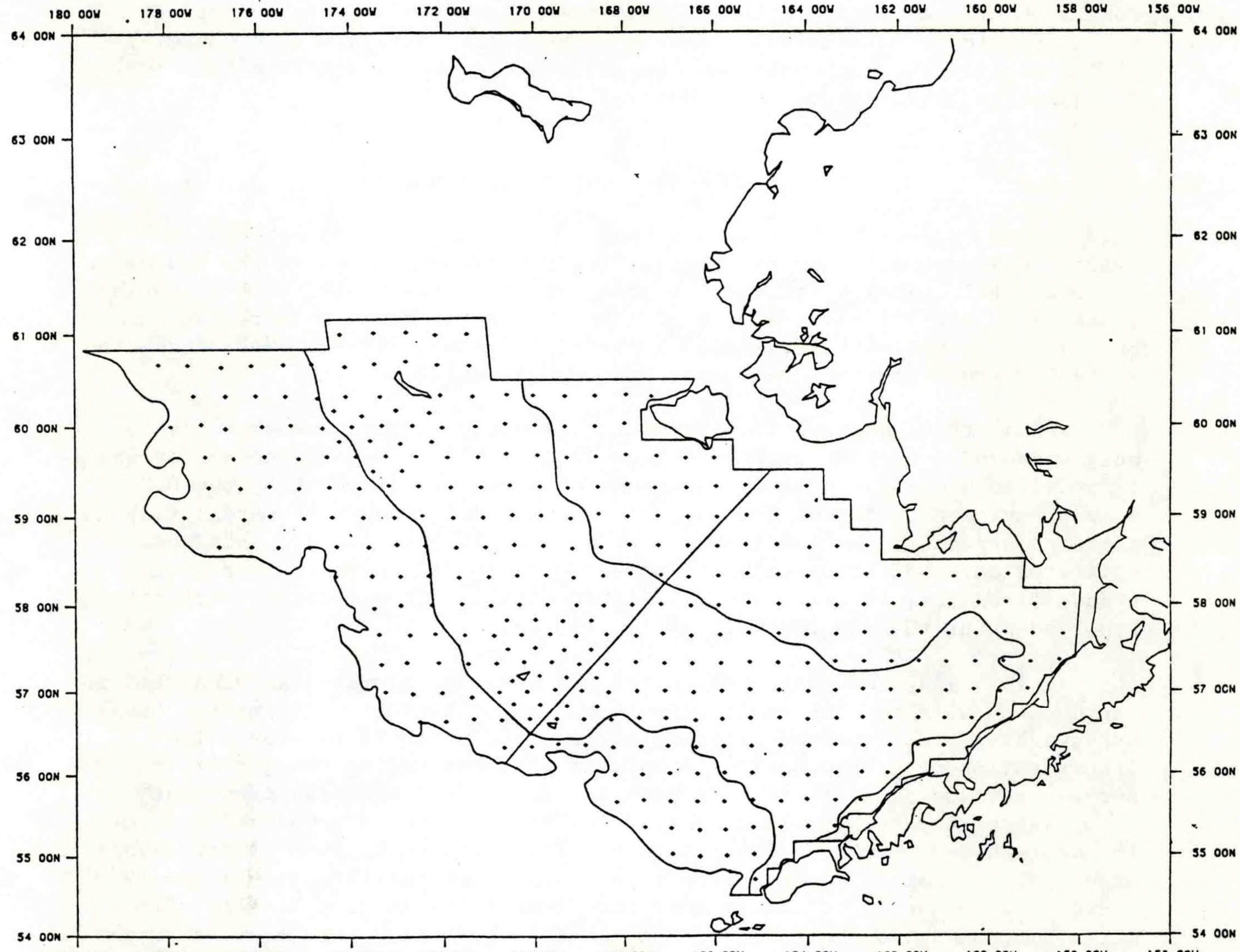


Figure 2.--Standardized survey area on the eastern Bering Sea continental shelf sampled during Northwest and Alaska Fisheries Center bottom trawl resource assessment surveys in 1975 and annually since 1979. Stratification of the survey area used in analyses of assessment data is also shown.

Table 3.--Biomass of eastern Bering Sea walleye pollock (million t) as estimated by various assessment methods, 1963-1985. CAGEAN biomass estimates are expressed as means and 95% confidence intervals.

Year	Survey		Cohort	
	Bottom	Bottom + midwater	Analysis[a]	CAGEAN[b]
1964			1.9	
1965			2.7	
1966			3.7	
1967			6.0	
1968			8.1	
1969			9.9	
1970			11.5	
1971			12.4	10.2 ± 7.2
1972			11.8	9.6 ± 6.6
1973			11.0	8.8 ± 5.6
1974			9.4	7.2 ± 5.0
1975			8.2	6.6 ± 4.0
1976			8.5	7.1 ± 3.6
1977			8.3	4.9 ± 1.1
1978			7.8	5.1 ± 1.2
1979	2.9[c] ± 0.5	10.5[d] ± 3.1	7.8	6.1 ± 1.2
1980	1.5[e] ± 0.4		9.1	8.9 ± 2.0
1981	2.5[c] ± 0.6		9.9	11.3 ± 2.9
1982	2.8[c] ± 0.7	7.8[d] ± 1.2	10.5	12.6 ± 3.4
1983	6.1[e] ± 1.0		9.9	12.5 ± 3.4
1984	4.6[e] ± 1.0		9.6	12.2 ± 3.7
1985	4.5[c] ± 0.8	9.4[d] ± 1.6	8.4	11.6 ± 8.3
1986	5.0[e] ± 1.0		6.7	8.3 ± 4.5
1987	5.2[e] ± 1.2			

[a]Cohort analysis (Pope 1972) tuned to hydroacoustic and bottom trawl survey estimates for years 1979, 1982, and 1985.

[b]CAGEAN model (Deriso et al. 1985) tuned with hydroacoustic and bottom trawl survey estimates for years 1979, 1982, and 1985; M = 0.3; Means and confidence intervals based on 50 bootstrap replications.

[c]Resource survey included shelf and slope bottom trawl components.

[d]Resource survey included midwater, shelf bottom trawl, and slope bottom trawl components.

[e]Resource survey included shelf bottom trawl component only.

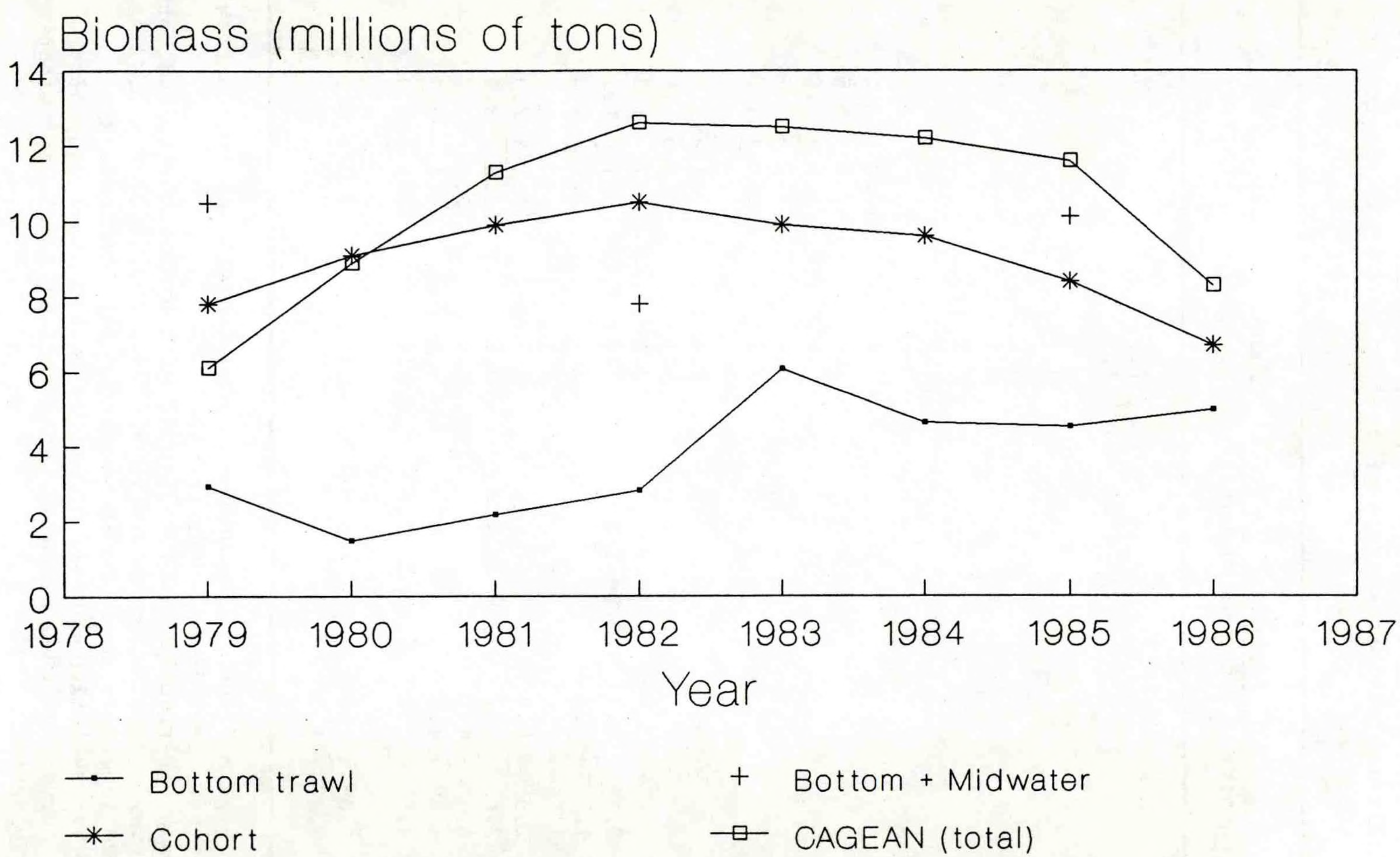


Figure 3.--Estimates of walleye pollock biomass in the eastern Bering Sea based on bottom trawl and hydroacoustic survey data and age structure models. See Table 3 for description of age structure models.

Relative Abundance Indices

Since the early 1970s annual pollock assessments and harvest recommendations have relied, in part, on the catch and effort data collected by the Japan Fisheries Agency. Several effort standardization procedures and efficiency adjustments were devised to determine the trend of pollock abundance (Low and Berger 1984; Okada 1984). For the Bering Sea, the CPUE of Japanese pair trawls was utilized in all analyses since this gear accounted for the largest portion of the catch. Each method indicated different trends in the pollock resource (Table 4). A common method was adopted in 1979 (Low and Ikeda 1980); however, in recent years this and the other CPUE trends appear to be in conflict with observed biomass trends. This is believed to be primarily due to the fishery following the very large 1978 year class which shifted from a pelagic to a demersal distribution with age and became more available to pair trawls and other bottom trawls (Bakkala et al. 1987a). Due to the discrepancy between CPUE and biomass estimates and the phasing out of foreign fishing, these CPUE trends no longer have any assessment value.

Age-Structured Models

Age-structured stock assessment models are used to estimate absolute population abundance and vital population rates of exploited stocks. The main advantage of age-structured stock assessment models over more traditional approaches such as stock production (Schaefer 1957) or dynamic pool (Beverton and Holt 1957) models is that they can be applied without knowledge of effective effort, catchability, or gear selectivity. These stock assessment techniques permit the population dynamics of an exploited stock to be reconstructed from catch data alone.

Input data to age-structured stock assessment models consist of catch-at-age data (in numbers) and an estimated rate of natural mortality. Age-structured stock assessment models can be categorized as either sequential population models (Fry 1949; Gulland 1965; Murphy 1965; Pope 1972) or separable models (Doubleday 1976; Pope and Shepherd 1982; Fournier and Archibald 1982; Deriso et al. 1985).

An advantage of sequential models is that results are very robust to violations of the underlying assumptions (Megrey 1983). If there are several exploited age groups in a cohort, then one can be reasonably confident of obtaining reliable estimates of the size of the year class when it is recruited to the fishery.

The results from cohort analysis and other sequential methods are very sensitive to the choice of the estimated fishing mortality on the oldest age of a cohort (terminal F) and the estimate of natural mortality. The accuracy of fishing mortality estimates increases if the ratio of fishing to total mortality is large and natural mortality is reasonably estimated (Pope 1972; Ulltang 1977; Jones 1981). Given that population estimates are only as good as the estimate of terminal fishing mortality, it follows that abundance estimates in the terminal year (the most recent fishing year) are necessarily the least accurate. Unfortunately, in fisheries management the size of the population in the terminal year of the analysis and the immediately preceding years is exactly the period of greatest interest.

Table 4.--Catch per unit effort (CPUE) of eastern Bering Sea walleye pollock by Japanese pair trawl vessels as computed by different methods, 1964-85.

	Method		
Year	Japan (t/hour)	U.S. (t/1,000 hp/hour)	INPFC*
1964	3.1	9.5	
1965	6.0	18.3	
1966	7.4	23.6	
1967	8.1	21.3	
1968	11.2	23.8	130
1969	14.3	31.5	132
1970	12.1	18.7	145
1971	11.2	14.2	152
1972	12.2	14.2	184
1973	10.2	8.6	164
1974	10.1	9.9	115
1975	9.1	9.2	100
1976	9.2	10.0	98
1977	9.2	8.7	97
1978	9.7	9.2	100
1979	9.8	9.9	103
1980	9.3	9.7	92
1981	9.6	6.4	95
1982	10.9	6.0	100
1983	11.5	9.3	121
1984	14.6	9.2	173
1985	14.6	9.9	155

* Percentages calculated relative to 1975 (Low and Ikeda 1980).

In order to improve estimates from sequential models, procedures have been developed to calibrate or "tune" these models (Pope and Shepherd 1985). The process of tuning sequential age-structured models usually involves an ad hoc approach in which terminal Fs are adjusted to catch-effort indices. Tuning the more structured separable model allows fishery-independent data to be incorporated simultaneously into the analysis along with the fishery data.

In the assessment of eastern Bering Sea pollock stocks, several age-structured stock assessment methods are employed. Traditional methods such as sequential population models (Gulland 1965) and cohort analysis (Pope 1972) have been used. Also a newer model, CAGEAN (Deriso et al. 1985), has been used in recent years. This newer model is a nonlinear log-catch model employing the separability assumption first proposed by Doubleday (1976).

Deriso et al. (1987) discuss extensions to the CAGEAN model that permit the incorporation of fishery-independent data into the analysis in hope that these data would help calibrate or "tune" resulting population biomass estimates and stabilize the fit. Briefly, this approach is implemented as follows. Survey population estimates (midwater plus bottom) for fully recruited ages (Bs) are used along with the catch estimates (Bc) to calculate an annual full-recruitment exploitation fraction (u = Bc/Bs). These calculated exploitation fractions, along with an estimate of natural mortality (M), are used to approximate the annual instantaneous full-recruitment fishing mortality rate (F) from the catch equation:

$$u = \frac{F}{F + M} [1-\exp(-F-M)]. \qquad (1)$$

Solutions for F from Equation (1) are used as estimates of annual effective fully recruited fishing effort, which can then be substituted into the auxiliary effort sums of squares term. Since the catchability coefficient is constrained to be equal to 1.0, these values are considered independent estimates of full-recruitment fishing mortality. In this approach, annual effective effort parameters estimated from the CAGEAN model can be different from values calculated from Equation (1). The degree of difference depends on how strongly the auxiliary effort sum of squares term is weighted (see equation 9 in Deriso et al. 1985). Means and variances of population biomass estimates were calculated with a Monte Carlo bootstrap analysis using 50 bootstrap replications.

The cohort analysis and CAGEAN models were "tuned" using auxiliary information based on data from Northwest and Alaska Fisheries Center (NWAFC) hydroacoustic and bottom trawl surveys of eastern Bering Sea pollock. In order to tune the models used to assess Bering Sea pollock, three assumptions regarding the fishery-independent information are necessary: 1) the relative age composition of pollock obtained from combined hydroacoustic-bottom trawl surveys are true estimates of the age composition of the population, 2) interannual changes in survey abundance estimates are proportional to abundance changes in the population, and 3) the average target strength coefficient used to scale echo integrator data to estimates of absolute density is correct.

Under the first assumption the terminal Fs were adjusted until the proportional age composition from the model was identical to the proportional age composition observed in the survey conducted in that year. The vector of F values in the terminal year was then scaled up or down under the second assumption so that the population trend from the cohort analysis approximated the abundance trend observed in surveys. For trend adjustment, the ratio of numbers of age 3 and older pollock estimated in the 1979, 1982, and 1985 surveys were used to adjust the cohort analysis trend. The F for the terminal age (age 9), in years prior to the terminal year were computed as the average of ages 7 and 8 assuming that catchability was similar for these ages.

The CAGEAN model was also tuned using survey data from 1979, 1982, and 1985. The survey data were used to estimate F for age 4 (the fully recruited age) from the exploitation fraction (catch in numbers/survey estimate). In the application of the CAGEAN model to Bering Sea pollock, the effort sum of squares weighting factor, lambda (see equation 9 in Deriso et al. 1985), was set to 1.0 which gives equal weight to the survey and fisheries data.

Initial estimates of the parameters in the CAGEAN model were obtained from cohort analysis results. In the CAGEAN model relative selectivity was set equal to 1.0 for age 4 and computed for all other ages. Previous analysis has shown that F peaks at age 4 and then decreases in older ages (Wespestad and Terry 1984; Bakkala et al. 1985c).

A critical factor in the accuracy of results from age-structured models is the instantaneous natural mortality rate (M). In a recent review, Lynde (1984) suggests that for eastern Bering Sea pollock estimates of natural mortality are on the order of 0.3-0.4, which is much lower than the 0.65 estimated by Chang (1974) but similar to the estimate of 0.4 used by Bakkala et al. (1979). Wespestad and Terry (1984) estimated M = 0.45 for age 2 and M = 0.30 for ages 3-9. These values have been used since 1982 in cohort analysis forecasts and appear to approximate the true rate of natural mortality for pollock. In the CAGEAN model, a constant value of 0.30 was used since there is no provision for variable age-specific values of M in the computer program.

Biomass estimates from the two models are presented in Table 3 and Figure 3 with estimates of abundance from surveys. The tuned cohort analysis shows a major increase in the late 1960s with a peak in the early 1970s. Results indicate that abundance was low around the time the fishery began with an estimated biomass in 1964 of about 2 million t but then increased four-to sixfold in the following 8-9 years. The cohort analysis estimated peak abundance in 1971 at 12.4 million t, but the CAGEAN model estimate for 1971 was lower, 10.2 $\pm$ 7.2 million t. Following a peak level of abundance in 1971 the population declined to a low of 4.9-8.3 million t in the late 1970s, depending on the model (Table 3). From 1979 to 1982 biomass increased, but it has been declining in recent years following lower levels of recruitment in the early 1980s.

The results of cohort analysis indicate that pollock has been exploited relatively lightly since 1977. Exploitation rates on age groups 3-9 have varied from 10 to 18% since 1977 as shown below:

Year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Biomass (million t)	7.1	6.8	6.4	6.4	8.9	9.3	9.6	8.3	8.4	6.7
Catch (million t)	0.98	0.98	0.91	0.96	0.97	0.96	0.98	1.10	1.18	1.19
Exploit. Rate	0.14	0.14	0.14	0.15	0.11	0.10	0.10	0.13	0.14	0.18
Spawners (billions)	9.55	9.19	8.55	8.48	11.58	13.14	13.14	11.61	10.78	9.02

RECRUITMENT TRENDS

Estimates of recruitment were examined to project future abundance trends and potential yield. Recruitment indices (number of age 1 pollock) were obtained from the annual groundfish survey (Fig. 4). These recruitment indices were compared to the number of age 3 pollock estimated using cohort analysis (Fig. 5). This comparison indicated a linear relationship which was used to project age 3 recruitment in 1987-89.

Cohort analysis estimates of age 3 pollock entering the population have varied from a high of 15.1 billion in 1981 to 1.8 billion in 1984, and have averaged 7.58 billion since 1981. The following table shows that since the very strong 1978 year class, recruitment of age 3 pollock was average through 1985 except for a very weak 1981 year class.

	Year class								
	1978	1979	1980	1981	1982	1983	1984	1985	1986
Survey Estimates (billions)	8.2	--	1.0	0.8	3.7	0.3	4.0	2.2	0.3

	Year of recruitment as age 3								
	1981	1982	1983	1984	1985	1986	1987	1988	1989
Cohort Estimates Age 3 (billions)	15.1	5.7	7.4	1.8	7.9	[2.2]	[8.4]	[5.4]	[2.2]

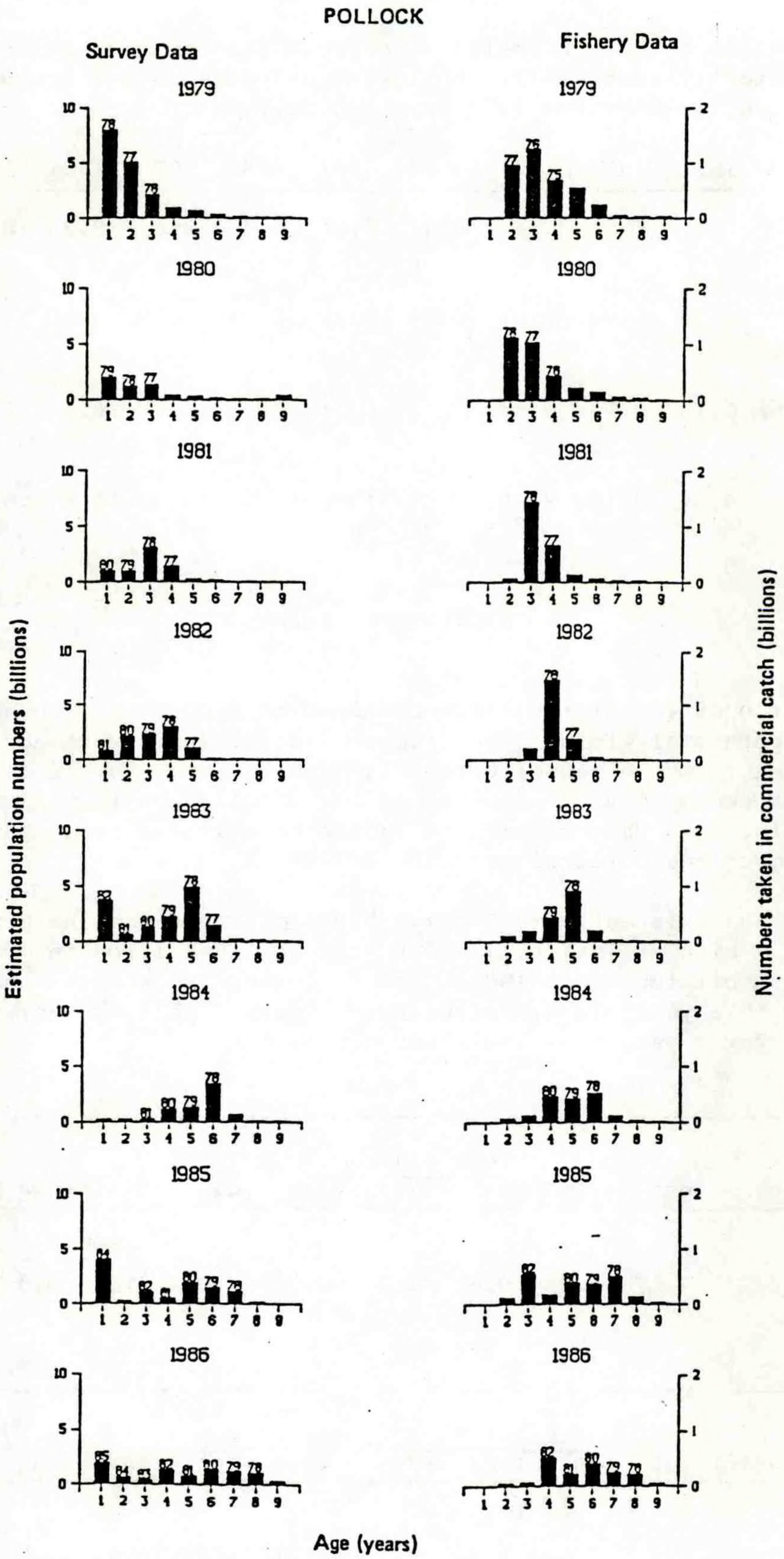


Figure 4.--Age composition of eastern Bering Sea pollock derived from bottom trawl surveys and from the commercial fishery. Principal year classes are shown above bars.

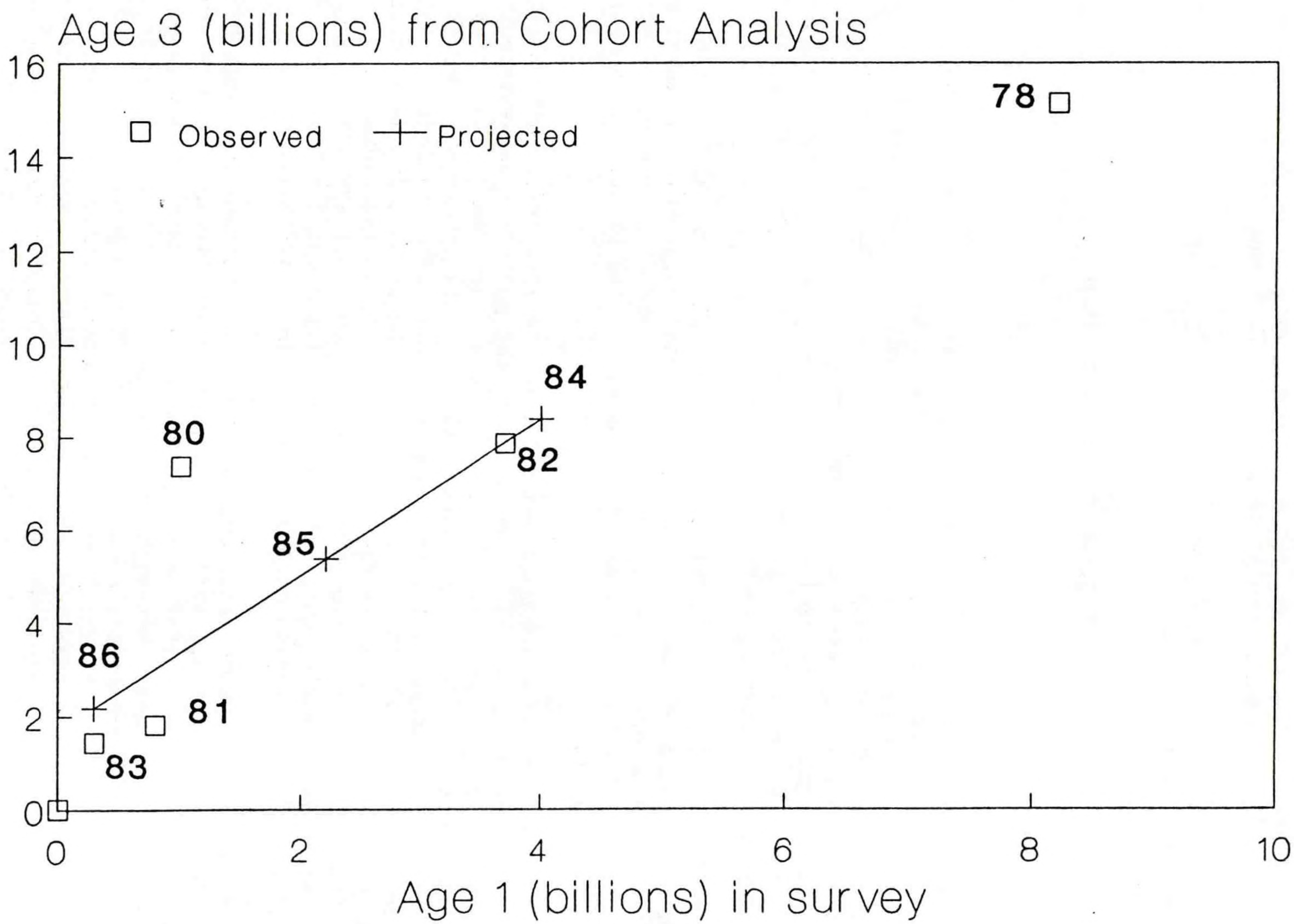


Figure 5.--Relationship between survey estimates of age 1 and cohort analysis estimates of age 3 walleye pollock in the eastern Bering Sea. Age 3 recruitment for 1978 and 1980-83 year classes are observed values and for 1984-86 year classes projected values.

Projected recruitment (bracketed values) is estimated to be low in 1986 and 1989, but slightly above and below average in 1987 and 1988, respectively. Since age information was not yet available from the 1987 survey, fish less than 20 cm (Fig. 6) were assumed to be age 1 (1986 year class).

For the Aleutian Islands area the data are insufficient to estimate any recruitment index.

MAXIMUM SUSTAINABLE YIELD

Eastern Bering Sea

Maximum sustainable yield (MSY) for eastern Bering Sea pollock is estimated to be 2.3 million t based on a model incorporating pollock population dynamic parameters. The model (Walters 1969) is an age structured model which incorporates the Beverton and Holt yield equation, a population decay function and a spawner recruit function. Input to the model consisted of the estimated number of pollock by age in the base year (1985), natural mortality, spawner-recruit parameters, and growth and fishery parameters (Table 5).

The MSY estimate of 2.3 million t is similar to the MSY estimate of 2.5 million t obtained by Wespestad and Terry (1984) using the same model with different parameters; however, these estimates are greater than the MSY estimate of 1.5 million t obtained by Low et al. (1978) using a general production model.

The model results are most sensitive to the spawner-recruit relationship (Fig. 7). The Ricker model was used to fit the pollock spawner-recruit data because this method is sensitive in situations where cannibalism is an important population regulating mechanism. Cannibalism is believed to be an important source of mortality in the eastern Bering Sea pollock population. A Beverton-Holt (1957) model was also fit to the pollock spawner-recruit data, but this model did not fit the data as well as the Ricker model ($R = 0.51$ vs. $R = 0.81$, respectively). Figure 7 shows that MSY occurs at the point of maximum recruitment, which is 8.4 billion age 3 pollock produced from a spawning population of 5.2 billion pollock (4.7 million t).

An additional important factor in the determination of pollock MSY is the selectivity pattern. Pollock fishing mortality exhibits a dome-shape curve, which indicates that pollock selectivity increases to a maximum at ages 4-5 and then decreases with age. This pattern is believed due to a combination of catchability and availability (Wespestad and Megrey 1987). Therefore, to calculate the level of fishing that produces MSY two sets of possible selectivity patterns were examined: 1) the average selectivities computed from the F values obtained in cohort analysis; and 2) a pattern based on data presented by Smith (1981), where age 3 is only partially available but older ages are fully selected.

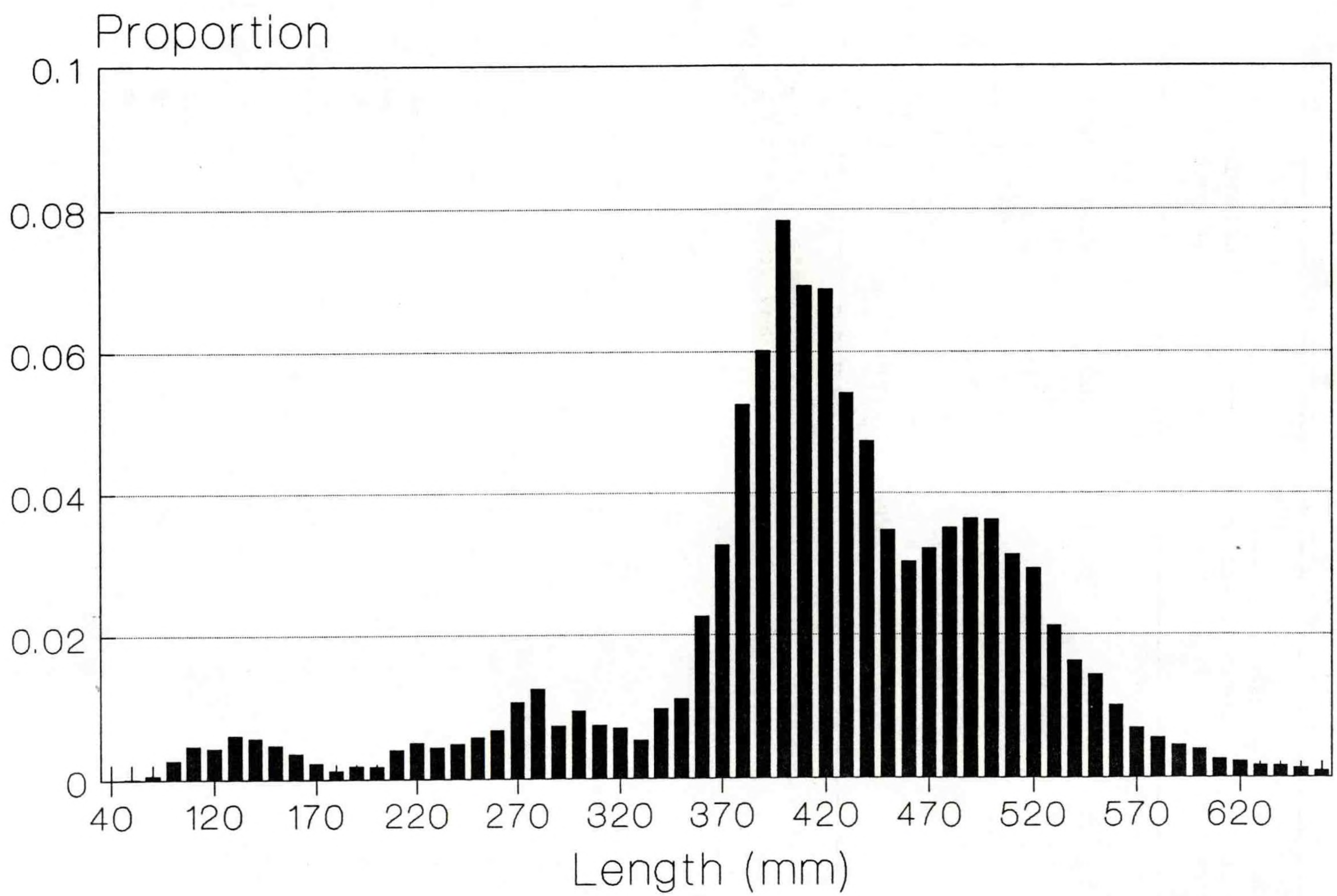
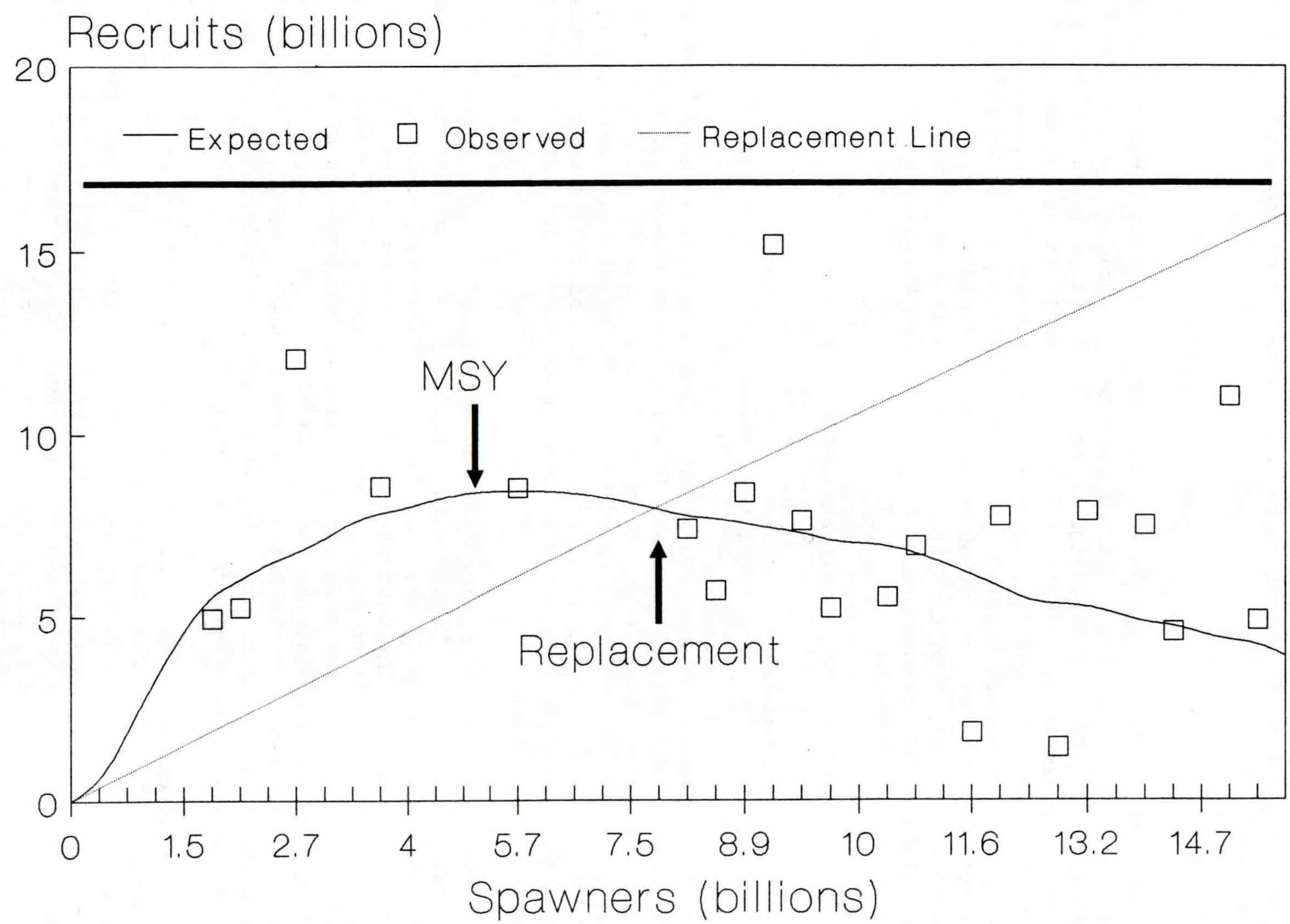


Figure 6.--Size frequency of eastern Bering Sea walleye pollock captured in the 1987 NWAFC bottom trawl survey.

Table 5.--Major life history and fishery parameters for eastern Bering Sea walleye pollock.

Age	Natural mortality rate	Mean Length (cm)	Mean weight (kg)	Proportion mature	Selectivity proportion	
					a	b
2	0.45	28.04	0.105	0.008	0.30	0.07
3	0.30	34.68	0.251	0.289	0.69	0.89
4	0.30	40.03	0.409	0.641	0.96	1.00
5	0.30	43.29	0.465	0.842	1.00	1.00
6	0.30	46.82	0.650	0.901	0.78	1.00
7	0.30	50.20	0.798	0.947	0.61	1.00
8	0.30	52.46	0.892	0.963	0.49	1.00
9	0.30	53.21	0.945	0.970	0.42	1.00

[a]Selectivity computed from Cohort analysis estimated F values.
[b]Calculated by comparing fishery and survey age compositions (Smith 1981).



R=4.002 S exp -0.175 S

Figure 7.--Spawner-recruit relationship for eastern Bering Sea walleye pollock.

For the case of dome-shaped selectivity MSY is achieved when F = 0.83. With asymptotic selectivity, MSY is achieved at F = 0.68, a lower level of effort because of the higher availability of older pollock. In terms of biomass the rates of removal at MSY are 47 to 48% of the exploitable biomass (ages 3-9).

Aleutian Islands

For the Aleutian Islands region, a separate catch level has in the past been established, although there is movement of pollock to and from the eastern Bering Sea. Interchange between areas is believed to be low and biomass appears to be relatively stable in the Aleutian Islands area. Based on the bottom trawl surveys, the Aleutian component was estimated at about 1.0 million t in recent years. Assuming that the biomass is a long-term average and that the population dynamics are similar to those of the eastern Bering Sea region, then applying the MSY exploitation rate of 47% results in a preliminary MSY estimate of 470,000 t for the Aleutian stock.

ACCEPTABLE BIOLOGICAL CATCH

Eastern Bering Sea

The acceptable biological yield for eastern Bering Sea pollock was evaluated at the MSY, replacement (fishing = recruitment), and $F_{0.1}$ fishing rates. The yield and biomass predictions resulting from fishing at these levels in 1988-90 are shown in Figure 8. The projections were derived from the Walters (1969) model with input consisting of 1985 cohort analysis estimates, cohort analysis-trawl survey recruitment projections, and the 1985-87 catch data.

The projections indicate that the biomass of eastern Bering Sea pollock in 1988 is expected to be above the level that will produce MSY. However, if estimated recruitment in the near future is correct, biomass is expected to decrease. How much the biomass decreases depends on future exploitation and recruitment. The fit of pollock recruitment to the Ricker model is fairly good (Fig. 7). For the most part, observed recruitment is close to expected and the few large deviations have primarily been due to greater than expected recruitment. Although the fit is reasonably good, there are many sources of error and bias in the relationship which warrant judicious use of the spawner-recruit relationship (Walters and Ludwig 1981).

The spawner-recruit relationship can be used as a guide to establishing harvest levels. The data for pollock show that the replacement level, the point where recruits equal spawners, is 7.9 billion pollock. Estimated spawning stock size has been much greater than 7.9 billion in recent years. The spawning biomass in excess of replacement contributes nothing to future abundance, and in fact, may actually decrease pollock recruitment. Therefore, the most conservative approach is to exploit pollock at a level that maintains the spawning population near the replacement level. Fishing mortality rates in the range of 0.40-0.45 would keep the spawning population at the replacement level.

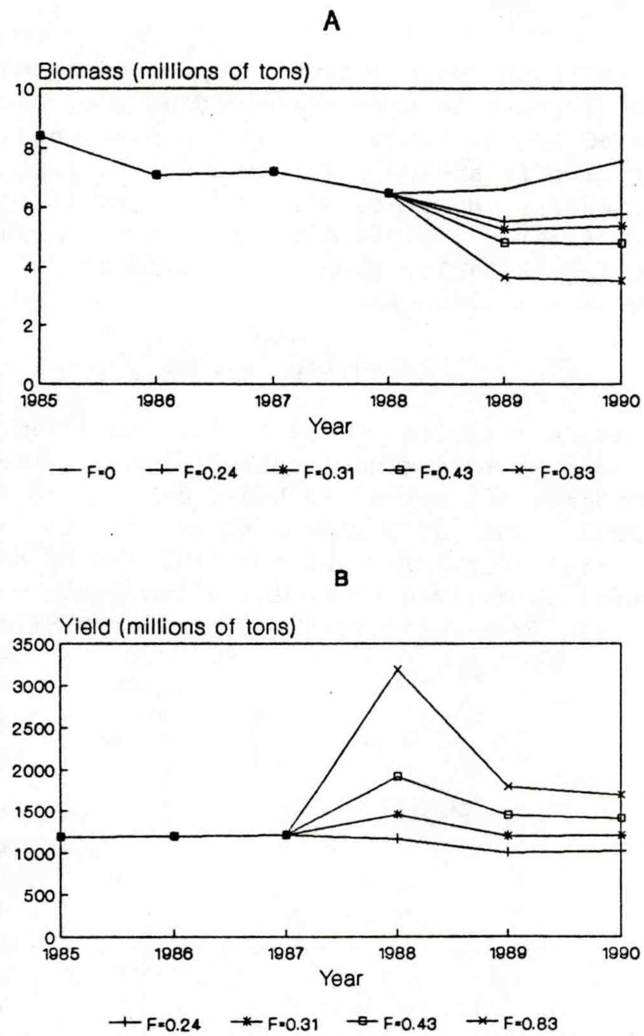


Figure 8.--Predicted biomass (A) and yield (B) of walleye pollock in the eastern Bering Sea for various fishing mortality rates. The fishing mortality rate (F) of 0.24 represents the value that would yield 1.2 million t. F = 0.31 is the $F_{0.1}$ value, F = 0.43 is the theoretical rate which maintains the spawning population at near the replacement level, and F = 0.83 is the theoretical fishing rate to achieve maximum sustainable yield.

Since the pollock stock is projected to decrease below the replacement stock level in the near future, it may be appropriate to exploit at a lower level at this time. One method of establishing a lower rate of harvest is to utilize yield-per-recruit theory and the $F_{0.1}$ concept. For eastern Bering Sea pollock the $F_{0.1}$ level of fishing is $F = 0.31$, equivalent to an exploitation rate ($\mu = 0.23$). At the $F_{0.1}$ fishing rate the 1988 yield is estimated to be 1.5 million t and the 1988 exploitable biomass to be 6.5 million t.

The above estimates were derived by projecting the 1985 cohort analysis population forward in time while adding projected recruitment and subtracting estimated annual catches using the same models used to estimate MSY. In yield-per-recruit analysis all ages in the fishery are assumed to be available to the fishery. However, with reduced availability of older pollock the rate of fishing and yield of these older fish is reduced. If the older fish were fully available, then yield would be 1.7 million t and exploitable biomass 6.6 million t.

Aleutian Islands

In the Aleutian Islands region the status and dynamics of pollock are not as well understood as in the eastern Bering Sea. Since quantitative data are sparse and abundance estimates are based on limited observations, acceptable biological catch (ABC) should be set as low as possible until better data become available. The ABC for 1988 should be set at 230,000 t. This level of harvest is derived by applying the eastern Bering Sea $F_{0.1}$ exploitation rate ($F = 0.31$) to the estimated 1 million t biomass.

PACIFIC COD

by

Grant G. Thompson and Allen M. Shimada

INTRODUCTION

Pacific cod, *Gadus macrocephalus*, are distributed widely over the Bering Sea continental shelf and slope. Table 1 summarizes the catch history of the commercial fishery operating on this stock. During the early 1960s, a large Japanese longline fishery harvested cod for the frozen fish market. Beginning in 1964, the Japanese trawl fishery for walleye pollock (*Theragra chalcogramma*) 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. Although foreign trawl effort has fallen off dramatically in recent years, significant cod catches were still taken by the Japanese longline fishery through 1987. By 1980, a U.S. domestic trawl fishery and several joint venture fisheries had begun 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 1986 took 101,100 metric tons (t), or 72% of the total cod 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 decreased to between 36,600 and 63,800 t in 1971-79. Catches in 1980-86 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 emerging U.S. joint venture and domestic fisheries (Table 1). 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. The 1986 catch was only slightly smaller, totaling 140,900 t for the combined areas.

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 sevenfold 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 surveys that have sampled major portions of the eastern Bering Sea, the catch per unit effort (CPUE) of cod increased approximately nine times (from 2.7 to 24.8 kg/ha) between 1975 and 1983 (solid line, Fig. 1). In 1987, CPUE was 24.6 kg/ha, indicating that relative abundance remains high.

Table 1.--Commercial catches (t) of Pacific cod by area and nation, 1964-86[a].

Year	Japan	U.S.S.R.	R.O.K.[b]	Other[c] Non-U.S. Nations	U.S.[d] Joint Ventures	U.S.[e] Domestic	Total	EBS&AI Grand Total
Eastern Bering Sea								
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	
1986	35,616	0	4,053	186	57,827	36,691	134,373	
Aleutian Islands Area								
1964	241	-	-				241	13,649
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	63,84
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
1986	0	0	0	5	6,115	319	6,439	140,812

[a] Catch data for 1964-79 as reported by fishing nations. Catch data for 1980-86 as reported by French et al. (1981 and 1982), Nelson et al. (1983b and 1984), and Berger et al. (1985a, 1986, and 1987a).

[b] Republic of Korea.

[c] Taiwan, Poland, Federal Republic of Germany, and People's Republic of China.

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

[e] Fish caught and processed by U.S. operations.

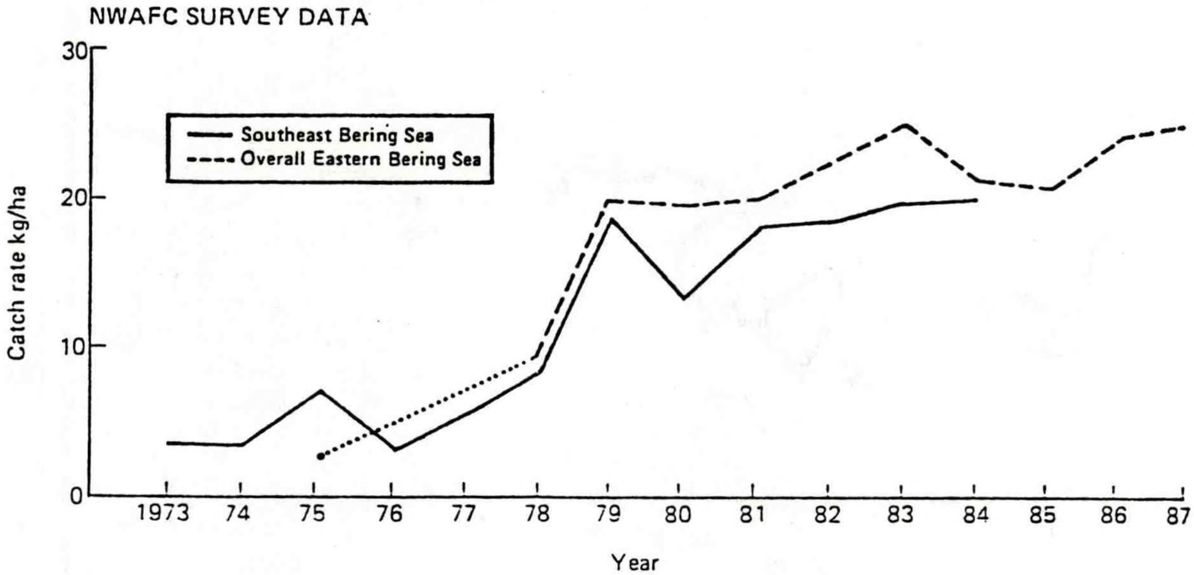


Figure 1.--Relative abundance of Pacific cod as shown by Northwest and Alaska Fisheries Center (NWAFC) bottom trawl surveys.

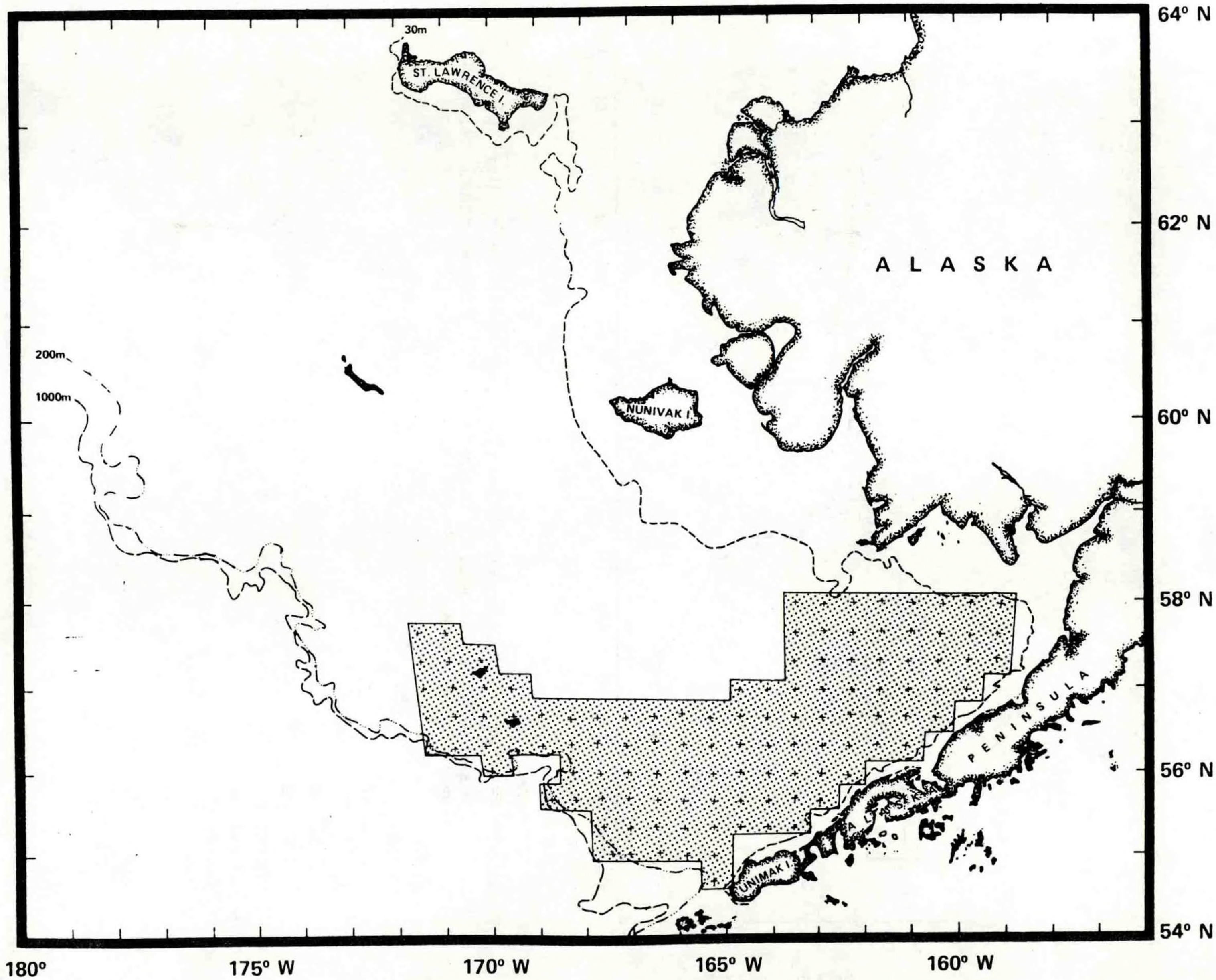


Figure 2.--Comparative fishing area sampled annually during Northwest and Alaska Fisheries demersal trawl surveys in 1973-87.

Biomass Estimates

Estimates of biomass from 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 relatively constant since 1983, with most biomass estimates falling within the range of the other years' confidence intervals. The biomass estimate for 1987 is the highest to date (1,142,400 t).

Four biomass estimates have been derived from surveys in the Aleutian Islands region (Table 3); three based on summer cooperative U.S.-Japan surveys of the overall Aleutians in 1980, 1983, and 1986, and the other on a U.S. winter survey in the eastern Aleutians (Bakkala et al. 1983). The estimates from the summer surveys covering the entire Aleutian chain (170°E - 165°W) showed a sizable increase (54%) in the mean values between 1980 and 1986, even greater than the 24% 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 any of the 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 diagrams are plotted in terms of biomass and numbers for both the 1986 and 1987 shelf surveys in Figure 3. To assist in translating numbers at length into numbers at age, a total of 326 fish from the 1984 survey were aged by the fin ray technique developed by Lai (1985) at the NWAFC. However, fin rays were not collected from survey samples in all years, making direct application of Lai's technique impossible for some samples. This problem was circumvented by utilizing the "iterated age-length key" approach developed by Kimura and Chikuni (1987). Applying this technique to the length-frequency data for 1981-87 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; however, it produces results that seem to match the evidence provided by the progression of the 1977-1978 length-frequency mode.

Data in Table 4 track the declining importance of the once-dominant 1977 and 1978 year classes. 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 1982-85. It is unlikely that any one of these incoming year classes will have an impact equal to that of the 1977 year class, but taken together they indicate that the stock should remain relatively healthy into the near future.

MAXIMUM SUSTAINABLE YIELD

It is apparent that the eastern Bering Sea cod population is subject to wide fluctuations in abundance (Table 2). 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

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
1987	1,142,400	1,002,400 - 1,282,500

Table 3.--Estimates of Pacific cod stock biomass (t) 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
1986	summer	181,700	41,500

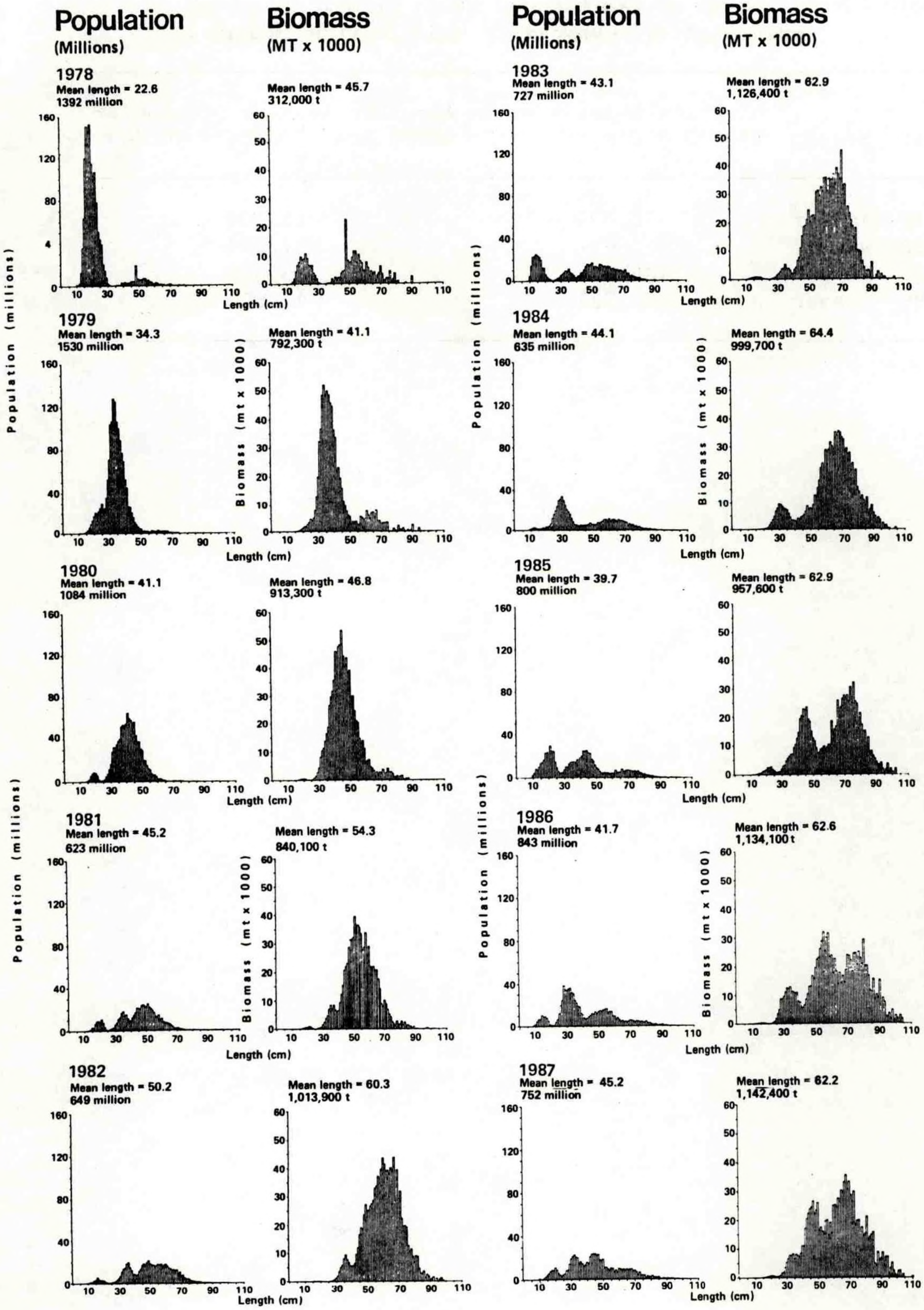


Figure 3.--Population and biomass estimates by centimeter length interval for Pacific cod as shown by NWAFC bottom trawl surveys in 1978-1987.

Table 4.--Estimated numbers (millions) of Pacific cod at age in 1981-87 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	1986	1987
0	0.50	5.65	104.40	9.40	27.52	33.88	4.36
1	61.43	23.49	106.29	31.05	212.64	47.64	73.39
2	135.69	136.42	81.06	304.67	193.28	400.33	229.02
3	229.45	173.61	140.17	58.74	194.40	120.31	220.35
4	107.47	93.91	77.57	32.45	23.68	88.61	47.65
5	56.38	98.84	76.92	58.48	19.52	34.06	47.70
6	22.30	68.01	78.73	71.57	54.24	58.70	63.07
7	3.74	22.72	38.31	45.40	57.92	42.13	44.96
8	0.56	2.53	0.36	6.35	3.44	5.82	2.22
9	5.05	19.99	17.30	9.27	5.44	1.23	9.97
10+	0.50	3.76	5.96	7.68	7.92	10.76	9.42
Total	623.07	648.93	727.07	635.06	800.00	843.46	752.09

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 follow a very tight pattern. For these reasons, any attempt to estimate maximum sustainable yield (MSY) must be considered highly tentative at the present time. Nevertheless, since MSY is an important management tool, preliminary estimates have been computed using stock reduction analysis (SRA), the simple (constant recruitment) form of the Beverton-Holt model, and a revised version of the eastern Bering Sea cod model (Thompson and Shimada 1987).

Stock Reduction Analysis

Stock reduction analysis represents one method of implementing the delay-difference equation of Deriso (1980) as generalized by Schnute (1985). The delay-difference equation is a biomass-based production function that approximates the behavior of an age-structured model exhibiting knife-edge recruitment, age-invariant mortality rates (above the age of recruitment), a Brody (1945) weight-age relationship, and an arbitrary stock/recruit relationship. As it is usually applied, SRA employs a set of life history parameter estimates and a time series of catch data to solve the delay-difference equation and the catch equations simultaneously. This is typically accomplished by assuming that the stock is in equilibrium prior to the second year of the time series, and by assuming either a known biomass estimate for some year during the time series or a known biomass ratio for some pair of years during the time series.

Data from the Pacific cod fishery, however, present a problem for the usual implementation of SRA. Given the pattern of non-decreasing catch levels observed in the Pacific cod fishery, the assumption of initial biomass equilibrium causes SRA to generate a declining biomass trend. This result is difficult to reconcile with the survey biomass estimates from the last several years. To force SRA to match survey results more closely, an alternative implementation was employed in which the results were constrained to reproduce the estimates of recruited biomass given by the U.S.-Japan cooperative surveys in 1979 and 1985. Biomass estimates from the cooperative survey were selected because they include the slope component of the stock. The years 1979 and 1985 were chosen because they represent the earliest and most recent survey years, respectively, thus providing the best hope of accurately extrapolating biomass trends through time. The recruited portion of the stock was defined as the portion comprised of individuals greater than or equal to 40 cm in length (Shimada 1985).

Technically, when the analysis is constrained to reproduce two biomass estimates and the assumption of initial biomass equilibrium is retained, the model is overspecified. This results in SRA generating an initial recruitment level which does not satisfy the assumption of initial biomass equilibrium, but which does satisfy every other equation in the model. Because the error occurs at the start of the time series, the impact on final biomass estimates should be small. However, it should be noted that this particular implementation of SRA has not been subject to formal peer review.

Other SRA parameters used were as follow: age at recruitment = 3 years, rho (a parameter in Schnute's (1985) parametrization of the Brody growth equation) = 0.9453, the ratio of weight at age 2 to weight at age 3 = 0.2680, and natural mortality (M) = 0.22 (Thompson and Shimada 1987). Rho and the ratio of weight at age 2 to weight at age 3 were calculated from the following length-age and weight-length equations:

$$L(age) = 84.008*(1.-\exp(-0.203*(age+0.806))), \quad (1)$$

and

$$W(L) = 0.00608*L^{3.1635}, \quad (2)$$

where L = length in centimeters, and W = weight in kilograms. Equation (1) was estimated from the 1984 pooled (male and female) sample using Faben's (1965) technique (Thompson and Shimada 1987).

The 1979 and 1985 cooperative survey estimates of recruited biomass were 309,000 and 1,036,500 t, respectively. Thus, SRA was constrained to reproduce a biomass increase of over threefold. This proved to be impossible except under an extremely strong stock/recruit relationship. Using Kimura's (In press) parametrization of the Beverton-Holt recruitment function, the strength of the stock/recruit relationship varies with the parameter $\underline{a}$. When $\underline{a}$ = 1.0, recruitment is constant. As $\underline{a}$ decreases, the strength of the stock/recruit relationship intensifies, until recruitment is proportional to biomass when $\underline{a}$ = 0. As $\underline{a}$ approaches 0, MSY approaches infinity. The largest value of $\underline{a}$ which was able to satisfy the constraints was $\underline{a}$ = 0.114. This value corresponded to an MSY of 224,000 t, which was produced at a recruited biomass (shelf and slope combined) of 1,107,300 t.

This estimate corresponds to the eastern Bering Sea portion of the stock only, and needs to be expanded to incorporate the Aleutian Islands component. A reasonable method of making this expansion would be to use the past ratios between the survey biomass estimates of the shelf and Aleutian Islands areas. A weighted average based on the 1980, 1983, and 1986 surveys of the two areas indicates that multiplying the shelf component by 1.1735 will result in an appropriate expansion. Applying this procedure gives a total MSY for the eastern Bering Sea and Aleutians areas combined of 262,900 t.

It is important to emphasize that the results of this particular application of SRA should be viewed with caution, since they are products of a deterministic model which is attempting to simulate what may be a largely stochastic phenomenon. Furthermore, the model is fairly simplistic, and does not take explicit account of temporal or geographic patterns of fishing effort, the differential impacts of competing gear types, or partial recruitment of cohorts.

Beverton-Holt Model

The constant recruitment form of the Beverton-Holt model was also used to generate an estimate of MSY for this stock. A number of important management measures can be calculated from this model using only three inputs: the Brody (1945) coefficient for growth in length (K), the instantaneous natural mortality rate (M), and the ratio (c) formed by dividing length at the time of recruitment by asymptotic length.

To increase the utility of the measures generated by the model, the analysis was extended to include stochastic variability in the inputs. This was accomplished by assigning a coefficient of variation to each of the three input parameters (K, M, and c) and assuming that the value of each input parameter was normally distributed. The value of M used in SRA (0.22) was retained for the Beverton-Holt analysis. Values of K (0.203) and c (0.5382, assuming that age of recruitment = 3 years) were obtained from Equation (1). In the absence of any estimates for the coefficients of variation associated with these parameters, values of 0.1 were used for each.

Given these values, it was possible to compute the ratio of MSY to the product of W_{max} and R, where W_{max} = asymptotic weight and R = number of recruits (a constant). The results of the Beverton-Holt analysis showed that this ratio has a median value of 0.19, with a 95% confidence interval running from 0.13 to 0.29. An estimate of W_{max} (7.44 kg) was computed from Equations (1) and (2). Assuming that the number of recruits corresponds to the average simulated number of age three fish in the years 1981-85 as estimated by Thompson and Shimada (1987), R can be estimated at 142 million fish. Applying these figures to the MSY/W_{max}R ratio of 0.19 gives a median MSY estimate of 200,700 t. Using the confidence interval for MSY/W_{max}R gives an MSY range of 137,300-306,400 t.

Multiplying these figures by 1.1735 to incorporate the Aleutian Islands component of the stock gives a median MSY of 235,500 t, and a confidence interval of 161,100-359,600 t.

Eastern Bering Sea Cod Model

To obtain a more detailed estimate of MSY, the eastern Bering Sea cod model (Thompson and Shimada 1987) was altered to incorporate a stock/recruit relationship. As has already been noted, it is extremely difficult to fit a meaningful stock/recruit curve to the available data. A variety of methods were used to find the best possible relationship. The most meaningful fit proved to be a Beverton-Holt recruitment curve, using numbers of age 3 fish as the dependent variable, and egg production as the independent variable. However, even this curve yielded an R^2 of only 0.23. Egg production was calculated using the method described by Bakkala et al. (1986c).

Given this stock/recruit relationship, it was possible to run the model to equilibrium and solve numerically for the combination of fishing effort levels (trawl and longline) that resulted in MSY. This analysis gave an MSY value of 175,500 t for the eastern Bering Sea portion of the stock, or 205,900 t (175,500 t x 1.1735) for the eastern Bering Sea and Aleutians areas combined.

Because the parameters of the stock/recruit relationship used in this analysis are somewhat uncertain, it may be useful to examine the behavior of the model under a constant recruitment scenario as well. (To distinguish the two forms of the model, the version employing the Beverton-Holt recruitment curve shall be referred to as the "density-dependent" version, and the constant recruitment form shall be referred to as the "density-independent" version). Assuming a constant recruitment value equal to the average simulated recruitment from 1981 to 1985 (Thompson and Shimada 1987), a density-independent estimate of MSY for the eastern Bering Sea was calculated at 241,700 t, giving a figure of 283,600 t for the region as a whole.

Conclusions Regarding MSY

It is interesting to note that the MSY estimates obtained from all four analyses compare favorably (262,900 t, 235,500 t, 205,900 t, and 283,600 t), despite the fact that very different recruitment assumptions are involved: the SRA estimate assumes an extremely strong stock/recruit relationship, the Beverton-Holt analysis and the density-independent version of the eastern Bering Sea cod model both assume constant recruitment, and the density-dependent version of the eastern Bering Sea cod model assumes an intermediate stock/recruit relationship.

In considering these numbers, however, it should be remembered that the Federal Guidelines for Fishery Management Plans define MSY relative to "prevailing ecological and environmental conditions." It is quite conceivable that the ecological and environmental conditions responsible for the current high abundance of this stock will not prevail indefinitely, in which case a new (presumably lower) estimate of MSY will be needed. Nevertheless, under prevailing ecological and environmental conditions the best estimate of MSY probably comes from the density-dependent version of the eastern Bering Sea cod model (205,900 t).

ACCEPTABLE BIOLOGICAL CATCH

The North Pacific Fishery Management Council has established a default method for the computation of acceptable biological catch (ABC), to be used unless another method can be shown to be superior on purely biological grounds. The default method computes ABC as the product of recruited biomass and the MSY exploitation rate. The four methods used to provide preliminary estimates of MSY (SRA, Beverton-Holt, and the two versions of the eastern Bering Sea cod model) can also be used to generate estimates of the MSY exploitation rate.

Stock Reduction Analysis

The same parameters used to generate the SRA estimate of MSY give an MSY exploitation rate of 0.2023. When the delay-difference equation is used to project the population forward, a 1988 recruited biomass of 1,309,100 t is obtained for the shelf/slope region, which can be expanded to 1,536,200 t for the eastern Bering Sea and Aleutians areas combined. Applying an MSY exploitation rate of 0.2023 to these projected biomasses gives an ABC of 264,800 t for the eastern Bering Sea component of the stock, or 310,700 t for the eastern Bering Sea and Aleutians areas combined.

Annual Surplus Production

Interestingly, the SRA estimate of ABC is close to the estimate of annual surplus production (ASP) obtained for 1988 from the eastern Bering Sea cod model. As discussed above, a major modification was made to this model by incorporating a stock/recruit relationship. Also, the model was brought up to date by re-estimating some of the inputs. For example, the regression of domestic annual harvest (DAH) against time was re-estimated to incorporate the latest datum, arriving at the following equation ($R^2 = 0.985$):

$$DAH = -12.0143 + 18.0679*(year - 1980). \qquad (3)$$

Equation (3) yields a 1988 DAH estimate of 132,500 t. Based on this DAH estimate, and using 1986 simulated numbers at age to seed the model, 1988 ASP for the eastern Bering Sea was projected to be 277,400 t. This estimate may be on the high side, since the model's 1987 biomass estimate turned out to be approximately 7% above the survey biomass estimate (although the model estimate did fall well within the survey's confidence interval). The ASP estimate of 277,400 t corresponds to an exploitation rate (defined as catch divided by July survey biomass) of approximately 21%.

Beverton-Holt Model

The parameters used in the stochastic Beverton-Holt model give a median F value at MSY of 0.53, with a 95% confidence interval (based on an assumed 10% coefficient of variation for each of the three input parameters) running from 0.32 to 1.43. An estimate of ABC for the eastern Bering Sea may thus be obtained by assuming that the mean 1988 recruited biomass on the shelf is equal to the recruited portion of the 1987 survey biomass, expanding that figure to account for the slope component of the stock, then multiplying that amount by 0.53. (For a continuous-time, biomass-based model such as the Beverton-Holt model, the appropriate calculation of catch is F times mean annual biomass.)

The recruited portion of the shelf biomass can be estimated as the portion of the biomass contributed by individuals at least 40 cm in length, which was approximately 1,043,600 t according to the 1987 shelf survey. A reasonable method of expanding this figure to include the slope component of the stock would be to use the past ratios between the cooperative shelf/slope survey biomass estimates and the shelf survey biomass estimates. A weighted average of this ratio for the years 1979, 1982, and 1985 gives a coefficient of 1.1218, which results in a total recruited biomass (shelf/slope) of 1,170,700 t. The ABC corresponding to this biomass, based on an F value of 0.53, is 620,500 t. Expanding for the Aleutians component of the stock gives a recruited biomass of 1,373,800 t and an ABC of 728,200 t.

There are some problems with using the Beverton-Holt model to estimate ABC. First, because the model does not project the population into the next year, 1987 survey biomass must be used as a surrogate for 1988 mean biomass. Since the estimated exploitation rate at MSY is higher than the exploitation rates observed in recent years (see below), 1987 survey biomass will likely be an overestimate of 1988 mean biomass, thus causing ABC to be overestimated also.

Historical exploitation rates (catch in biomass divided by survey biomass) for Pacific cod in the eastern Bering Sea (1987 rate is based on projected catch):

Year:	1981	1982	1983	1984	1985	1986	1987
Rate:	0.0619	0.0543	0.0739	0.1110	0.1386	0.1151	0.1222

Further problems may arise from the strong assumption of constant recruitment. If recruitment is density-dependent at moderate stock sizes, then ABC will again be overestimated, and the stock will be pushed to a level below that associated with MSY.

Eastern Bering Sea Cod Model

In addition to determining MSY and ASP, the eastern Bering Sea cod model can project ABC according to the default formula. The same analysis used to estimate MSY can also be used to estimate the biomass level corresponding to MSY, as well as the exploitation rate (defined for the model as catch divided by July survey biomass) associated with MSY.

For the density-dependent form of the model, these values are 1,208,900 t (eastern Bering Sea only) and 15%, respectively. The model can then be used to project the population forward under the MSY exploitation rate to determine ABC for 1988. This procedure yields a 1988 ABC of 203,000 t for the eastern Bering Sea portion of the stock. Projected biomass at age and catch at age under this scenario are given for 1987-88 in Table 5.

Table 5 indicates heavy exploitation of older age groups (i.e., ages 8 and older). This is a reflection of the survey and observer data to which the simulation was fitted. If the survey tends to underestimate the abundance of older age groups, then the simulation will tend to overestimate exploitation rates for the same groups. It should also be noted that the biomass estimates shown in Table 5 represent July survey biomass, not biomass at the start of the harvest year (which explains why catch can exceed biomass for the oldest age groups).

In expanding their catch estimate to include an Aleutians component, Thompson and Shimada (1987) adopted a strategy based on historic trends in the catch for the eastern Bering Sea versus the eastern Bering Sea and Aleutians combined. The relationship estimated by Thompson and Shimada has since been re-estimated to take into consideration the most recent datum, yielding the following equation ($R^2 = 0.891$):

$$\ln(1 - P_{EBS}) = -0.9375 - 0.2692*(\text{year} - 1980), \qquad (4)$$

where P_{EBS} is proportion of the total catch (combined areas) taken from the eastern Bering Sea. Solving equation (4) for P_{EBS} in 1988 gives a figure of 0.9546, implying an ABC for the Aleutian area in 1988 of 10,000 t, or a total ABC of 213,00 t for the combined areas.

Table 5.--Projected age distributions (thousands of t) of biomass at time of survey and catch (assuming a 1988 exploitation rate of 15%) for Pacific cod in the eastern Bering Sea.

	1987		1988	
Age	Biomass	Catch	Biomass	Catch
0	0.1	0.0	0.1	0.0
1	17.2	0.1	11.5	0.1
2	61.4	0.3	114.3	0.4
3	408.5	3.4	102.3	1.2
4	189.5	3.9	520.5	10.3
5	191.9	8.8	206.7	10.5
6	90.0	11.7	182.4	24.6
7	162.6	49.4	70.5	32.0
8	92.5	58.5	89.6	77.7
9	7.2	9.4	28.7	43.1
10	0.6	3.8	0.9	3.0
Total	1221.5	149.3	1327.7	202.9

It should be noted that this manner of expanding the eastern Bering Sea estimate to include the Aleutians component of the stock is different than the method used for the other analyses considered here, where a simple ratio of biomasses was applied to ABC. If the "biomass ratio" method was used to expand the eastern Bering Sea ABC estimate, total ABC would equal 238,000 t.

The density-independent form of the model (where recruitment equals the average simulated recruitment from 1981-85) can also be used to estimate ABC. Using the same procedure described above for the density-dependent version of the model, biomass at MSY was estimated at 927,700 t, exploitation rate at MSY was estimated at 26%, and 1988 eastern Bering Sea ABC was estimated at 328,300 t. The density-independent estimate of total ABC would thus be 343,900 t using the method of Thompson and Shimada (1987), or 385,300 t using the biomass ratio method.

Conclusions Regarding ABC

There appears to be no biological justification for departing from the Council's default formula for ABC. Although any estimate of MSY (and therefore any estimate of MSY exploitation rate) must be considered preliminary at this time, the robustness of the independent MSY estimates derived in this document lends some credence to their use. Of the methods presented here, the following facts indicate that the density-dependent version of the eastern Bering Sea cod model is the most appropriate: 1) the model provides a more detailed representation of the stock and its fishery than do either SRA or the Beverton-Holt model; 2) the model, in a slightly simpler form, has been a good predictor of biomass trends over the past 2 years; and 3) by incorporating the best stock/recruit relationship available, the density-dependent form of the model guards against overestimates of the MSY exploitation rate that might arise under the density-independent version or the Beverton-Holt model. For these reasons, it is recommended that ABC be set at the level of 213,000 t indicated by the density-dependent form of the eastern Bering Sea cod model, using the Aleutian expansion technique suggested by Thompson and Shimada (1987).

It should be stressed that ABC is not meant to be a substitute for optimum yield. There may be many reasons for choosing a catch level other than the ABC estimates given here. For example, the uncertainty involved in model calculations may warrant selection of a more conservative catch level. Allocative issues may also merit consideration; for example it may be preferable to defer potential harvests until a later time when the domestic industry is fully capable of utilizing them. From a purely biological standpoint, the most important conclusion is that Pacific cod resource is probably capable of withstanding a wide range of harvests without damaging its long-term viability.

YELLOWFIN SOLE

by

Richard G. Bakkala and Vidar G. Wespestad

INTRODUCTION

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

CONDITION OF STOCK

Catch Statistics

Following a period of intense exploitation in 1959-62, when catches averaged 404,000 metric tons (t) annually, catches declined, particularly in the 1972-77 period (ranging from 42,000 to 78,000 t) (Table 1). The low catches in 1972-77 were due primarily to the absence of a directed fishery for yellowfin sole by the U.S.S.R. With the resumption of the U.S.S.R. fishery in 1978, the initiation of joint venture and directed Republic of Korea (R.O.K.) fisheries for yellowfin sole in 1980, and the improved condition of the resource, catches steadily increased to a recent peak of 227,000 t in 1985, the highest catch since 1962. Catches in 1986 declined moderately to about 209,000 t because of quota restrictions; preliminary estimates indicate that the 1987 catch declined further to 183,000 t, again due to quota restrictions.

In addition to the marked increase in the magnitude of catches, there has also been a major change in the dominate fisheries. The Japanese fishery has traditionally taken the largest catches of yellowfin sole, but U.S. joint venture fisheries began to dominate the fisheries in 1985, taking 56% of the total. Their portion of the catch increased to 73% in 1986 and will approach 100% in 1987.

A recent and interesting development in joint venture fisheries has been the extension of fishing areas for yellowfin sole to very shallow waters (as shallow of 5-6 m) of Togiak Bay on the north side of Bristol Bay. These waters are inside those sampled (as shallow as 20 m) during Northwest and Alaska Fisheries Center (NWAFC) surveys. Unconfirmed reports indicate that catches in Togiak Bay may have been as high as 40,000 t in 1987. Thus, there may be a substantial biomass of yellowfin sole at times in waters shallower than those surveyed although it is unknown if large numbers of yellowfin sole

Table 1.--Annual catches of yellowfin sole in the eastern Bering Sea (east of 180° long. and north of 54°N lat.) in metric tons.[a]

Year	Japan	U.S.S.R.	R.O.K.[b]	Other non-U.S. fisheries	U.S. joint ventures	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
1986	49,318		7,632	247	151,400	208,597

[a]Sources of catch data: 1954-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to the United States by fishing nations and available Northwest and Alaska Fisheries Center, 7600 Sand Point Way NE, Seattle, WA 98115; 1980-86, French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986, 1987a.

[b]Republic of Korea.

were in Togiak Bay during the period of survey activity in this area in June 1987. Plans are being made to sample Togiak Bay and other nearshore waters during the 1988 NWAFC survey.

Relative Abundance

Trends in relative abundance of yellowfin sole have previously been examined from Japanese pair trawl data and NWAFC survey data (Bakkala and Wespestad 1987). Japanese pair trawlers and other non-U.S. fishing vessels were phased out of the yellowfin sole fishery starting in 1987 because the total allowable catch was entirely allocated to U.S. joint venture fisheries. Thus, catch per unit effort (CPUE) estimates will not be available from the Japanese pair trawl fishery after 1986; catch and effort data from the Japanese fishery are not yet available for estimating a 1986 CPUE value.

To begin to develop a new time series of abundance indices from the fisheries, catch and effort data from the joint venture fisheries were examined. Catches by this fishery gradually increased from 9,600 t in 1980 (when the fishery started) to 32,800 t in 1984 and then increased sharply to 126,400 t in 1985 and 151,400 t in 1986 (Table 1). During 1980-84 the fishery mainly operated along the north side of the Alaska Peninsula, but in 1985 and 1986 most of the catch was taken in central shelf waters. Because of this discontinuity in areas of fishing, and the possibility that abundance estimates from early years of the fishery may have been more severely influenced by improvements in fishing techniques, data from only 1985 and 1986 were used to estimate CPUE from the joint venture fishery.

The data used in the analysis were collected by U.S. observers aboard the joint venture processing vessels. These data were from 0.5° lat. by 1° long. statistical blocks in which fishing was carried out in both 1985 and 1986 (Fig. 1) using hauls sampled by the observers and which contained at least 20% yellowfin sole. The CPUE estimates from this fishery (Fig. 2) were only slightly different in 1985 (2.85 t per hour trawled) and 1986 (2.92 t per hour), suggesting little change in the abundance of yellowfin sole between the 2 years.

Indices of abundance from NWAFC survey data have shown a major increase in abundance of yellowfin sole during the late 1970s increasing from 21 kg/ha in 1975 to 40 kg/ha in 1979 (Fig. 2). This increase has also been documented through CPUE values from the Japanese pair trawl fishery and by cohort analysis. The CPUE values from NWAFC surveys showed further apparent substantial increases through 1983 which were followed by substantial decreases through 1985. These wide fluctuations in abundance were unreasonable considering the slow growth and long life span of yellowfin sole. Therefore, the survey CPUE estimates were not believed to reflect the actual trends in abundance of yellowfin sole between 1981 and 1985 (Bakkala and Wespestad 1987).

The survey CPUE values continued to decline between 1985 and 1986 from 49.0 kg/ha to 40.2 kg/ha compared to the stable trend shown by CPUE values from the joint venture fishery in this period. The 1987 survey CPUE increased again to 53.0 kg/ha which is similar to the 1985 value and indicated little change in population abundance between 1985 and 1987 if the 1986 survey estimate is discounted. The fluctuations in CPUE between 1985 and 1987 indicate that survey abundance estimates continue to be somewhat erratic.

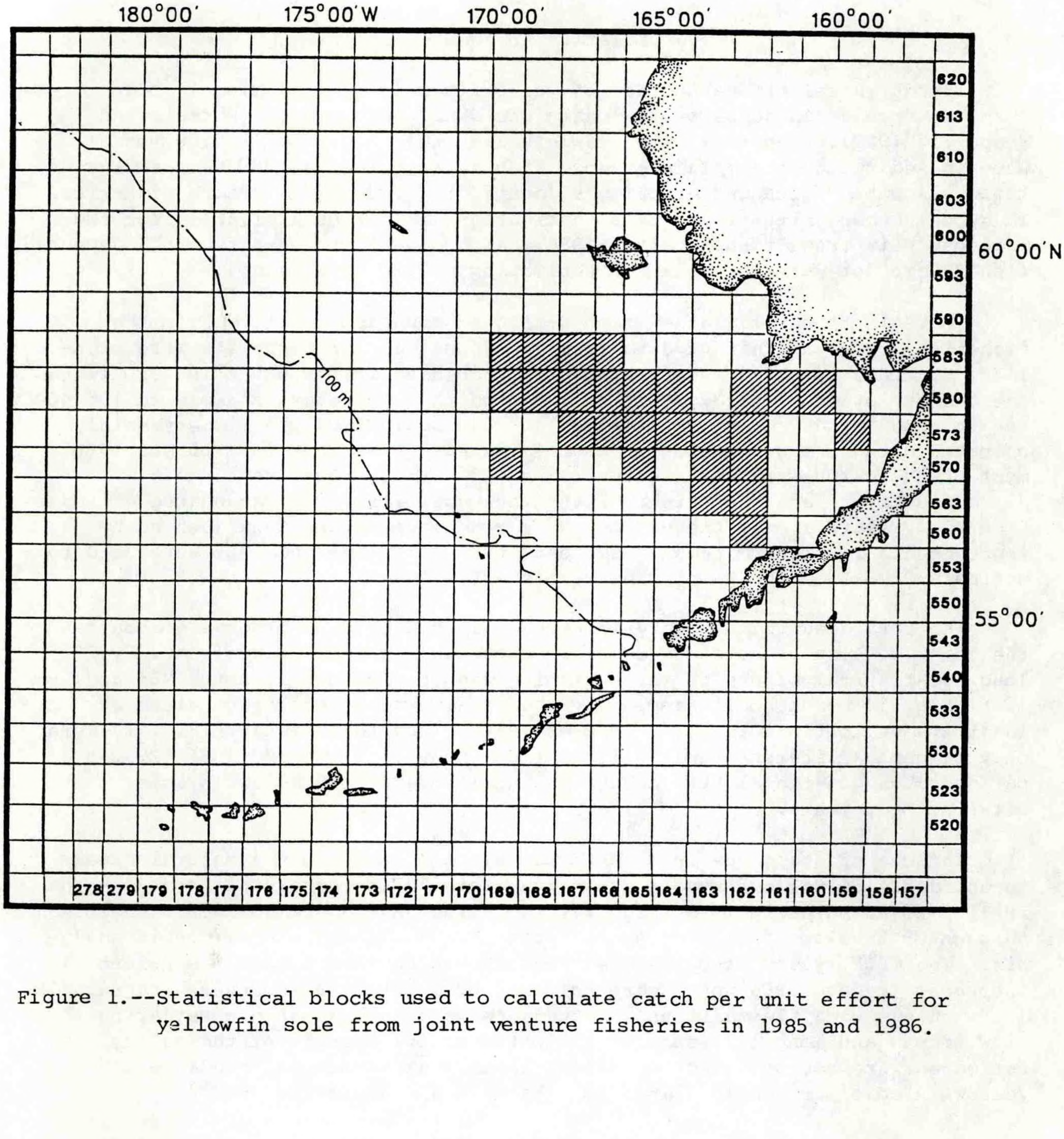


Figure 1.--Statistical blocks used to calculate catch per unit effort for yellowfin sole from joint venture fisheries in 1985 and 1986.

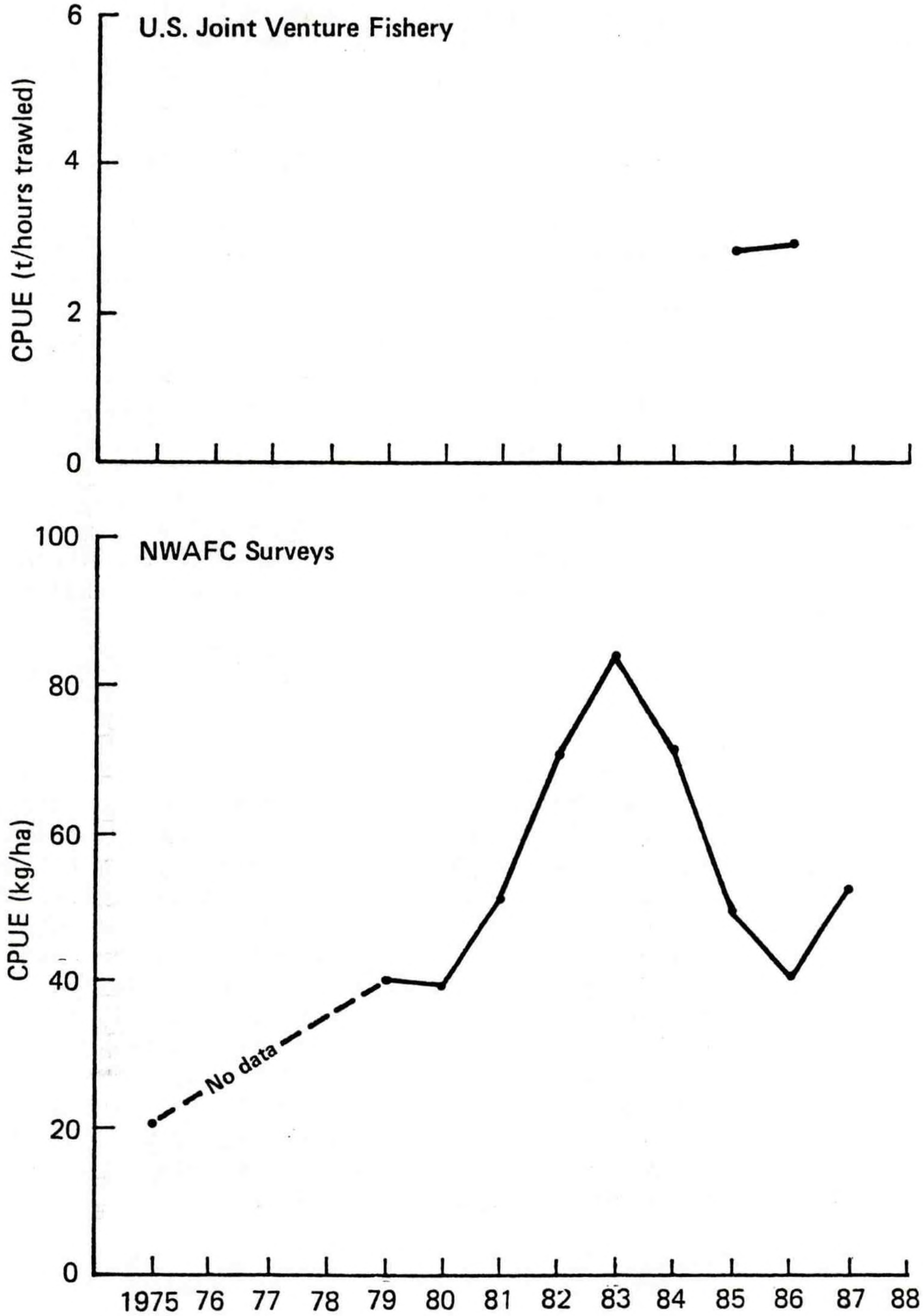


Figure 2.--Catch per unit effort of yellowfin sole in the eastern Bering Sea as shown by U.S. joint venture fishery data (see text) and by Northwest and Alaska Fisheries Center (NWAFC) survey data.

Age Composition

The primary reason for the sustained increase in abundance of yellowfin sole, which started as early as 1972 and continued until 1983 or 1984, has been the recruitment of two series of strong year classes. Initial increases were from a series of strong year classes spawned in 1966-70 which formed the principal age groups in commercial catches until the early 1980s (Fig. 3). The increase was sustained through the early 1980s by the emergence of a second series of strong year classes spawned in 1973-77. This later series of strong year classes now form the main body of the population based on survey data and, starting in 1985, began to form the principal ages in the commercial catch (Fig. 3). Survey age data through 1981 had indicated that the 1971 and 1972 year classes were weaker than adjacent year classes. However, more recent survey data and commercial fishery data in particular, have shown the 1971 to 1972 year classes to also be relatively strong. The 1971 to 1977 year classes should support the fishery through at least the end of this decade.

There is no indication from the most recent survey data of strong recruitment from the 1978 to 1980 year classes. Based on years of survey data since 1979 judged to be the most reliable (1979-81, 1985-86), the strength of the 1978 to 1980 year classes, which are now recruiting to the fishery, are estimated to be below average.

Biomass Estimates

Survey Based Estimates

The survey biomass estimates from a standardized area of the eastern Bering Sea encompassing waters 20-200 m deep from the Alaska Peninsula north to the latitude of St. Matthew and Nunivak Islands are given in Table 2. Estimates are given separately for mainly unexploited ages (less than age 7) and exploited ages (ages 7 and older). The estimates show an approximate doubling of biomass between 1975 and 1979 with a further increase to 2.1 million t in 1981 for the exploitable portion of the population. As described earlier, survey abundance estimates fluctuated erratically between 1981 and 1985 with the biomass of the exploitable population increasing to 3.7 million t in 1983 and then decreasing sharply to 2.1 million t in 1985. There was a further, although much more moderate, decline in 1986 to 1.8 million t and then an increase to 2.4 million t in 1987. Overlapping 95% confidence intervals for all age groups combined, however, indicate that the 1985 to 1987 biomass estimates were not significantly different.

Cohort Analysis 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 1985 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. In the past, terminal F values were "tuned" by the trend in survey abundance estimates and survey

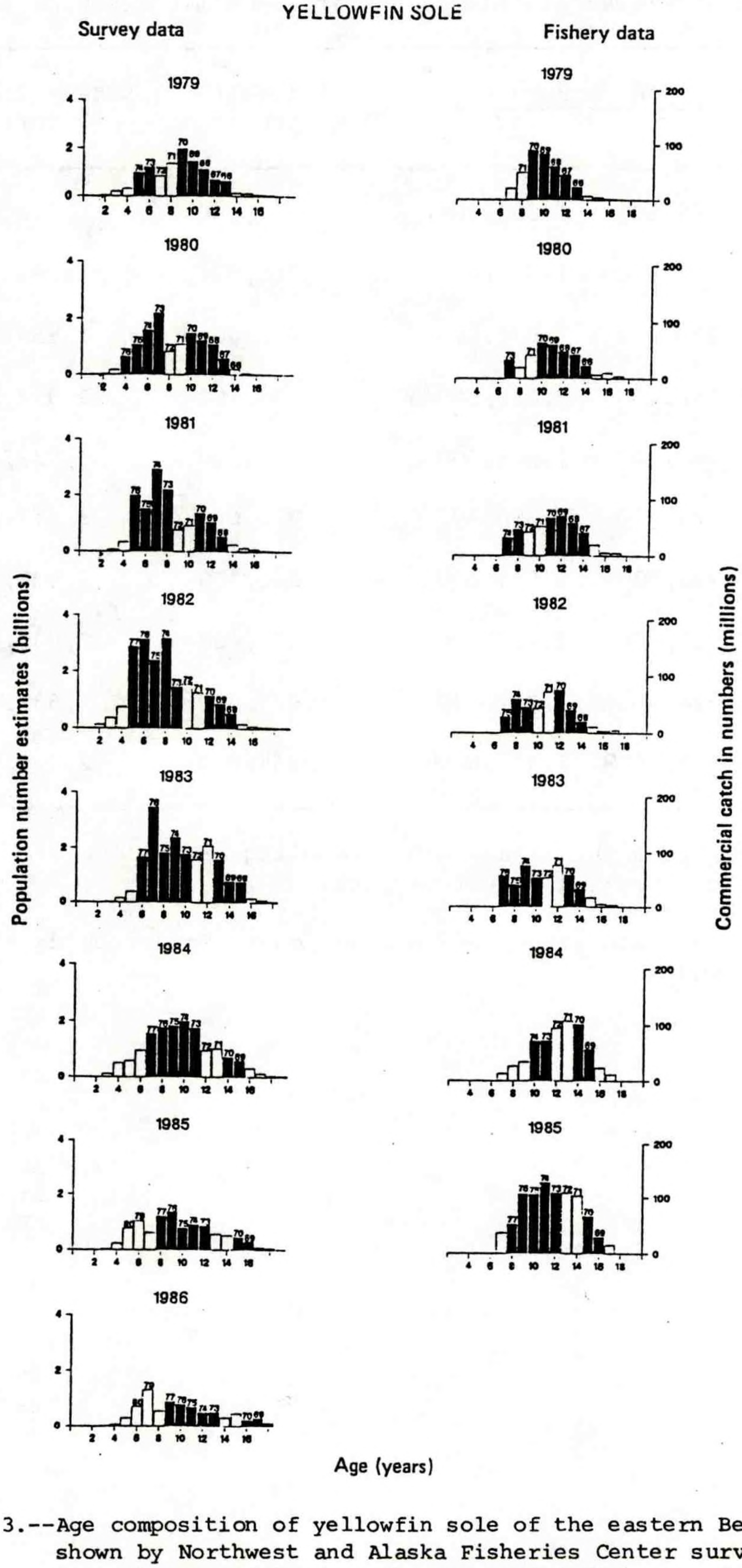


Figure 3.--Age composition of yellowfin sole of the eastern Bering Sea as shown by Northwest and Alaska Fisheries Center survey data and U.S. observer data from the commercial fishery. Year classes for more abundant ages are shown above the appropriate bars, and darkened bars represent stronger than average year classes.

Table 2.--Estimated biomass (t) of yellowfin sole in the eastern Bering Sea based on Northwest and Alaska Fisheries Center resource assessment surveys.[a]

Year	Age groups ≤6	Age groups ≥7	Total biomass	95% Confidence intervals (t) for total estimates
1975	169,500	803,000	972,500	812,300 - 1,132,700
1979	211,500	1,655,000	1,866,500	1,586,000 - 2,147,100
1980	235,900	1,606,500	1,842,400	1,553,200 - 2,131,700
1981	343,200	2,051,500	2,394,700	2,072,900 - 2,716,500
1982	665,700	2,609,600	3,275,300	2,733,600 - 3,817,100
1983	222,500	3,688,100	3,910,600	3,447,800 - 4,373,300
1984	183,500	3,136,800	3,320,300	2,929,800 - 3,710,800
1985	155,000	2,122,400	2,277,400	2,003,000 - 2,551,900
1986	78,700	1,787,700	1,866,400	1,587,000 - 2,149,300
1987	98,000[b]	2,367,800[b]	2,465,800	2,091,100 - 2,840,600

[a]Estimates are from the standardized sampling area shown in Figure 2 of the walleye pollock section of this report.

[b]Preliminary estimate using 1987 survey length-frequency data and the 1986 survey age-length key.

age composition in the terminal year. However, because the survey abundance trends have been erratic since 1981, the use of abundance trends from the surveys was not possible. Thus, the cohort analysis was only tuned to the survey age composition in 1985 under the assumption that the survey age composition accurately reflected the age composition of the population. 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 ages 7-17 are shown in Table 3. 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 11.

The trend in abundance shown by the cohort analysis during the late 1970s is similar to that shown by NWAFC survey data indicating a major increase between the middle and late 1970s (Table 4). During the early 1980s, the two sources of data showed continuing increases in abundance of exploitable age groups (age 7 and older) although the magnitude of the estimates (in million t) differed substantially in some years as shown below:

	1979	1980	1981	1982	1983	1984	1985	1986	1987
Biomass from survey data	1.655	1.606	2.052	2.610	3.688	3.137	2.122	1.788	2.368
Biomass from cohort analysis	1.339	1.542	1.723	1.809	1.985	2.062	1.880	--	--

The estimates from cohort analysis have been lower, particularly during 1982-84 when the survey estimates showed unreasonable fluctuations. In 1985 the estimates from the survey and cohort analysis were similar. The trends in abundance shown by cohort analysis appear much more reasonable during 1981-85 than those from the survey data. The trend from cohort analysis indicates that abundance peaked in 1984 and declined in 1985. As described earlier, overlapping 95% confidence intervals for the survey biomass estimates indicate that abundance has not changed significantly between 1985 and 1987.

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.

Table 3.--Estimates of fishing mortality (F) by age for yellowfin sole of the eastern Bering Sea, 1977-85.

Age	1977	1978	1979	1980	1981	1982	1983	1984	1985
7	0.0080	0.0321	0.0112	0.0155	0.0155	0.0192	0.0268	0.0081	0.0000
8	0.0262	0.0658	0.0276	0.0122	0.0248	0.0340	0.0317	0.0144	0.0370
9	0.0389	0.0835	0.0536	0.0266	0.0297	0.0280	0.0516	0.0317	0.0690
10	0.1181	0.1307	0.0743	0.0454	0.0389	0.0349	0.0387	0.0571	0.1200
11	0.1530	0.2346	0.1039	0.0658	0.0565	0.0638	0.0522	0.0619	0.1280
12	0.1536	0.1626	0.1378	0.1010	0.0934	0.0760	0.0835	0.1125	0.1150
13	0.0437	0.2951	0.1248	0.1703	0.1586	0.0640	0.0711	0.1477	0.1680
14	0.0648	0.1401	0.1365	0.1648	0.2215	0.0691	0.0626	0.1585	0.1900
15	0.0607	0.1248	0.0580	0.1867	0.1752	0.0749	0.0684	0.1364	0.1340
16	0.0628	0.0909	0.0528	0.1820	0.1986	0.0320	0.0450	0.1214	0.0900
17	0.0630	0.0900	0.0530	0.1820	0.1036	0.0200	0.0400	0.1200	0.1000

Table 4.--Estimated numbers and biomass of yellowfin sole (for ages fully recruited to survey trawls) in the eastern Bering Sea, 1977-85, based on cohort analysis.

Age	1977	1978	1979	1980	1981	1982	1983	1984	1985
Numbers (billions)									
7	2.496	2.249	1.970	2.295	2.139	1.549	2.262	1.733	.000*
8	1.745	2.196	1.931	1.728	2.004	1.868	1.348	1.953	1.524
9	.993	1.508	1.823	1.666	1.514	1.734	1.602	1.158	1.708
10	.672	.847	1.230	1.533	1.439	1.304	1.495	1.349	.995
11	.361	.530	.659	1.013	1.299	1.228	1.117	1.276	1.130
12	.118	.275	.372	.527	.841	1.089	1.022	.940	1.064
13	.118	.090	.207	.287	.423	.679	.895	.833	.745
14	.049	.100	.059	.162	.215	.320	.565	.739	.638
15	.039	.041	.077	.046	.122	.153	.265	.471	.560
16	.010	.033	.032	.064	.034	.091	.126	.219	.364
17	.004	.008	.027	.027	.048	.025	.078	.107	.172
Total	6.606	7.876	8.388	9.348	10.078	10.038	10.773	10.778	8.899
Biomass (1,000 t)									
7	280	252	221	257	240	173	253	194	0*
8	236	296	261	233	271	252	182	264	206
9	158	240	290	265	241	276	255	184	272
10	124	157	228	284	266	241	277	250	184
11	76	111	138	213	273	258	234	268	237
12	27	64	86	122	195	253	237	218	247
13	31	24	55	76	112	179	236	220	197
14	14	28	17	46	60	90	159	208	179
15	12	12	23	14	36	45	78	139	166
16	4	12	11	23	12	32	45	78	130
17	2	3	10	10	17	9	28	39	63
Total	962	1,198	1,339	1,542	1,723	1,809	1,985	2,062	1,880

*Estimate not available for the last year of the analysis.

ACCEPTABLE BIOLOGICAL CATCH

An assessment of the current condition of the yellowfin sole population is complicated by the inconsistency in survey abundance estimates and the lack of biomass estimates from cohort analysis after 1985. The cohort analysis indicates that abundance of the population peaked in 1984 and started to decline in 1985. However, it should be noted that results from age structured models for the last 2 or 3 years of the analysis may be less accurate than those for earlier years because the most recent estimates are sensitive to errors in the terminal fishing mortalities used. Abundance estimates from the joint venture fishery were stable from 1985 to 1986 while survey biomass estimates varied in 1985-87 from 1.8 to 2.4 million t. Overlapping 95% confidence intervals, however, suggest that the 1985 to 1987 estimates were not significantly different. Survey age data show that the latest series of strong year classes (1973-77) are fully recruited to the survey area and fishing gear and that the strength of the 1978 to 1980 year classes are below average. Based on these age data, abundance of the population would be expected to decline although the survey and fishery data have not yet produced consistent evidence of a decline.

Despite the inconsistencies in the data, biomass estimates from survey data and cohort analysis show that the abundance of the yellowfin sole population remains high and perhaps in the vicinity of 2.0 million t. As discussed earlier, some additional biomass may exist in waters shallower than those sampled by NWAFC surveys as evidenced by substantial catches (perhaps as much as 40,000 t) in these nearshore waters by the U.S. joint venture fishery.

In developing an acceptable biological catch (ABC) estimate, two methods were used: yield per recruit and the optimal $F_{0.1}$ fishing method. In the yield per recruit model (Beverton and Holt 1957) input data were estimates of natural mortality (M = 0.12) and von Bertalanffy growth parameters (k = 0.11, t_o= 0.22, and W_{oo} = 745 g). Age 9, which is the age that is approximately 50% recruited to the fishery, was used as the age of recruitment. Results of the analysis follow.

		Yield/recruit	Recruitment at age 9 (billions of fish)			ABC (t)		
M	$F_{0.1}$	(g)	Low	Average	High	Low	Average	High
0.12	0.17	161	1.16	1.52	1.82	186,400	245,200	293,500

The second method of deriving ABC was based on the optimal $F_{0.1}$ fishing strategy derived from yield per recruit theory (ICES 1984; Deriso 1985). Using the following M values and von Bertalanffy growth parameter (M = 0.12 and k = 0.11), optimal $F_{0.1}$ was calculated as 0.1443 which produces an optimal exploitation rate of 0.123. Applying this optimal exploitation rate to the current estimated exploitable biomass of 2.0 million t produces an ABC of 246,000 t. This estimate is similar to the ABC of 245,200 t from the yield per recruit analysis for average recruitment.

Thus, yield per recruit and the optimal $F_{0.1}$ fishing strategy are in agreement in suggesting that the population can be exploited at about 245,000 t. However, evidence from survey age data suggests that the population is entering a period of lower than average recruitment. In addition, the inconsistencies in the survey abundance estimates places some doubt as to the exact magnitude of the biomass. Therefore, it is recommended that ABC be set at a median value for low and average recruitment as shown by the yield per recruit model or 216,000 t.

GREENLAND TURBOT

by

Richard G. Bakkala, Grant G. Thompson, and Miles S. Alton

INTRODUCTION

Greenland turbot, Reinhardtius hippoglossoides, is a large flatfish reaching a length of 120 cm and a weight of 17 kg (37 lbs). The average size in the 1985 fishery on the continental slope of the eastern Bering Sea was 59 cm and 2.2 kg (4.8 lbs). Juveniles spend the first 3 or 4 years in continental shelf waters and then move to the continental slope where they generally spend the remainder of their life. This species ranges into the Aleutians region where their abundance is lower than in the eastern Bering Sea. The absence of young juveniles in the Aleutians suggests that the population in the Aleutians originates from the eastern Bering Sea. Thus, the populations in the two regions are believed to represent a single stock.

Because of the similarities in life history characteristics, Greenland turbot and arrowtooth flounder, Atheresthes stomias, were managed as a complex until 1985. However, the condition of the two species has differed markedly in recent years which has resulted in the separate management of the two species starting in 1986.

CONDITION OF STOCK

Catch Statistics

Commercial catches of Greenland turbot and arrowtooth flounder were not reported separately during the 1960s. During this period combined catches of the two species ranged from 10,000 to 58,000 t annually and averaged 33,700 t. Beginning in the 1970s the fishery for Greenland turbot intensified with catches of this species reaching a peak in 1972-76 of between 63,000 and 78,000 t annually (Table 1).

Catches declined after implementation of the Magnuson Fisheries Conservation and Management Act in 1977 from levels in 1972-76, but were still relatively high in 1980-83 with an annual range of 48,000 to 57,000 t. Since 1983, however, catches steadily declined to 9,900 t in 1986. This decline is due in part to catch restrictions placed on the fishery because of evidence of declining recruitment to the exploitable stock, but also to the phasing out of non-U.S. fisheries.

Japanese fisheries accounted for the majority of the Greenland turbot catch from both the eastern Bering Sea and Aleutians Islands area through 1986 (Table 1). Small trawlers of the landbased dragnet and North Pacific trawl fisheries have targeted Greenland turbot and have taken most of the overall catch. In 1978-83 catches by these trawlers in the eastern Bering Sea ranged from 30,100 to 41,200 t but declined to 14,200 t in 1985. The Japanese mothership fishery, which operated on the continental shelf and did not

Table 1.--All nation catches (t) of Greenland turbot in the eastern Bering Sea and Aleutian Island regions.[a]

Year	Japan	U.S.S.R.	Other[b] non-U.S. fisheries	U.S. joint ventures[c]	U.S. domestic[d]	Total	Total for regions combined
Eastern Bering Sea							
1970	14,715	4,976				19,691	
1971	30,193	10,271				40,464	
1972	49,813	14,697				64,510	
1973	43,354	11,926				55,280	
1974	58,834	10,820				69,654	
1975	52,625	12,194				64,819	
1976	51,656	8,867				60,523	
1977	25,669	2,039				27,708	
1978	35,852	1,571				37,423	
1979	34,089	626	283			34,998	
1980[e]	-	-	-	12		48,856	
1981[e]	-	-	-			52,921	
1982[e]	-	-	-	11		45,805	
1983[e]	-	-	-	4		43,443	
1984[e]	-	-	-	22		21,317	
1985[e]	-	-	-	9		14,698	
1986[e]	-	-	-	29	886	7,710	
Aleutians Islands region							
1970	285					285	19,976
1971	1,750					1,750	42,214
1972	12,713	161				12,874	77,384
1973	8,327	339				8,666	63,946
1974	8,749	49				8,788	78,442
1975	2,970					2,970	67,789
1976	1,955	112				2,067	62,590
1977	2,449	4				2,453	30,161
1978	4,765		1			4,766	42,189
1979	6,411					6,411	41,409
1980[e]	-	-	-	1		3,697	52,553
1981[e]	-	-	-	2		4,400	57,321
1982[e]	-	-	-	1		6,317	52,122
1983[e]	-	-	-			4,115	47,558
1984[e]	-	-	-	1		1,803	23,120
1985[e]	-	-	-	2		33	14,731
1986[e]	-	-	-	7	2,048	2,154	9,864

[a]Sources of data: 1970-76, Wakabayashi and Bakkala 1978; 1977-79, catches submitted to United States by fishing nations and available Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98115 ; 1980-86, French et al. 1981, 1982; Nelson et al. 1983a; 1984; Berger et al. 1985b, 1986, 1987a.

[b]Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.

[c]Joint ventures between U.S. fishing vessels and non-U.S. processing vessels.

[d]Fish caught and processed by domestic operations.

[e]Catches by individual non-U.S. nations not available.

target on Greenland turbot, took juveniles as a by-catch in target fisheries for other species. The incidental catch of Greenland turbot by the mothership fishery was as high as 11,900 t in 1978 but declined rapidly after 1980 to 300 t in 1985.

Relative Abundance

Three sources of data have been used to examine trends in relative abundance of Greenland turbot: Northwest and Alaska Fisheries Center (NWAFC) survey data, Japanese-reported catch and effort data from their landbased dragnet fishery which extends back to 1970, and catch and effort data collected by U.S. observers aboard land-based and other Japanese small trawlers which extends back to 1978. 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.

Data from the landbased fishery, which only operated west of 170°W long. because of Japanese fishery regulations, were analyzed by 0.5° lat. by 1° long. statistical blocks in which Greenland turbot composed 50% or more of the overall reported catch. This method was believed to limit the effort to that targeting on Greenland turbot.

Catch and effort data collected by U.S. observers were from the complete eastern Bering Sea slope region (>184 m). Data were from all Japanese small trawlers, including landbased trawlers, and thus included catches from waters both east and west of 170°W long. The observer data used were from the months of May-August because the fishery in 1984-86 mainly operated in these months. All catch and effort data were used regardless of the proportion of Greenland turbot in the catches.

Relative abundance estimates from NWAFC surveys on the continental shelf, which mainly sample young (age 1-4) juveniles, show relatively stable abundance of these young Greenland turbot between 1975 and 1980 and then a marked decline with catch per unit effort (CPUE) falling from 2.7 kg/ha in 1980 to 0.1 kg/ha in 1986 (Fig. 1). There was a slight increase in 1987 to 0.2 kg/ha; however, this increase was neglible. Numbers of young fish (≤40 cm) increased from 4.3 to 5.1 million in the survey area but these numbers are extremely low compared to numbers estimated in earlier years (Fig. 2). Thus, the near recruitment failure that has been observed since about 1980 continued through 1987.

This poor recruitment of juveniles also appears to be shown by the incidence of Greenland turbot in catches by the Japanese mothership fishery on the shelf which declined from 11,900 t in 1978 to 300 t in 1985.

The poor recruitment on the shelf was further reflected by a sharp decline in abundance of older juvenile Greenland turbot on the continental slope through 1984 based on catch rates of mainly immature fish (males <55 cm, females <70 cm) by Japanese small trawlers (Fig. 3). However, the 1985 catch rate value increased markedly for these older juveniles. There were

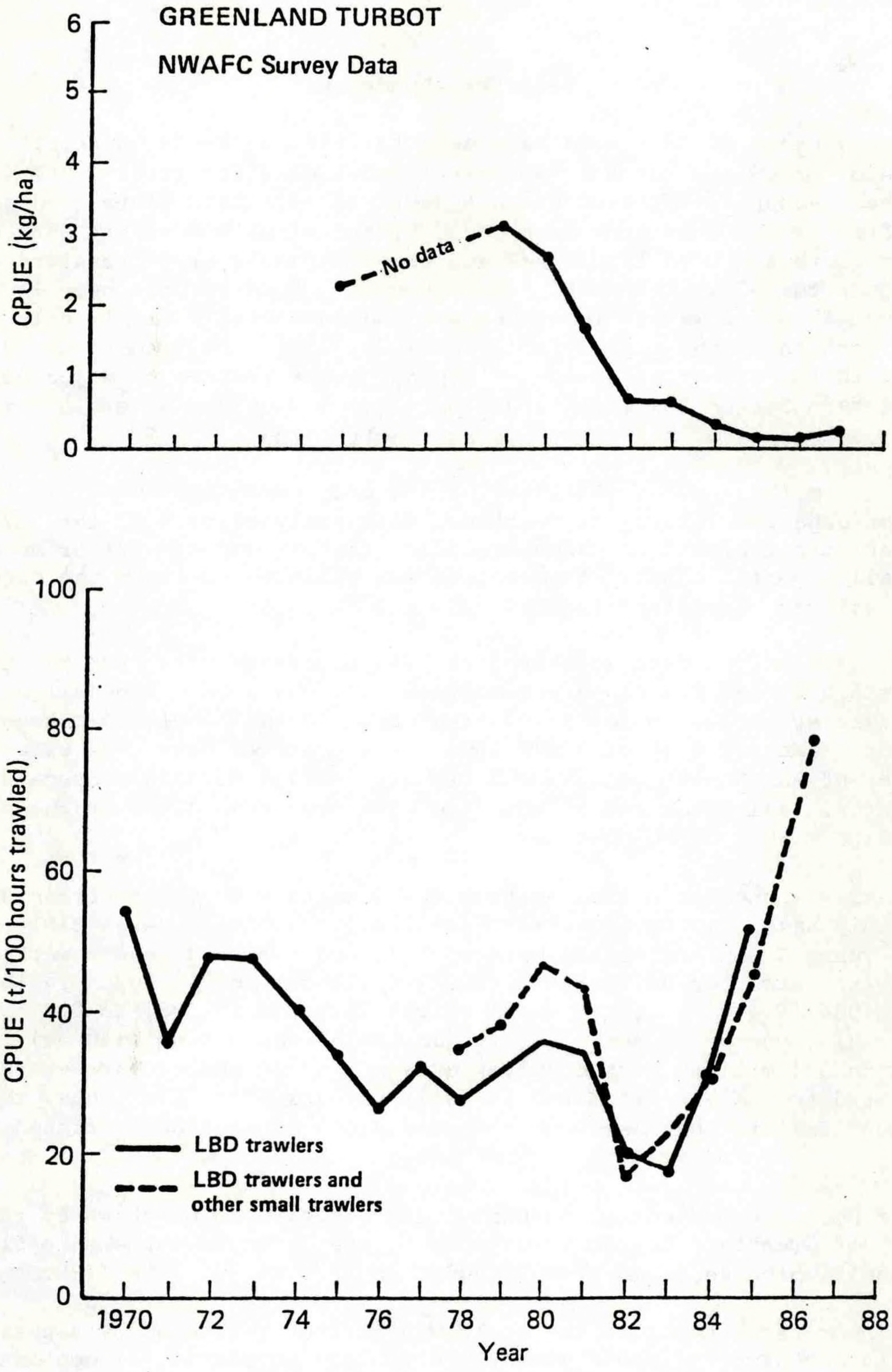


Figure 1.--Catch per unit effort (CPUE) of young juvenile Greenland turbot on the eastern Bering Sea continental shelf as shown by Northwest and Alaska Fisheries Center (NWAFC) survey data, and of older juveniles and adults on the continental slope as shown by data from Japanese landbased dragnet (LBD)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

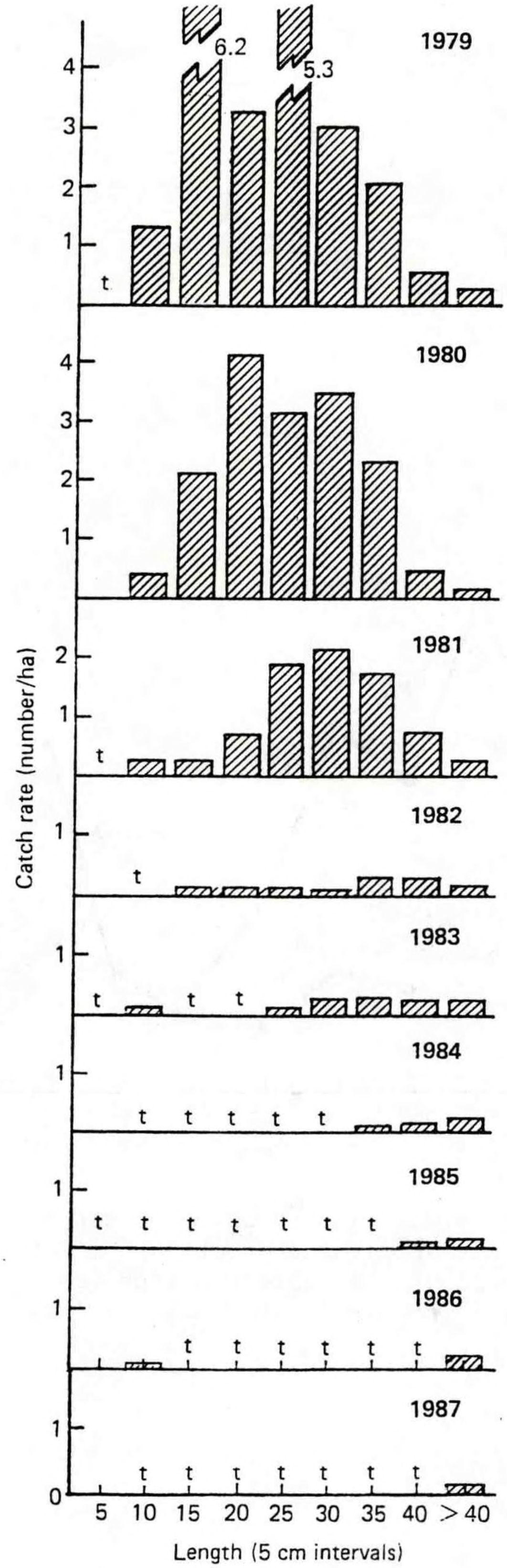


Figure 2.--Catch per unit effort of young juvenile Greenland turbot on the continental shelf of the eastern Bering Sea as shown by Northwest and Alaska Fisheries Center survey data. The letter t represents trace catches.

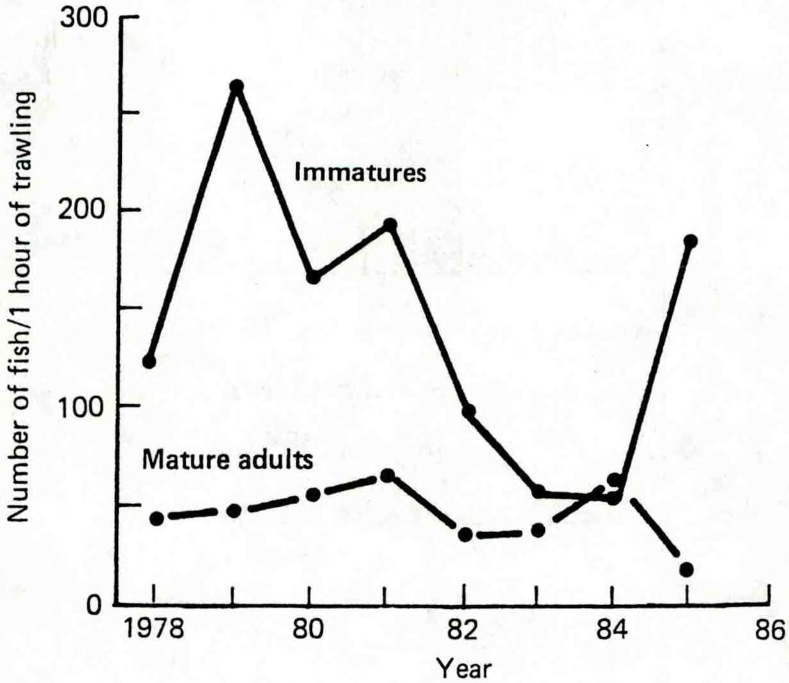


Figure 3.--Catch per unit effort of older immature and adult Greenland turbot on the continental slope of the eastern Bering Sea as shown by data from Japanese small trawlers.

also sharp increases in CPUE values for the overall slope populations from the landbased and all small trawler fleets in 1985 and 1986 (Fig. 1). The CPUE values for mainly mature Greenland turbot (males ≥55 cm, females ≥70 cm) as shown by observer data from all small trawlers was relatively stable between 1978 and 1984, showing some increase between 1983 and 1984 but declining to the lowest value observed in 1985 (Fig. 3). Thus, the higher CPUE values in 1985 and 1986 from the small trawlers apparently come from higher catch rates of older juvenile fish on the slope.

Results from the various sources of CPUE data for the most recent years are obviously in conflict. The NWAFC survey data show very poor recruitment of young juvenile fish over the past 8 years. This poor recruitment was also reflected by the decline in older juveniles on the slope through 1984. These data would suggest a continued decline in abundance of older juveniles, but instead the CPUE values from the small trawlers sharply increased in 1985 and 1986. The reason for this increase in CPUE is unknown but may result from a number of causes. The fishery may have altered fishing techniques or changed fishing areas to more efficiently catch Greenland turbot, or for some other reason the 1985 and 1986 CPUE data may not be comparable to those from earlier years. It is also possible that there has been some recruitment of juvenile fish from waters north of those sampled by the NWAFC surveys, such as from the U.S.S.R. fishery zone. Clearly, recruitment of young juveniles has declined to very low levels on the eastern Bering Sea shelf (Fig. 2). There is every reason to believe that the poor recruitment will reduce the abundance of the exploitable population and evidence of this has been shown by U.S.-Japan cooperative surveys on the slope and by small trawler CPUE data through 1984. Thus, it is difficult to believe that the anomalous results from the 1985 and 1986 small trawler data showing sharp increases in CPUE reflect the actual trend in abundance of the exploitable stock.

Biomass Estimates

Biomass estimates from NWAFC surveys on the eastern Bering Sea shelf and U.S.-Japan cooperative surveys on the eastern Bering Sea slope and in the Aleutian Islands region are given in Table 2. The estimates from the NWAFC surveys on the eastern Bering Sea shelf, primarily representing age 1-4 juveniles, show an increase in biomass between 1975 (126,700 t) and 1979 (225,600 t) but a persistent decline since 1979 to only 5,600 t in 1986. The 1987 estimate was higher at 10,600 t but this increase was neglible when compared to estimates from earlier years.

Biomass estimates for older juveniles and adult Greenland turbot on the continental slope of the eastern Bering Sea also show a persistent decline from 123,000 t in 1979 to 79,200 t in 1985. Based on the magnitude of commercial catches in 1981 (52,900 t) and 1982 (45,800 t) in this region, it is assumed that the biomass of the adult stock is underestimated by survey data. In the Aleutians region, biomass estimates have increased from 48,700 t in 1980 to 76,500 t in 1986. The reason for this opposite trend in the Aleutians is unknown but may be the result of migration of adult fish from the eastern Bering Sea.

Table 2.--Biomass estimates (t) for Greenland turbot from U.S. and Japanese surveys in the eastern Bering Sea and Aleutian Islands region.*

	Eastern Bering Sea			
Year	Shelf	Slope	Shelf and slope combined	Aleutians
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	---	---	76,500
1987	10,600	---	---	---

*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.

Size and Age Composition

Age samples for Greenland turbot have been collected annually during NWAFC surveys and from the fishery by U.S. observers, but these samples have not been aged over several past years. Age data from earlier years show that catches on the continental shelf are mainly age 1-3 fish while the fishery on the continental slope takes fish ranging from 3 to 19 years old. The size composition of fish taken by small trawlers ranges from about 35 to 100 cm (Fig. 4). Smaller fish are more abundant in catches west of 170°W long., (which corresponds to the slope regions north of the Pribilof Islands), while larger fish are more prevalent in catches east of 170°W long., (which corresponds to the southern slope region) and in the Aleutians. Alton et al. (1987) hypothesized on the movements of Greenland turbot from this and other data; their hypothesis suggests that juveniles mainly recruit to the northern slope area and then shift to the southern slope area as they age and reach maturity. Some of the adult fish are also believed to migrate to the Aleutian Islands area from the eastern Bering Sea.

MAXIMUM SUSTAINABLE YIELD RANGE

The apparent recruitment failure which has been observed in the eastern Bering Sea turbot stock over the last several years makes estimation of maximum sustainable yield (MSY) difficult. Nevertheless, since MSY is an important management tool, preliminary estimates have been computed using two methods: stock reduction analysis (SRA) (Kimura and Tagart 1982; Kimura et al. 1984; Kimura 1985) and the "simple" model of Beverton and Holt (1957). The results of these computations are shown in this section in terms of feasible MSY ranges.

Stock Reduction Analysis

Stock reduction analysis is one method of implementing the delay-difference equation of Deriso (1980) as generalized by Schnute (1985). The delay-difference equation is a biomass-based production function that can be used in the absence of age data to approximate the behavior of an age structured model exhibiting knife-edge recruitment, age-invariant mortality rates (above the age of recruitment), a Brody (1945) weight-age relationship, and an arbitrary spawner-recruit relationship. As it is usually applied, SRA employs a set of life history parameter estimates and a time series of catch data to solve the delay-difference equation and the catch equations simultaneously. This is typically accomplished by assuming that the stock is in equilibrium prior to the second year of the time series, and by assuming either a known biomass estimate for some year during the time series or a known biomass ratio for some pair of years during the time series.

The parameters used in applying SRA to the eastern Bering Sea turbot stock were as follow: age at recruitment = 5 years, instantaneous rate of natural mortality = 0.18, rho (a coefficient in Schnute's parameterization of the Brody growth equation) = 1.034, and the ratio of weight at age 4 to weight at age 5 = 0.609. The latter pair of parameters were estimated from

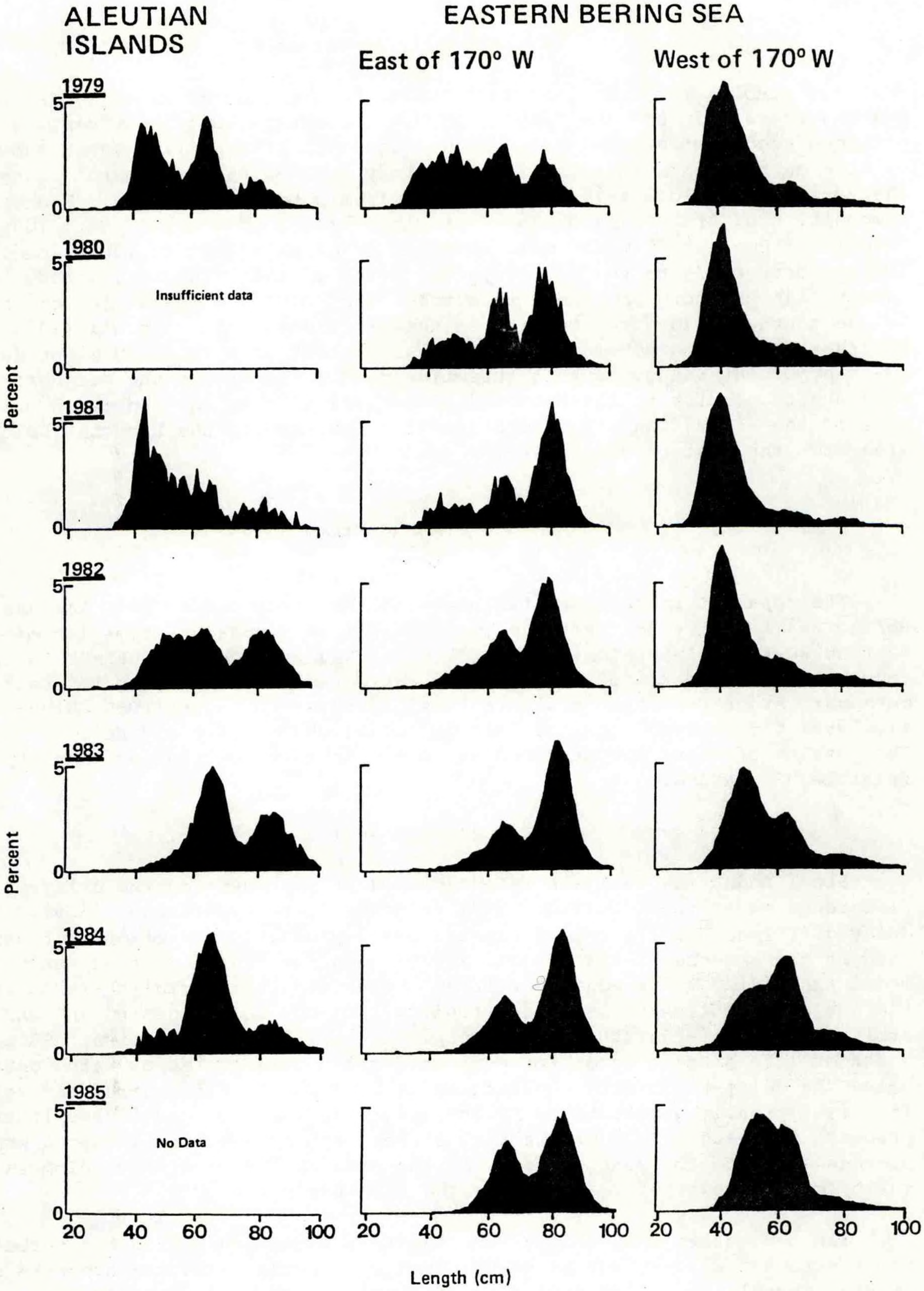


Figure 4.--Length composition of Greenland turbot taken by Japanese small trawlers in the eastern Bering Sea and Aleutians, 1978-85.

the following length-age and weight-length equations:

$$L(age) = 88.788*(1.-\exp(-0.141*(age-0.173))), \quad (1)$$

and

$$W(L) = (2.2*10^{-6})*L^{3.346}, \quad (2)$$

where L = length in centimeters, and W = weight in kilograms. The analysis was constrained to produce a 50% decline in biomass between 1970 and 1984, corresponding to the decline in fishery CPUE observed during that period.

A variety of spawner-recruit relationships are consistent with the above parameters. Using Kimura's (In press) parameterization of the Beverton-Holt recruitment function, the strength of the relationship varies inversely to the parameter $\underline{a}$. When $\underline{a}$ = 1.0, recruitment is constant. As $\underline{a}$ decreases, the strength of the spawner-recruit relationship intensifies, until recruitment is proportional to biomass when $\underline{a}$ = 0. Since it has not been possible to identify a spawner-recruit relationship for this stock, the results of SRA were examined under the full range of possible $\underline{a}$ values. The results gave estimates of MSY for the eastern Bering Sea and Aleutian Islands ranging from 0 (in the limiting case of $\underline{a}$ = 0.0) to 45,900 t (at $\underline{a}$ = 1.0). A sample of the SRA output is shown below.

Beverton-Holt recruitment parameter a	Virgin biomass (1960)	Recruitment biomass (1960)	Maximum sustainable yield
0.00	1,374,100	65,100	0
0.20	1,292,800	61,200	6,300
0.40	1,208,400	57,200	13,000
0.60	1,119,621	53,044	20,500
0.80	1,023,600	48,500	29,700
1.00	912,800	43,200	45,900

It is important to emphasize that the results of this particular application of SRA should be viewed with caution, since they result from a deterministic model which is attempting to simulate what may be a largely stochastic recruitment pattern. Furthermore, the model is fairly simplistic and does not take explicit account of temporal or geographic patterns of fishing effort, the differential impacts of competing gear types, or partial recruitment of cohorts.

Beverton-Holt Yield-Per-Recruit Analysis

The simple model of Beverton and Holt (1957) was also used to generate an MSY range for this stock. A number of important management measures can be calculated from this model using only three inputs: the Brody (1945) coefficient for growth in length (K), the instantaneous natural mortality rate (M), and the ratio (c) formed by dividing length at the time of recruitment by asymptotic length.

To determine an MSY range from this analysis, the model was enhanced to include stochastic variability in the inputs. This was accomplished by assigning a coefficient of variation to each of the three input parameters (K, M, and c) and assuming that the value of each input parameter was normally distributed. The mean values for each of the parameters were as follows: M = 0.18, K = 0.141, and c = 0.4937 (from Equation (1), assuming knife-edge recruitment at age 5). In the absence of any estimates for the coefficients of variation associated with these parameters, values of 0.1 were used for each.

Given any set of values for these stochastic parameters, it was possible to compute the ratio of MSY to the product of Wmax and R, where Wmax = asymptotic weight and R = constant recruitment biomass. For the turbot fishery, this ratio has an estimated median value of 0.15, with a 95% confidence interval running from 0.11 to 0.21.

This ratio can be converted into an MSY estimate by multiplying through by the product of Wmax and R. A Wmax estimate of 7.27 kg was calculated from Equations (1) and (2). Using this estimate together with the SRA estimate of R under the constant recruitment scenario (43,200 t) gives a median MSY estimate of 47,100 t. This compares very favorably with the SRA estimate (45,900 t) obtained under the equivalent assumption of constant recruitment (a = 1.0). Applying the confidence interval for MSY/WmaxR gives an MSY range of 34,500-66,000 t.

ACCEPTABLE BIOLOGICAL CATCH

The North Pacific Fishery Management Council (NPFMC) has established a default method for the computation of acceptable biological catch (ABC), to be used unless another method can be shown to be superior on purely biological grounds. The default method computes ABC as the product of recruited biomass and the MSY exploitation rate. However, the NPFMC has expressed a preference for using the exploitation rate corresponding to $F_{0.1}$ (Gulland and Boerema 1973) in the case of turbot. Therefore, ABC was computed as the product of projected exploitable biomass and the exploitation rate corresponding to $F_{0.1}$, as determined by SRA.

To account for the apparent failure of recruitment in recent years, SRA biomass projections assumed an 80% reduction in recruitment for the years 1986-88. When the parameter a in the Beverton-Holt recruitment function was varied over its feasible range, ABC estimates ranging from 0 (in the limiting case of a = 0.0) to 40,700 t (at a = 1.0) were generated. A sample of the output obtained under different levels of a is shown below.

Beverton-Holt recruitment parameter a	Exploitation rate at $F_{0.1}$	Projected biomass (1988)	Acceptable biological catch
0.0	0.0000	484,300	0
0.2	0.0090	460,300	4,100
0.4	0.0206	435,600	9,000
0.6	0.0370	410,100	15,200
0.8	0.0625	383,400	24,000
1.0	0.1148	354,100	40,700

Since the nature of the spawner-recruit relationship for this stock is presently unknown, a reasonable means of obtaining a single ABC from the SRA results would be to integrate the individual ABC estimates over the range of a. This gives an average ABC of approximately 14,100 t, which is generated at a = 0.57. Of course, when a is fixed at 0.57, other performances of the fishery (e.g., MSY) are fixed as well. Shown below are some of the results corresponding to a = 0.57.

Virgin biomass (1960)	Maximum sustainable yield	Exploitation rate at $F_{0.1}$	Projected biomass (1988)	Acceptable biological catch
1,133,300	19,300	0.0341	414,000	14,100

It should be stressed that ABC is not meant to be a substitute for optimum yield. There may be many reasons for choosing a catch level other than the ABC estimate given here. For example, the uncertainty involved in model calculations may warrant selection of a more conservative catch level. The ongoing recruitment failure exhibited by this stock raises special concern in this regard. Because of the uncertainty regarding recruitment, it is not clear that any level of harvest would be low enough to insure the continued viability of the Greenland turbot fishery.

ARROWTOOTH FLOUNDER

by

Richard G. Bakkala and Grant G. Thompson

INTRODUCTION

Arrowtooth flounder, Atheresthes stomias, is a relatively large flatfish which occupies eastern Bering Sea continental shelf waters almost exclusively until age 4 but at older ages occupies both shelf and slope waters. Data from 1979 and 1982 U.S.-Japan cooperative surveys indicate that the proportion of a given age occupying slope waters gradually increases from age 5 to 9, but that some older fish continue to occupy shelf waters. This species ranges into the Aleutian Islands region where their abundance is lower than in the eastern Bering Sea. The population in the Aleutians and eastern Bering Sea are managed as a single stock although the stock structure has not been studied.

Highest concentrations of arrowtooth flounder are found in the southern portion of the eastern Bering Sea over the depth range of 100-700 m. The distribution of arrowtooth flounder overlaps with that of a similar species, Kamchatka flounder, A. evermanni, which has a more northerly distribution than arrowtooth flounder in the eastern Bering Sea. Because taxonomic differences between the two forms are not readily apparent, the two species are usually grouped in commercial catches and during resource assessment surveys.

Arrowtooth flounder was managed with Greenland turbot as a species complex until 1985 because of the similarities in their life history characteristics and exploitation. Greenland turbot has been the target species of the fisheries while arrowtooth flounder are only taken as a by-catch of the fishery. Because the condition of the two species has differed markedly in recent years, management starting in 1986 has been by individual species.

CONDITION OF STOCK

Catch Statistics

Reported catches of arrowtooth flounder and Greenland turbot were combined during the 1960s; and thus, catch trends of arrowtooth flounder are not available for this period. The fisheries for Greenland turbot intensified during the 1970s and the by-catch of arrowtooth flounder is assumed to have also increased. In 1971-76, catches of arrowtooth flounder probably reached peak levels ranging from 13,000 to 25,000 t and averaging 18,700 t (Table 1).

Catches decreased from 1972-76 levels after implementation of the Magnuson Fisheries Conservation and Management Act in 1977, averaging 13,850 t annually in 1977-83. Following 1983 there was a further decline to 6,900 t in 1986 because of catch restrictions placed on the fishery for Greenland turbot as

Table 1.--Commercial catches (t) of arrowtooth flounder by nation in the eastern Bering Sea and Aleutian Islands region[a]

Year	Eastern Bering Sea						Aleutian Islands Region						Totals for regions combined
	Japan	U.S.S.R.	Other non-U.S. fisheries[b]	U.S. joint ventures[c]	U.S. domestic[d]	Total	Japan	U.S.S.R.	Other non-U.S. fisheries	U.S. joint ventures	U.S. domestic	Total	
1970	9,354	3,244				12,598	274					274	12,872
1971	11,603	7,189				18,792	581					581	19,373
1972	3,823	9,300				13,123	1,217	106				1,323	14,446
1973	4,929	4,288				9,217	3,682	23				3,705	12,922
1974	2,823	18,650				21,473	3,195					3,195	24,668
1975	1,241	19,591				20,832	641	143				784	21,616
1976	1,674	16,132				17,806	1,370					1,370	19,176
1977	6,160	3,294				9,454	2,015	20				2,035	11,489
1978	5,691	2,576	91			8,358	1,780	2				1,782	10,140
1979	5,288	948	1,685			7,921	6,436					6,436	14,357
1980[e]	-	-	-	87		13,761	-	-	-			4,603	18,364
1981[e]	-	-	-	5		13,473	-	-	-	16		3,640	17,113
1982[e]	-	-	-	38		9,103	-	-	-	59		2,415	11,518
1983[e]	-	-	-	36		10,216	-	-	-	53		3,753	13,969
1984[e]	-	-	-	200		7,980	-	-	-	68		1,472	9,452
1985[e]	-	-	-	448		7,288	-	-	-	59	17	87	7,375
1986[e]	-	-	-	3,298	1	6,761	-	-	-	78	64	142	6,903

[a]Sources of data: 1960-76, Wakabayashi and Bakkala 1978; 1977-79, data submitted to United States by fishing nations and available Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98115; 1980-86, French et al. 1981, 1982; Nelson et al. 1983a, 1984; Berger et al. 1985b, 1986, 1987a.

[b]Republic of Korea, Taiwan, Poland, and Federal Republic of Germany.

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

[d]Fish caught and processed by U.S. domestic operations.

[e]Catches by individual non-U.S. nations not available.

evidence of declining recruitment of this latter species accumulated. The phasing out of the foreign fishery in the U.S. fishery zone has probably also accounted for declines in catches of arrowtooth flounder.

Relative Abundance

Indices of relative abundance for arrowtooth flounder have recently increased substantially in both continental shelf and slope waters. Since 1981 the catch per unit effort (CPUE) from Northwest and Alaska Fisheries Center (NWAFC) surveys on the shelf have increased steadily, from 1.2 kg/ha to 6.2 kg/ha in 1987 (Fig. 1). This increase on the shelf has been followed by a substantial increase in CPUE on the slope, from 1.5 to 10.8 t per hour trawled as shown by data from the Japanese landbased fishery (Fig. 1). These latter CPUE values are based on catch and effort data from all 0.5 lat. by 1° long. statistical blocks in which arrowtooth flounder were taken by the landbased fishery. Fishery data are not yet available for calculating a CPUE value for 1986.

Biomass Estimates

Biomass estimates from NWAFC surveys on the continental shelf have shown consistent increases since 1975 with the exception of 1985 (Table 2). The increases were moderate through 1982 but were much more substantial in later years with the biomass increasing by more than fourfold from 67,400 t in 1982 to 290,600 t in 1985. Increasing abundance of arrowtooth flounder was also shown by U.S.-Japan cooperative survey data on the continental slope of the eastern Bering Sea and in the Aleutian Islands region (Table 2). Thus, all survey and fishery data agree in reflecting this increase in abundance. Combining the most recent survey estimates from shelf and slope areas of the eastern Bering Sea and Aleutians indicates that the current biomass of arrowtooth flounder is 365,000 t in the eastern Bering Sea, 125,700 t in the Aleutians, and 490,700 t in the two regions combined.

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 previously (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

It is apparent that the eastern Bering Sea arrowtooth flounder population is subject to wide fluctuations in abundance. The survey data indicate rapid increases in stock biomass during a period when catches have been relatively constant. These facts are difficult to reconcile in a deterministic model unless an extremely strong spawner-recruit relationship is assumed. Furthermore, the lack of ageing for this species for several years, makes it difficult to estimate recruitment. For these reasons, it is considered inappropriate to attempt an estimate of maximum sustainable yield (MSY) at the present time.

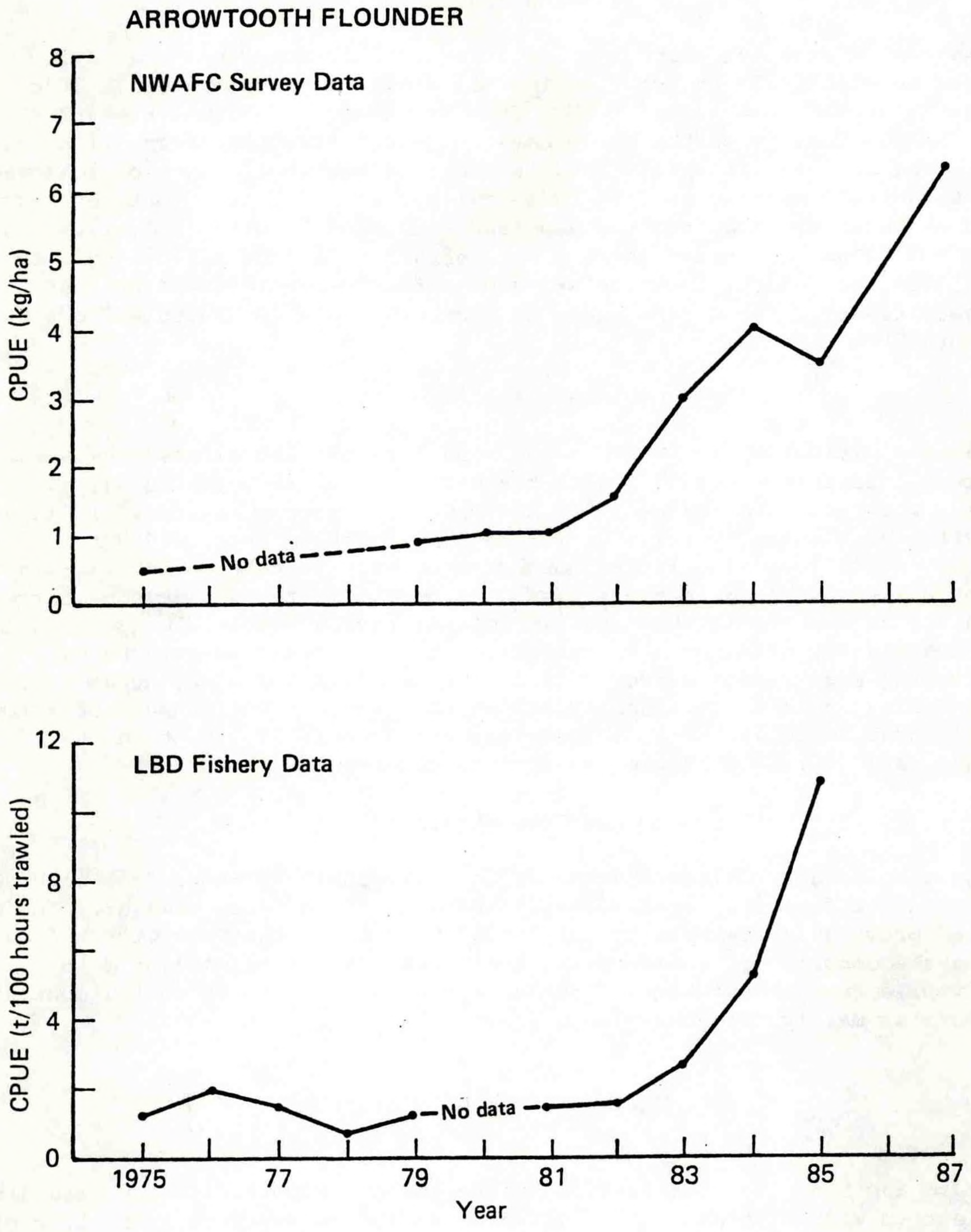


Figure 1.--Catch per unit effort (CPUE) of arrowtooth flounder on the eastern Bering Sea continental shelf as shown by Northwest and Alaska Fisheries Center (NWAFC) survey data and on the continental slope as shown by Japanese landbased dragnet (LBD) fisheries data.

Table 2.--Biomass estimates (in metric tons) for arrowtooth flounder from U.S. and U.S.-Japanese cooperative surveys in the eastern Bering Sea and Aleutian Islands region.

	Eastern Bering Sea			
Year	Shelf	Slope	Shelf and slope combined	Aleutians
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	---	---	125,700
1987	290,600	---	---	---

ACCEPTABLE BIOLOGICAL CATCH

The North Pacific Fishery Management Council has established a default method for the computation of acceptable biological catch (ABC), to be used unless another method can be shown to be superior on purely biological grounds. The default method computes ABC as the product of recruited biomass and the MSY exploitation rate. Although available data are insufficient to estimate MSY, the "simple" model of Beverton and Holt (1957) can be used to estimate the instantaneous rate of fishing mortality which would prevail at MSY (F_{MSY}) given an assumption of constant recruitment. The Beverton-Holt model requires three inputs to estimate F_{MSY}: the Brody (1945) coefficient for growth in length (K), the instantaneous natural mortality rate (M), and the ratio (c) formed by dividing length at the time of recruitment by asymptotic length.

To increase the utility of the measures generated by the model, the analysis was extended to include stochastic variability in the inputs. This was accomplished by assigning a coefficient of variation to each of the three input parameters (K, M, and c), and assuming that the value of each input parameter was normally distributed. A value for K was obtained from the following nonlinear least squares regression of length against age, based on data from the 1982 U.S.-Japan cooperative survey:

$$L_i = 58.99(1 - \exp(-0.169(i + 0.497))), \qquad (1)$$

where i = age. Assuming that the age of recruitment is 4 years, Equation (1) sets c = 0.5323. The natural mortality rate was set at 0.2, following Okada et al. (1980). In the absence of any estimates for the coefficients of variation associated with these parameters, values of 0.1 were used for each.

These parameters give a median F_{MSY} estimate of 0.51, with a 95% confidence interval (based on an assumed 10% coefficient of variation for each of the three input parameters) running from 0.29 to 1.47. An estimate of ABC for the eastern Bering Sea may thus be obtained by assuming that the mean 1988 recruited biomass on the shelf is equal to the recruited portion of the 1987 survey biomass, expanding that figure to account for the slope component of the stock, and then multiplying that amount by 0.51. (For a continuous-time, biomass-based model such as the Beverton-Holt model, the appropriate exploitation rate is F, applied to mean annual biomass.)

The recruited portion of the shelf biomass can be estimated as the portion of the biomass contributed by individuals at least 28 cm in length, which was approximately 255,000 t according to the 1987 shelf survey. A reasonable method of expanding this figure to include the slope component of the stock would be to use the past ratios between the cooperative survey biomass estimates and the shelf survey biomass estimates. A weighted average of this ratio for the years 1979, 1982, and 1985 gives a coefficient of 1.5177, which results in a total recruited biomass (shelf plus slope) of 387,000 t. The ABC corresponding to this biomass, based on an F value of 0.51, is 197,400 t.

To account for catches in the Aleutian Islands subarea, the ABC estimate needs to be expanded. The 1986 biomass estimate from the Aleutians was 125,700 t. Assuming that mean Aleutians biomass in 1988 will be equal to 1986 survey biomass, and that the ratio of recruited biomass to total biomass in the Aleutians is the same as on the shelf, mean recruited biomass for the Aleutians in 1988 would be 110,300 t. Based on this extrapolation, total recruited biomass for the Aleutians and eastern Bering Sea combined would be 497,300 t, implying an overall ABC of 253,600 t.

However, there are some problems with using the Beverton-Holt model to estimate ABC. First, because the model does not project the population into the next year, a recent survey biomass estimate must be used as a substitute for 1988 mean biomass. Since the estimated F at MSY is higher than the F values observed in recent years, 1987 survey biomass will likely be an overestimate of 1988 mean biomass, thus causing ABC to be overestimated also. Further problems may arise from the strong assumption of constant recruitment inherent in the model. If recruitment is density-dependent at moderate stock sizes, then ABC will again be overestimated, and the stock will be pushed to a level below that associated with MSY.

For these reasons, it is recommended that both F_{MSY} and survey biomass estimates be set at the lower ends of their respective confidence intervals for the purpose of calculating ABC. This would imply a mean 1988 recruited biomass of 332,100 t in the eastern Bering Sea, and 45,600 t in the Aleutians. Applied to the lower bound of the confidence interval for F_{MSY} (0.29), this gives a 1988 ABC of 109,500 t.

Finally, it should be stressed that ABC is not meant to be a substitute for optimum yield. There may be many reasons for choosing a catch level other than the ABC estimate given here, which is simply an application of the formula prescribed by the North Pacific Fishery Management Council. For example, the uncertainty involved in model calculations may warrant selection of a more conservative catch level. Allocative issues may also merit consideration; for example, it may be preferable to defer potential harvests until a later time when the domestic industry is fully capable of utilizing them. From a purely biological standpoint, the most important conclusion is that the arrowtooth flounder resource is probably capable of withstanding a wide range of harvests without damaging its long-term viability.

OTHER FLATFISH

by

Gary E. Walters and Karen L. Halliday

INTRODUCTION

The "other flatfish" species complex has been managed as a unit through 1987 and is made up of the following small flatfishes which have distributions that are restricted mainly to continental shelf waters of the eastern Bering Sea: flathead sole, *Hippoglossoides elassodon* (due to problems of identification, data given here for flathead sole includes Bering flounder, *Hippoglossoides robustus*); rock sole, *Lepidopsetta bilineata*; Alaska plaice, *Pleuronectes quadrituberculatus*; and small amounts of miscellaneous flatfishes including rex sole, *Glyptocephalus zachirus*; Dover sole, *Microstomus pacificus*; starry flounder, *Platichthys stellatus*; longhead dab, *Limanda proboscidea*; and butter sole, *Isopsetta isolepis*. Only small amounts of "other flatfish" are taken in the Aleutian Islands region.

All-nation catches of these species increased from around 30,000 metric tons (t) in the 1960s to a range of 65,000 to 92,000 t in 1970-72 (Table 1). At least part of this increase was due to better species identification and reporting of catches in the 1970s. After 1971, catches declined to less than 25,000 t in 1975-82 but have subsequently increased steadily to 78,000 t in 1986.

The species composition of catches has been highly variable, as indicated below.

	Percent composition		
Period	Rock sole	Flathead sole	Alaska plaice
1963-70	23	67	10
1971-75	58	39	3
1976-81	28	31	38
1982-84	45	14	37
1985	53	8	35
1986	30	7	60

Rock sole was an important element of the catch in most years. Flathead sole has been of decreasing importance while Alaska plaice has increased.

Table 1.--All-nation catches of other flatfishes in the eastern Bering Sea and Aleutian Islands region in metric tons (1980-86 data include catches from joint venture operations between U.S. fishing vessels and non-U.S. processing vessels).[a]

Year	Rock sole	Flathead sole	Alaska plaice	Miscellaneous flatfish[b]	Total
1963	5,029	29,639	975	-	35,643
1964	3,390	25,331	1,883	-	30,604
1965	3,825	6,841	1,020	-	11,686
1966	9,186	11,045	4,633	-	24,864
1967	4,787	23,469	3,853	-	32,109
1968	5,267	21,761	2,619	-	29,647
1969	9,242	18,565	6,942	-	34,749
1970	20,125	41,163	3,402	-	64,690
1971	40,420	51,040	992	-	92,452
1972	60,829	15,694	290	-	76,813
1973	23,837	18,165	1,917	-	43,919
1974	20,011	14,958	2,388	-	37,357
1975	12,014	5,888	2,491	-	20,393
1976	9,964	8,162	3,620	-	21,746
1977	2,914	7,909	2,589	981	14,393
1978	3,323	6,957	10,420	340	21,040
1979	1,468	4,351	13,672	233	19,724
1980	7,601	5,247	6,908	650	20,406
1981	9,021	5,218	8,653	536	23,428
1982	11,844	4,509	6,811	645	23,809
1983	13,618	5,240	10,766	830	30,454
1984	18,750	4,458	18,982	2,096	44,286
1985	37,678	5,636	24,888	2,977	71,179
1986	23,483	5,132	46,519	2,535	77,669

[a]Catches in 1977-83 differ from those shown by Bakkala (1985). 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, 1987b.

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

CONDITION OF STOCKS

Relative Abundance

Because "other flatfishes" are usually taken incidentally in fisheries targeting on other species, indices of abundance from commercial fisheries data seldom 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.

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 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 trawls used in 1982 compared to those 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 levels seen in recent years.

The CPUE values since 1975 for a large-scale standardardized area of the eastern Bering Sea are illustrated in Figure 1. These trends indicate that the abundance of rock sole remained relatively stable from 1975 to 1979, increased moderately through 1981, and then increased sharply after 1981. The abundance of flathead sole appeared relatively stable from 1975 to 1979 and then increased moderately each year between 1980 and 1984. After a slight decrease in 1985, the values have resumed the steady increase. The trend for Alaska plaice shows an increase from 1975 to 1982 and then a decrease beginning with the 1985 values. Values for the last 3 years have been nearly constant. Values of CPUE for these species were lower in 1985, suggesting that abundance may have peaked. However, it is believed that the values for 1985 were due to a change in the sampling plan during that survey and do not reflect actual changes in abundance.

Biomass Estimates

Estimates from the 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 t, declined in 1985 and has since remained stable near 550,000 t. 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 1987 estimate shows a continuing increase to 1,249,800 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 estimates have increased steadily to a new high of 406,000 t in 1987. The biomass of the miscellaneous species of flatfish increased through 1982, declined through 1985, and increased moderately in 1986. The 1987 estimate, at 47,800 t, was nearly the same as 1986.

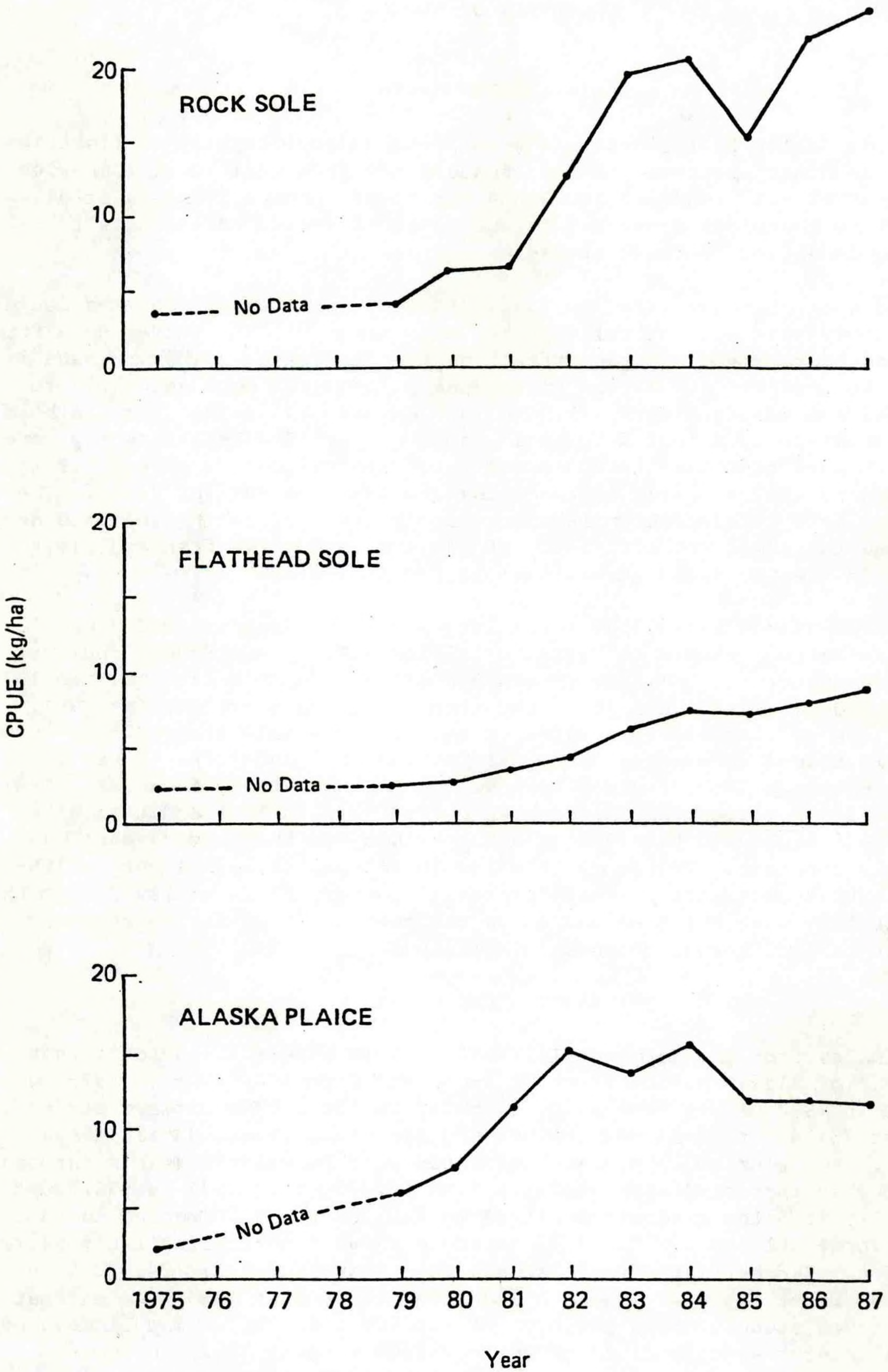


Figure 1.--Relative abundance in catch per unit effort (CPUE) of rock sole, flathead sole, and Alaska plaice from Northwest and Alaska Fisheries Center bottom trawl surveys.

Table 2.--Estimated biomass (in metric tons) of species in the other flatfish complex in the eastern Bering Sea and Aleutians regions based on NWAFC research vessel survey data in 1975 and 1979-86.

		Species				
Year	Area	Rock sole	Flathead sole	Alaska plaice	Others	Total all species
1975	EBS[a]	175,500	100,700	103,500	22,200	401,900
1979	EBS	194,700	104,900	277,200	50,900	627,700
1980	EBS	283,800	117,500	354,000	56,500	811,800
	Aleut.[b]	28,500	3,300	0	2,700	34,500
1981	EBS	302,400	162,900	535,800	88,000	1,089,100
1982	EBS	572,200	197,400	700,200	147,800	1,617,600
1983	EBS	911,200	279,900	646,600	76,300	1,914,000
	Aleut.	23,300	1,500	0	2,700	27,500
1984	EBS	950,600	344,800	734,400	51,600	2,081,400
1985	EBS	720,300	329,900	553,300	33,000	1,636,500
1986	EBS	1,013,700	369,300	550,600	47,400	1,981,000
	Aleut.	26,900	9,000	0	6,100	42,100
1987	EBS	1,249,800	406,000	552,200	47,800	2,255,800

[a]Eastern Bering Sea.
[b]Aleutian Islands region west of 165°W long.

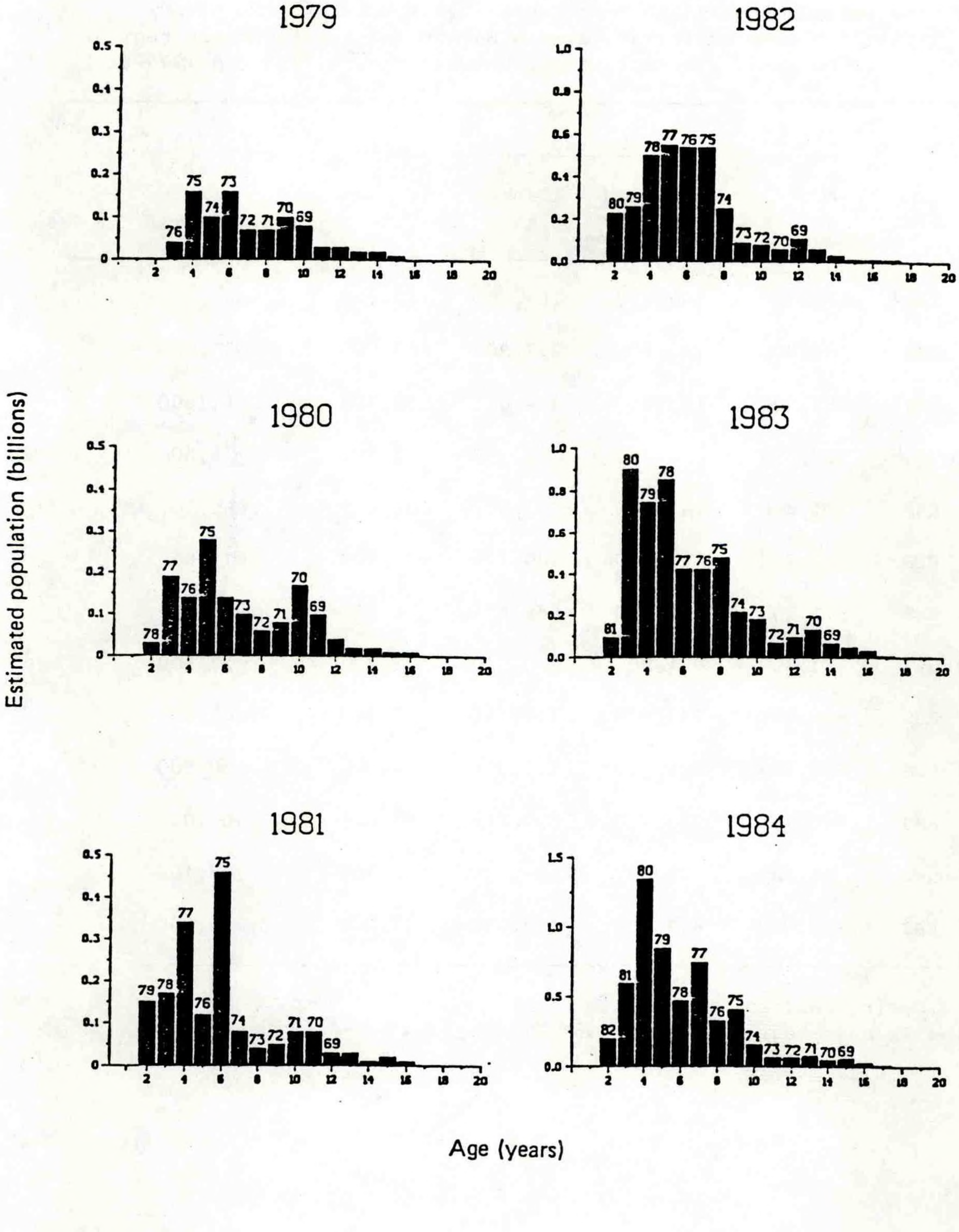


Figure 2.--Age composition of rock sole as shown by data collected on Northwest and Alaska Fisheries Center demersal trawl surveys.

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 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. The change in sampling plan in 1985 is now considered to be the major reason for these declines.

Age Composition and Year-Class Strength

The increases in abundance described earlier for the principal species in the "other flatfish" complex appear to be the result of the recruitment of series of relatively strong year classes. Rock sole ages have now been determined for the 1984 survey samples and show the continuing strength of the 1975-80 year classes (Fig. 2). Examination of the size composition suggests that strong recruitment continues into the 1980s (Walters and Halliday 1987).

Age samples for flathead sole have been examined only through 1982 (Fig. 3) and show the strength of the 1974-79 year classes. Examination of the size composition for the later years suggests strong recruitment at least into the early 1980s.

Age data for Alaska plaice also extends only through 1982 (Fig. 4). Unlike rock sole and flathead sole, Alaska plaice do not begin to recruit to survey gear until ages 4-5 at lengths generally greater than 20 cm (Fig. 5). However, the size distributions since 1979 give no indication of higher than normal recruitment beyond the 1975 year class.

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.

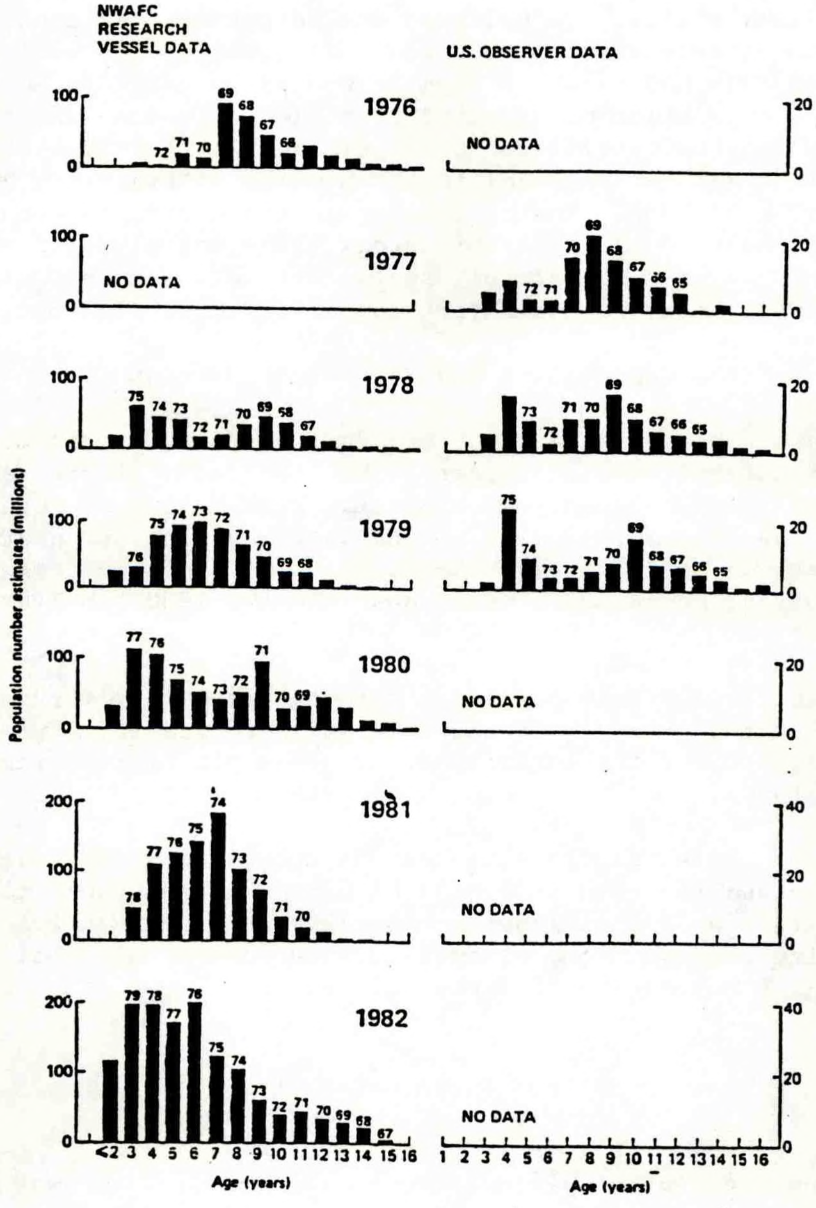


Figure 3.--Age composition of flathead sole as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

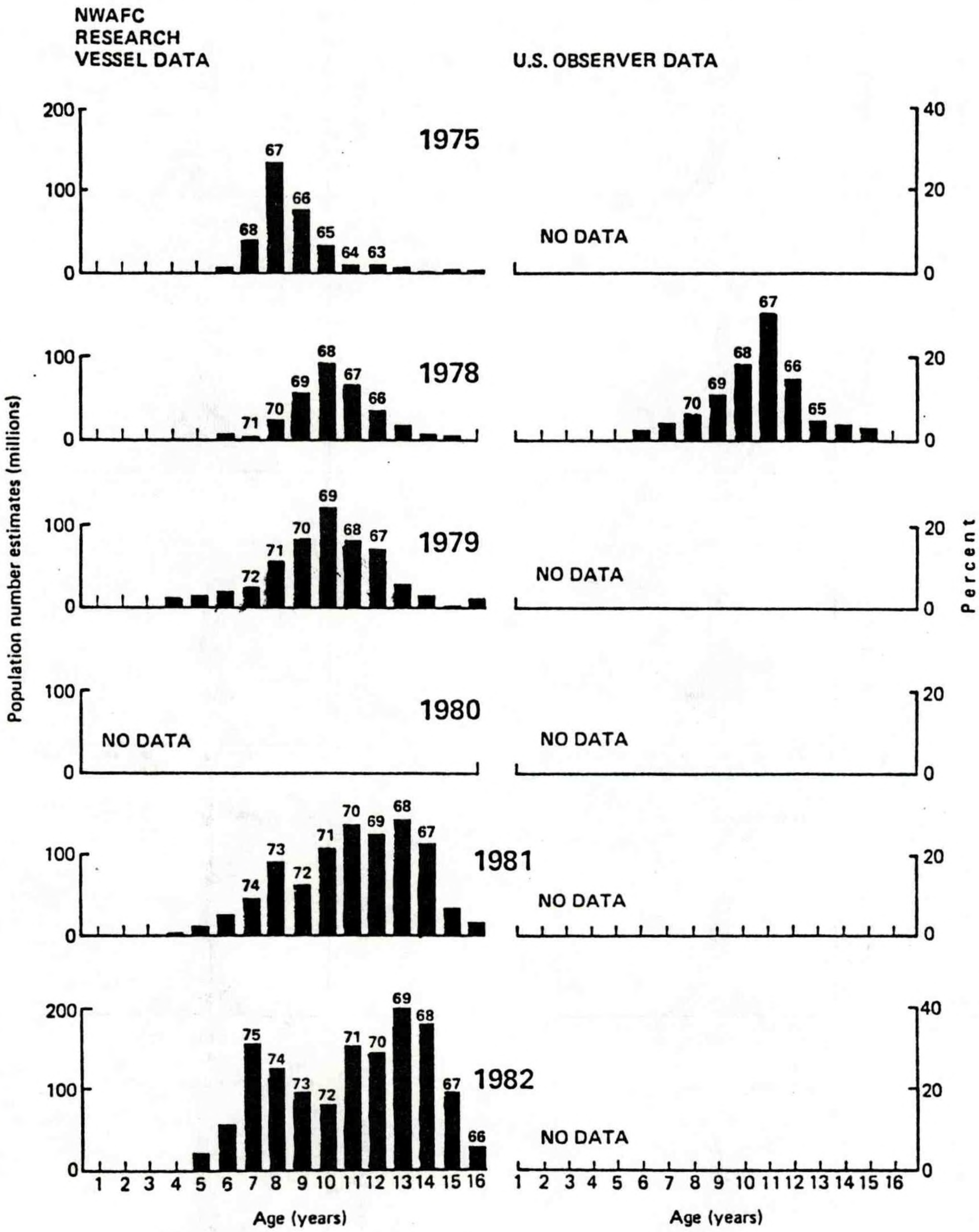


Figure 4.--Age composition of Alaska plaice as shown by data collected on Northwest and Alaska Fisheries Center (NWAFC) demersal trawl surveys and by U.S. observers in the commercial fishery.

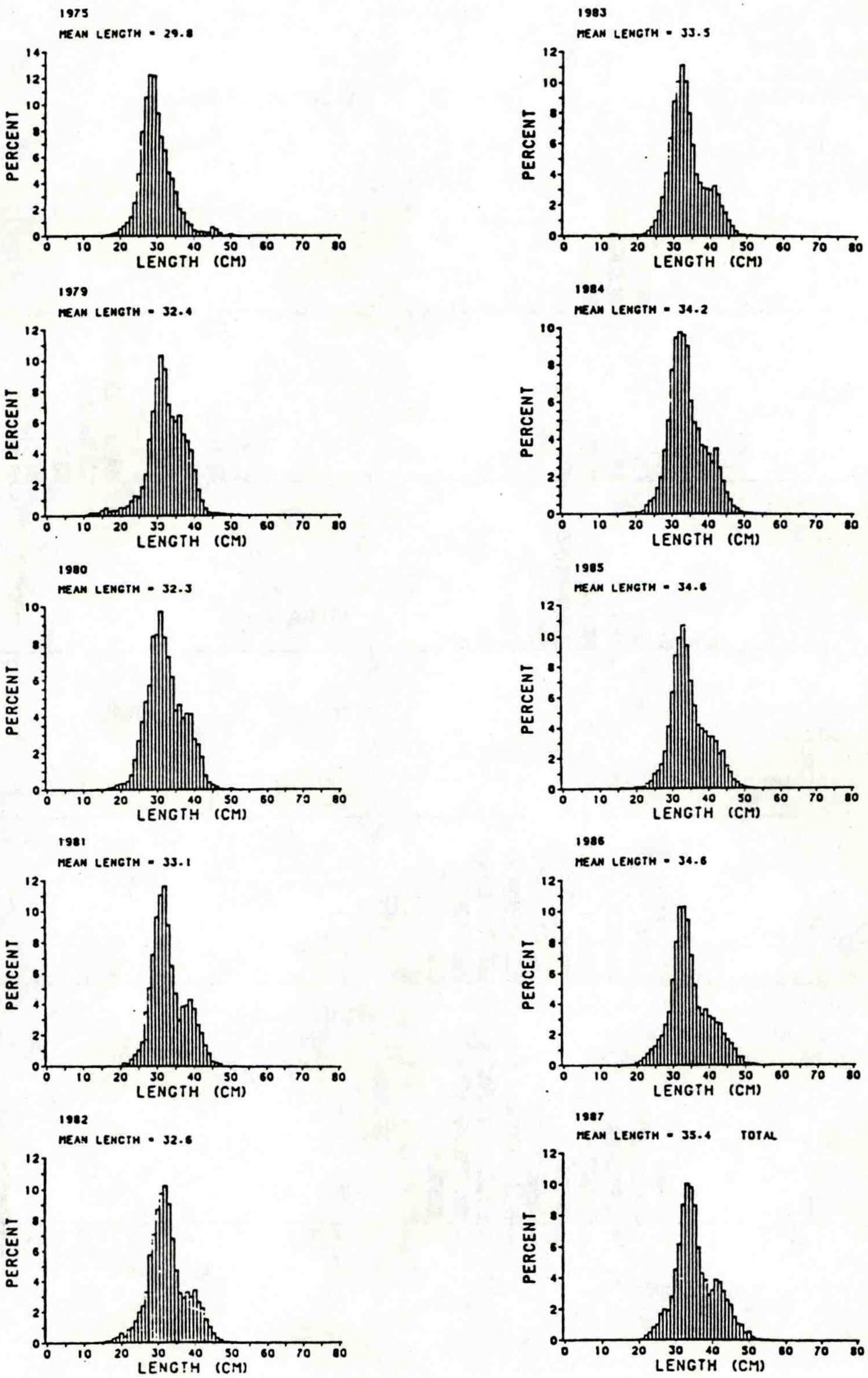


Figure 5.--Size composition of Alaska plaice from Northwest and Alaska Fisheries Center bottom trawl surveys.

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 North Pacific Fisheries Management Plan. Given the change 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. The changing composition of the catch and developing target fisheries for individual species in the complex suggest that MSY and acceptable biological catch (ABC) should be presented for each species.

Rock Sole

The biomass estimates based on resource assessment surveys for rock sole have been close to 1 million t since 1983 (Table 2). The application of a biomass-based cohort analysis (Zhang 1987) gives results suggesting the surveys underestimated biomass prior to the gear change in 1982 (Fig. 6). Since that time the values have generally increased and may be approaching carrying capacity. A biomass-based production model (Zhang 1987) gives an estimate of carrying capacity, B_{inf}:

$$\ln (B_t+1/(B_t \times e^{-F}t)) = r - r/B_{inf} \times \overline{B}t ,$$

where $\overline{B}t$ = the mean of B_t and B_t+1, r = the intrinsic rate of population growth. Through regression, values of r and B_{inf} are estimated. The estimates, based on data from the years 1975 through 1984, yields values of r = 0.311 and B_{inf} = 1,447,000 t. MSY is then derived as:

$$MSY = r\ B_{inf} / 4, \text{ yielding } MSY = 112,500 \text{ t} .$$

Recent estimates of MSY for rock sole have ranged from 40,000 to 70,000 t. However, it is obvious from the survey results that the stock continues to increase and that as long as recruitment remains high an MSY estimate over 100,000 t is not unreasonable.

Flathead sole

Biomass estimates for flathead sole (including Bering flounder) show a steady increase from 1979 to 1984; beginning in 1984, biomass appeared to level off near 350,000 t but increased to 400,000 t in 1987. Until we apply the biomass based cohort analysis to flathead sole, we must rely on an estimation according to the Alverson-Pereyra (1969) yield equation. Using an average of the biomass levels since 1984 as a representation of virgin biomass (362,500 t) and an instantaneous natural mortality rate of M = 0.20 to 0.23 results in an estimated MSY of 36,000 to 42,000 t.

Alaska Plaice

The biomass of Alaska plaice declined after reaching a peak of 734,000 t in 1984, but has stabilized near 550,000 t since. This indicates that the 1984 estimate may be a good approximation of maximum biomass for the stock. Using this value in the same yield equation as was used for flathead sole (at

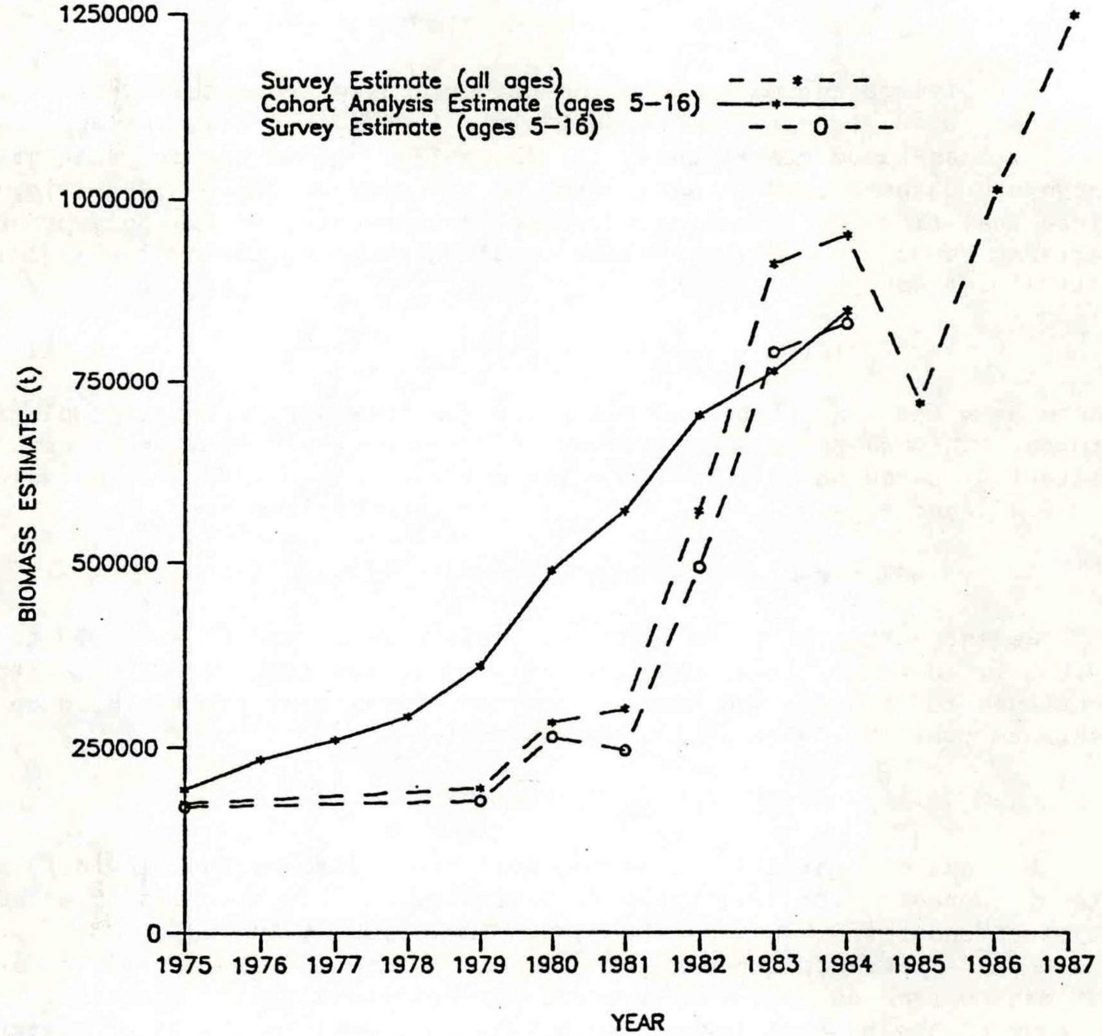


Figure 6.--Comparison of biomass estimates for rock sole from resource surveys and biomass-based cohort analysis.

M = 0.23) gives an estimated MSY of 84,500 t. Using the biomass-based cohort analysis and production model, Zhang (1987) has estimated MSY at 76,000 t. This value is based on better biological evidence and is recommended here.

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

The North Pacific Fishery Management Council has established a default method for the computation of ABC, to be used unless another method can be shown to be superior on purely biological grounds. The default method computes ABC as the product of recruited biomass and the MSY exploitation rate. It should be stressed that ABC is not meant to be a substitute for optimum yield. There may be many reasons for choosing a catch level other than the ABC estimate given here, which is simply an application of the formula prescribed by the council.

Rock sole

The biomass estimates for rock sole continue to climb and recruitment appears high. From the biomass-based production model of Zhang (1987), we find $F_{opt} = r/2 = 0.311/2 = 0.155 = F_{msy}$. Using a value of M = 0.2 (as used in the biomass-based cohort analysis), we can find the exploitation rate at MSY from the relationship:

$$u_{msy} = (F_{msy} / (F_{msy} + M)) (1 - e-(F_{msy} + M)).$$

This yields $u_{msy} = 0.1305$ and ABC = u_{msy} x present biomass = 163,000 t. Further refinement of the biomass-based cohort analysis (when 1985 and 1986 ageing data are available) will undoubtedly modify the value of MSY, and as a result, ABC. This value of ABC is approximately double previous estimates.

Flathead Sole

Flathead sole in the eastern Bering Sea is also currently at a biomass level exceeding B_{msy}. Using the default method yields exploitation rates from 20-23% and a range for ABC from 81,000 t to 94,000 t (mean value 87,500 t). A further evaluation of MSY, using the biomass-based cohort analysis and production model used for rock sole, will soon be forthcoming. Since the biomass estimates for flathead sole show some signs of stabilization, perhaps further analysis will result in more meaningful estimates.

Alaska Plaice

Although this stock is at present stable, it is still at a level well in excess of B_{msy}. Zhang (1987) has estimated MSY at 76,000 t and B_{msy} at 338,000 t. From the present biomass of 552,000 t, ABC can therefore theoretically be set at 124,000 t. However, this stock appears to have stabilized with no apparent large recruitment and an increasing minimum size

(Fig. 5). Therefore, an exploitation rate yielding a catch of no more than MSY 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

Sablefish, Anoplopoma fimbria, in north American waters range from 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. This 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.

CATCH HISTORY

Japanese longliners began targeting on sablefish in the eastern Bering Sea in 1959. 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 Islands and the Gulf of Alaska. Catches peaked in the Aleutian Islands at 3,530 t in 1972 (Table 2).

Catches declined in the eastern Bering Sea and the Aleutian Islands after 1972 largely due to declining stock abundance. Catches remained at relatively low levels after 1977 because of continued low stock abundance and catch restrictions placed on the fishery. Eastern Bering Sea catches have remained relatively stable since 1977, while catches in the Aleutian Islands decreased through 1980 and have been increasing since 1981 (Tables 1-2). Before 1984, non-U.S. vessels harvested most of the sablefish caught in the eastern Bering Sea and the Aleutian Islands region (Tables 1-2). The U.S. domestic fishery began to expand in 1984, and by 1986 caught 86 and 97% of the sablefish taken in the eastern Bering Sea and the Aleutian Islands, respectively.

CONDITION OF THE STOCK

Relative Abundance

In the past, catch per unit effort (CPUE) data from the Japanese longline fishery and data collected by U.S. observers on Japanese vessels provided information on the status of the resource. The CPUE data showed a general decline through 1977. Although fishing patterns changed after 1977 because of regulations and enactment of the Magnuson Fishery Conservation and Management Act (MFCMA), CPUE values continued to drop through 1979. From 1980

Table 1.--Annual sablefish catches in metric tons from the eastern Bering Sea by nation, 1956-86.[a]

Year	Japan	U.S.S.R.	Republic of Korea	Taiwan	U.S. domestic	U.S. joint ventures	Other[b] nations	Total[c]
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	35	168	2,206
1981	2,091	--	339	102	2	24	46	2,604
1982	2,315	--	506	208	148	6	1	3,184
1983	2,231	--	372	--	47	44	1	2,695
1984	1,006	--	179	--	1,518	76	13	2,793
1985	187	--	53	--	1,959	47	2	2,248
1986	73	--	36	--	2,734	347	--	3,189

[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 1977-86 provided by U.S. state fishery agencies; 1977-86 data for all other nations from U.S. Foreign Fisheries Observer Program.

[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 region by nation, 1963-86.[a]

Year	Japan	U.S.S.R.	Republic of Korea	U.S. domestic	U.S. joint ventures	Other[b] nations	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	70	--	--	--	--	2,936
1972	3,262	69	--	--	--	--	3,531
1973	2,740	62	--	--	--	--	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	4	8	274
1981	320	--	56	--	156	1	533
1982	715	--	92	28	118	1	955
1983	527	--	45	29	70	3	673
1984	717	--	7	47	272	1	1,043
1985	70	--	--	1,956	63	--	2,089
1986	--	--	--	3,053	83	--	3,135

[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 1980-86 provided by U.S. state fishery agencies; 1977-86 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.

through 1984, CPUE values showed an upward trend which is attributed to recruitment of the strong 1977 year class. Due to fishing regulations and the decline of Japanese effort, these data no longer provide current information on the status of the sablefish resource.

Japan and the United States have conducted annual cooperative longline surveys in the Gulf of Alaska since 1978. This survey has included the Aleutian Islands 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 effort in units of fish per hachi are multiplied by the respective areas of each depth stratum to obtain an index of relative population number (RPN). The relative population numbers by length group are calculated and then weighted by the mean body weight of fish in that length group to produce indices of relative population weight (RPW). These surveys provided relative population indices for 1982-86 in the eastern Bering Sea and 1980-86 in the Aleutian Islands region (Table 3).

Relative indices from the slope region of the eastern Bering Sea indicated a decline in relative abundance from 1982-83 and then an increase through 1985. The indices declined slightly in 1986. Relative indices from the Aleutian Islands increased from 1981 to 1985, and then decreased in 1986. Although the relative abundance in 1986 has decreased in both areas since 1985, the current levels are still higher than the levels in the early 1980s (Table 3). The increases are believed to reflect the recruitment of the strong 1977 year class. Although data from the 1987 longline survey have not been analyzed, a preliminary comparison indicates that the number of sablefish caught in 1987 in the eastern Bering Sea was much lower than the number caught in 1986. Thus, the relative indices from the 1987 survey are expected to show a continued decline.

Estimates of Absolute Abundance

There are two series of U.S.-Japan cooperative trawl surveys that provide biomass estimates for the eastern Bering Sea and the Aleutian Islands area. Trawl surveys on the eastern Bering Sea slope were conducted in 1979, 1981, 1982, and 1985, and provide estimates of the exploitable population. Trawl surveys of the eastern Bering Sea shelf are conducted annually, but sablefish have never occurred on the shelf in large numbers except for juveniles of the 1977 year class which showed up in large numbers in 1978. Trawl surveys are conducted triennially in the Aleutian Islands and biomass estimates from these surveys are available for 1980, 1983, and 1986. The Aleutian surveys also cover the southern part of International North Pacific Fisheries Commission Area 1 of the eastern Bering Sea which is not included in the eastern Bering Sea slope surveys. The biomass estimates from the southern part of Area 1 are added to the estimates from the eastern Bering Sea slope surveys to provide total biomass for statistical Areas 1 and 2 combined (see Fig. 1 of the Introduction section of this report).

The trawl survey biomass estimates for the eastern Bering Sea portions of Areas 1 and 2 increased from 1979 to 1982, but decreased to 34,700 t in 1985 (Table 4). The trawl survey estimates in the Aleutians portion of Area 1 have shown consistent increases since 1980, reaching 23,000 t in 1986 (Table 4). Assuming the biomass in the eastern Bering Sea portions of Areas 1 and 2 decreased 3.45%, based on the decline shown by the longline survey RPW between

Table 3.--Relative abundance indices of sablefish derived from U.S.-Japan cooperative longline surveys. Relative abundance is represented by relative population number (RPN) and relative population weight (RPW).[a]

Region	Year	Shelf (101-200 m)		Slope (201-1,000 m)		Total	
		RPN	RPW	RPN	RPW	RPN	RPW
Eastern Bering Sea[b]	1982	3	3	14	15	17	18
	1983	5	5	8	9	13	14
	1984	2	1	18	19	20	20
	1985	1	1	28	29	28	30
	1986	2	2	24	28	26	30
Aleutian Islands	1980	2	1	13	14	15	15
	1981	<1	<1	13	14	13	15
	1982	<1	<1	15	16	15	16
	1983	0	0	16	19	16	19
	1984	<1	<1	19	23	19	23
	1985	<1	<1	23	30	23	30
	1986	0	0	19	26	19	26

[a]The values shown are percentages of the 1979 Gulf of Alaska index which is considered the baseline year.

[b]RPN and RPW for the eastern Bering Sea are considered minimal estimates due to survey interference from killer whales.

Table 4.--Estimated biomass and relative population weight indices of sablefish on the continental slope from U.S.-Japan cooperative trawl and longline surveys.

Area	1979	1980	1981	1982	1983	1984	1985	1986
Trawl surveys (biomass in t)								
Eastern Bering Sea (Areas 1 & 2)	12,600	--	39,400	42,900	--	--	34,700	--
(95% Confidence intervals)	(0-56,900)		(23,800-55,100)	(35,800-50,100)			(28,400-41,100)	
Eastern Bering Sea (Area 1, N. Aleutians)	--	8,500	--	--	9,900	--	--	23,000
(95% Confidence intervals)		(0-17,500)			(400-19,300)			(0-60,800)
Aleutian region (Area 5)	--	20,300	--	--	68,500	--	--	96,300
(95% Confidence intervals)		(8,100-32,400)			(0-143,200)			(32,100-160,400)
Longline survey (relative population weight)*								
Eastern Bering Sea (Areas 1 & 2)	--	--	--	15	9	19	29	28
Aleutian region (Area 5)	--	14	14	16	19	23	30	26

* The values shown are percentages of the 1979 Gulf of Alaska index which is considered the baseline year.

1985 and 1986 the biomass in the eastern Bering Sea is estimated to be 33,500 t in 1986. Summing the two 1986 estimates (56,500 t) provides the best biomass estimate for sablefish in the eastern Bering Sea management area. The 1986 estimate represents a 6.5% increase over the combined estimates from the 1982 and 1983 trawl surveys in these areas.

The Aleutian Islands biomass estimate from the 1986 trawl survey was 96,300 t, representing a 41% increase from 1983, and a 374% increase from 1980. These increases in the eastern Bering Sea and Aleutians can probably be attributed to recruitment of the strong 1977 year class.

The overall increasing trend in biomass as indicated from the trawl slope surveys parallel the increases in the RPW indices from the longline surveys on the slope (Table 4). However, the increases in the RPW indices in the Aleutians are not as large as the increases in estimates of absolute biomass. The increases in abundance seemed to have peaked, as the 1986 RPW indices of abundance and preliminary indications from the 1987 longline survey suggest that abundance is now declining.

Sasaki (1987) 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-caught and longline-caught sablefish catch rates and felt that the above relationship would vary depending on the size composition of the sampled population. These findings suggest that the usefulness of a general, overall relationship is limited and that biomass estimates produced from the relationship may be biased.

RECRUITMENT STRENGTHS

Sablefish have rarely been observed on the shelf since the eastern Bering Sea trawl surveys were initiated in 1971, but age 1 juveniles 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 (Fig. 1). In 1981, the abundance on the shelf sharply declined when the 4-year-old fish moved to continental slope waters (Fig. 1).

The trawl slope surveys of the eastern Bering Sea also showed significant increases in abundance due to the 1977 year class. Population estimates by length groups (Fig. 2) showed that the population numbers quadrupled between 1979 (5.3 million fish) and 1982 (22.7 million fish).

There is some evidence of a more recent year class recruiting to the eastern Bering Sea shelf, but the abundance of this later year class is not of the magnitude of the 1977 year class. Length frequency data from the 1986 eastern Bering Sea trawl survey showed a bimodal distribution, with a dominate mode at 43-50 cm (Fig. 3). These were probably age 2 fish of the 1984 year class. However, the trawl survey did not show the continued presence of large numbers of juvenile sablefish on the shelf in 1987. The biomass of sablefish on the shelf dropped from 16,600 t in 1986 to 2,900 t in 1987.

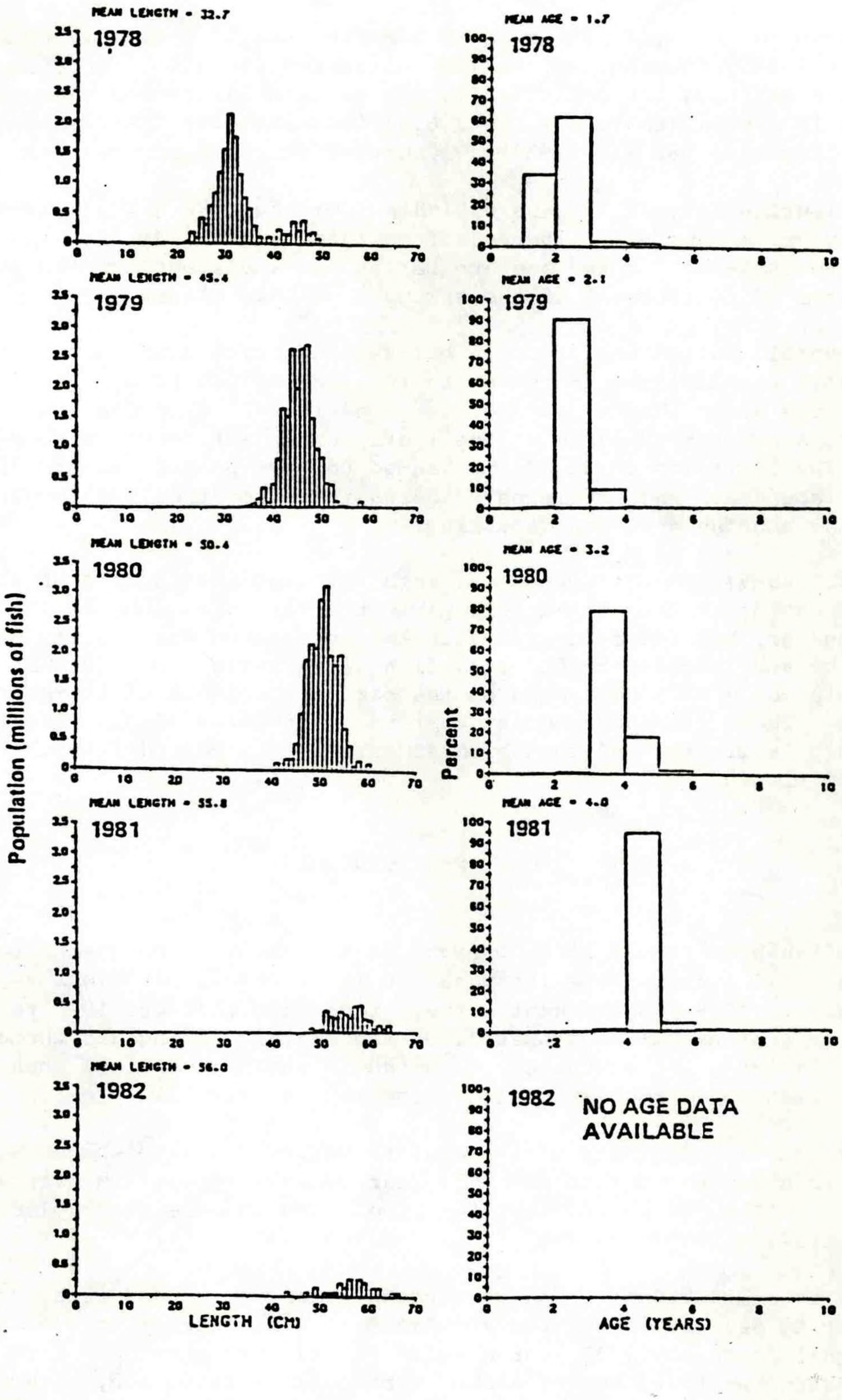


Figure 1.--Size and age composition of sablefish from the continental shelf area surveyed by U.S. research vessels, 1978-82. Age determinations for 1978 may be inaccurate due to differences in ageing structures; scales were used in 1978, and otoliths were used in subsequent years (Umeda et al. 1983).

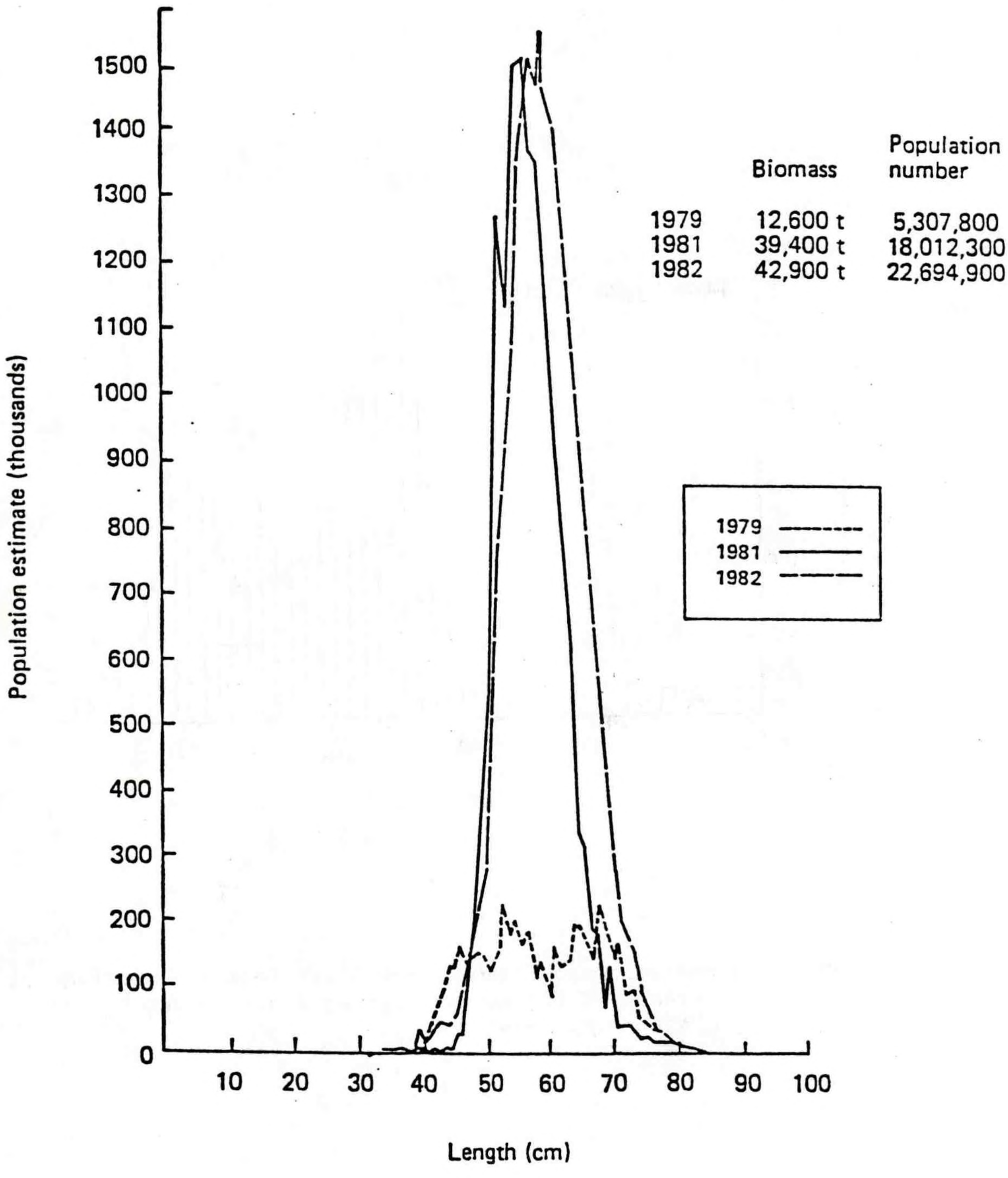


Figure 2.--Population estimates of sablefish by centimeter size-interval on the continental slope of the eastern Bering Sea as shown by data from cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, and 1982. Total estimated biomass and population number for the slope areas surveyed are also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

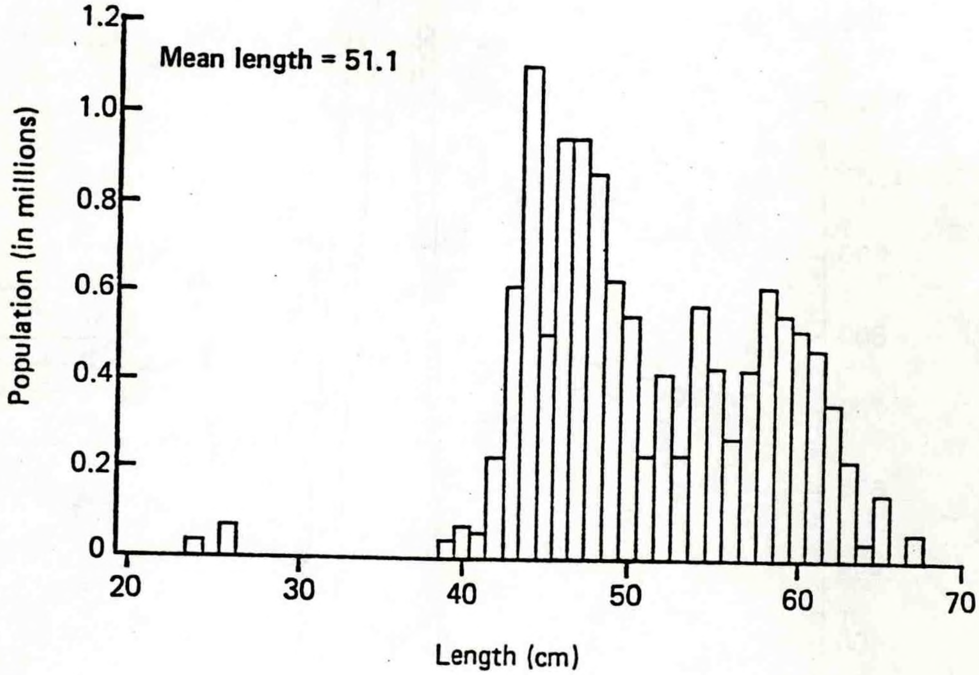


Figure 3.--Size composition of sablefish from the continental shelf of the eastern Bering Sea as shown by the 1986 U.S. trawl survey.

The cooperative longline surveys have not shown any indication of large numbers of sablefish on the shelf (Table 3); however, these surveys only sample a small portion of the 100-200 m depth stratum.

STOCK REDUCTION ANALYSIS

Generalized stock reduction analysis (SRA) (Kimura et al. 1984; Kimura 1985; Kimura In press) incorporating Schnute's (1985) form of the delay-difference equation, was applied to determine potential long-term production of sablefish in the Bering Sea. In addition to annual catches in weight, the model requires estimates of several other parameters: the instantaneous natural mortality rate (M), the delay-difference growth coefficients (RHO, OMEGA) (Schnute 1985), the age of recruitment to the fishable biomass (k), the Beverton-Holt recruitment coefficient (A) (Kimura In press), and for the analysis presented here, an estimate of current exploitable biomass.

A natural mortality rate of 0.1 was used for the SRA analysis (McDevitt 1987). The delay-difference growth coefficients were estimated from weight-at-age data collected in 1980 in the eastern Bering Sea (RHO = 0.8129, OMEGA = 0.6553). The age at recruitment used was 4 years. The Beverton-Holt recruitment coefficient (A) describes the strength of the stock recruitment relationship. When A = 1.0, recruitment is constant and the population is highly resilient. When A = 0.0, recruitment is proportional to biomass and when the population is reduced it is incapable of rebuilding. There is no sustainable level of fishing when recruitment is proportional to biomass. Values of A of 1.0, 0.889, and 0.750 were used in the analysis and represent constant recruitment and a 10 and 20% reduction, respectively, in recruitment to the virgin biomass if the spawning stock is reduced 50% of the virgin biomass. The estimate of current exploitable biomass at the beginning of 1987 was 152,800 t (1986 trawl survey estimates from the eastern Bering Sea and Aleutians combined). The SRA analysis was run with the combined catch data from the eastern Bering Sea and Aleutian Islands from 1959 to 1986, and with the assumption that the stock was close to its unexploited state in 1959 when the fishery started.

Solutions to the SRA equations are given in Table 5. The results show that the estimated virgin biomass ranged from 226,500 to 260,000 t, and that current biomass has been reduced by 33-41% of these initial levels. Maximum sustainable yields for the eastern Bering Sea-Aleutians regions ranged from 6,600 to 11,700 t. The biomass which produces MSY was estimated to range from 37,300 to 90,100 t. The assumption of constant recruitment in the SRA model is extremely optimistic, and implies that at equilibrium an exploitation rate of 31% could be maintained. In order to achieve a more reasonable exploitation rate under the constant recruitment assumption, F is constrained to equal the $F_{0.1}$ value. The equilibrium yield at the $F_{0.1}$ level is 10,100 t. The fishing mortality rate at this level is 0.13 and the exploitation rate is 12%, which is the same exploitation rate at MSY when A = 0.889.

According to the SRA analysis, present biomass is above the biomass level 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 recruitment relationship used in the model,

Table 5.--Solutions to the stock reduction analysis equations assuming a Beverton-Holt stock recruitment relationship.

Recruitment coefficient	Virgin biomass B_1	B_{87}/B_1	MSY	B_{MSY}	F_{MSY}	E_{MSY}
A = 1.0	226,500	0.67	11,700	37,300	0.40	0.31
A = 0.889	241,900	0.63	8,700	69,600	0.14	0.12
A = 0.750	260,000	0.59	6,600	90,100	0.08	0.07

MSY - Maximum sustainable yield.
B_{MSY} - Biomass which produces MSY.
F_{MSY} - Constant instantaneous fishing mortality rate at MSY.
E_{MSY} - Exploitation rate at MSY.

which may not accurately represent the sablefish stock-recruitment relationship. Strong year classes, which cannot be incorporated into the Beverton-Holt recruitment relationship in the model, can significantly increase yields over a short term.

Although the SRA results show that sustainable yields can be achieved at relatively low levels of biomass, it is unknown how recruitment and production are affected at low levels of biomass. The SRA results show potential long-term yields from the resource based on the growth and recruitment used in the model. In actuality, there is a great deal of uncertainty in the biological parameters used in the model, particularly in the recruitment relationship.

The SRA parameters were input into Schnute's (1985) delay-difference equation and projected forward to provide potential future stock sizes under the different recruitment levels and fishing mortality rates. The level of fishing and the associated yield which maintained the current biomass level was determined. This yield is the annual surplus production (ASP) from the stock.

The projected sablefish biomass levels under the three recruitment levels used in SRA (A = 1.0, 0.889 ,0.750) and fishing mortality rates of 0.03-0.05 are shown in Table 6. A fishing mortality rate of 0.04 approximately maintains the biomass at its current level within 5 years. The exploitation rate, assuming a natural mortality rate of 0.1 and a fishing mortality rate of 0.04, is 3.7%. Applying this exploitation rate to the mean biomass estimate in the eastern Bering Sea (56,500 t) provides an ASP value of 2,100 t. Similarly, applying this exploitation rate to the mean biomass estimate in the Aleutian Islands (96,300 t) provides an ASP value of 3,600 t.

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 estimated maximum sustainable yield (MSY) at 50,300 t for the Bering Sea to California region (Low and Wespestad 1979). This estimate was derived from a general production model. The MSY estimate was apportioned to regions according to historical catches: Bering Sea, 25%; Aleutian Islands, 4%; Gulf of Alaska, 47%; and the British Columbia-Washington region, 25%. Therefore, MSY was estimated at 13,000 t in the Bering Sea and 2,100 t in the Aleutian Islands. Historical CPUE data and biomass trends indicated that MSY was probably overestimated in the Bering Sea and underestimated in the Aleutian Islands by this method. The 13,000 t estimate for the Bering Sea included 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) re-evaluated 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

Table 6. --Projected sablefish biomass using Schnute's (1985) delay-difference equation with the SRA parameters under various recruitment and fishing rate scenarios. Biomass estimates are in thousands of metric tons, A is the Beverton-Holt recruitment coefficient, and year 1 is 1987.

Years of projection	A = 1.0 Fishing mortality rates (F)			A = 0.889 Fishing mortality rates (F)			A = 0.75 Fishing mortality rates (F)		
	0.03	0.04	0.05	0.03	0.04	0.05	0.03	0.04	0.05
1	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8	152.8
5	158.8	153.7	148.8	158.6	153.5	148.7	156.8	151.8	147.0
10	163.1	154.0	145.6	163.4	154.1	145.5	160.5	151.1	142.3

stock has undergone declines. Sustained exploitation at the levels of 69,600 t or 81,878 t would therefore not seem possible.

The MSY estimates from the SRA analysis ranged from 6,600 to 11,700 t for the eastern Bering Sea-Aleutian Islands regions combined. This MSY was apportioned to the eastern Bering Sea and the Aleutian Islands based on percentages of the RPW values in each region from the longline surveys. The MSY thus ranges from 2,983 to 5,288 t in the eastern Bering Sea, and from 3,630 to 6,435 t in the Aleutian Islands.

ACCEPTABLE BIOLOGICAL CATCH

The exploitation rates from SRA at the $F_{0.1}$ level for constant recruitment, and at the MSY level for the lower levels of recruitment, range from 7 to 12%. These rates are considered to be the most reasonable levels of exploitation. Applying these exploitation rates to the mean estimate of 1986 biomass in the eastern Bering Sea (56,500 t) results in a range of acceptable biological catches (ABC) of 3,900-6,800 t for the eastern Bering Sea. Similarly, applying the exploitation rates to the mean estimate of 1986 biomass in the Aleutian Islands (96,300 t) results in a range of ABCs from 6,700 to 11,600 t.

The recommended ABC for the eastern Bering Sea is 3,900 t, and 6,700 t for the Aleutian Islands. The lower bounds rather than the midpoints of the ABC ranges were chosen, given the variability associated with the biological parameters and biomass estimates for sablefish and the recent declines seen in the relative indices from the longline survey.

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 separate Pacific ocean perch stocks--the eastern Bering Sea stock and the Aleutians 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 Fishery Management Council (NPFMC).

Pacific ocean perch were highly sought after by Japanese and Soviet fleets and supported major trawl fisheries throughout the 1960s. These fisheries began in the eastern Bering Sea region in around 1960 and expanded into the Aleutians 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 Aleutians region in 1965 (Table 1). Catches have since declined sharply. In 1986 catches were but a small fraction of the peak levels: 849 and 338 t in the eastern Bering Sea and Aleutians region, respectively.

It is 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 since the 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 regions. 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.

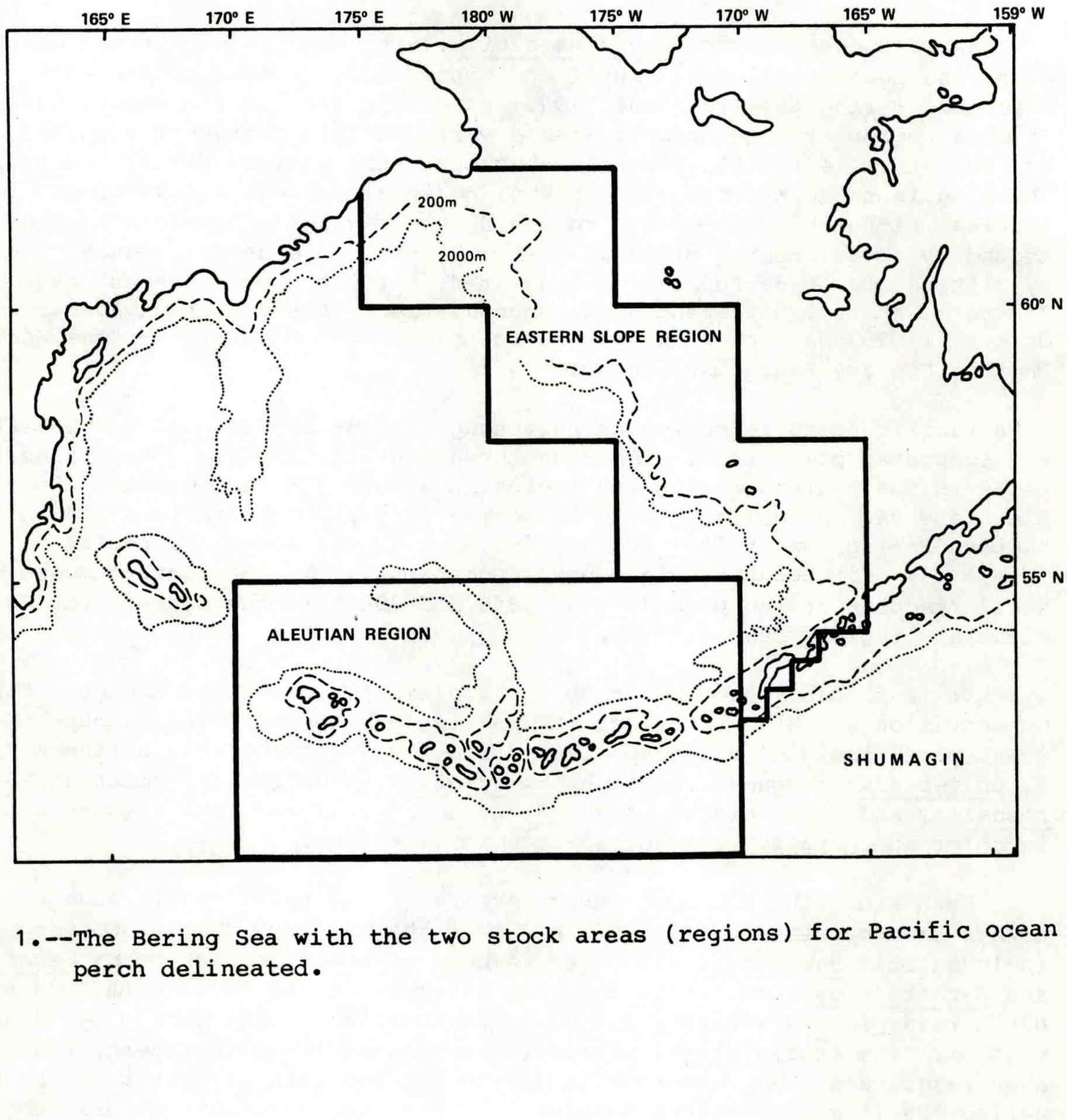


Figure 1.--The Bering Sea with the two stock areas (regions) for Pacific ocean perch delineated.

Table 1.--Catch (in metric tons) of Pacific ocean perch (Sebastes alutus)[a] from the eastern Bering Sea and Aleutian Islands regions, by fishery category, 1960-86[b].

	Eastern Bering Sea				Aleutian Islands			
	Non-U.S.	Domestic			Non-U.S.	Domestic		
Year	fisheries	DAP[c]	JVP[d]	Total	fisheries	DAP	JVP	Total
1960	6,100	--	--	6,100	--	--	--	--
1961	47,000	--	--	47,000	--	--	--	--
1962	19,900	--	--	19,900	200	--	--	200
1963	24,500	--	--	24,500	20,800	--	--	20,800
1964	25,900	--	--	25,900	90,300	--	--	90,300
1965	16,800	--	--	16,800	109,100	--	--	109,100
1966	20,200	--	--	20,200	85,900	--	--	85,900
1967	19,600	--	--	19,600	55,900	--	--	55,900
1968	31,500	--	--	31,500	44,900	--	--	44,900
1969	14,500	--	--	14,500	38,800	--	--	38,800
1970	9,900	--	--	9,900	66,900	--	--	66,900
1971	9,800	--	--	9,800	21,800	--	--	21,800
1972	5,700	--	--	5,700	33,200	--	--	33,200
1973	3,700	--	--	3,700	11,800	--	--	11,800
1974	14,000	--	--	14,000	22,400	--	--	22,400
1975	8,600	--	--	8,600	16,600	--	--	16,600
1976	14,900	--	--	14,900	14,000	--	--	14,000
1977	2,654	--	--	2,654	8,080	--	--	8,080
1978	2,211	--	--	2,211	5,286	--	--	5,286
1979	1,718	--	--	1,718	5,487	--	--	5,487
1980	1,050	--	47	1,097	4,700	--	Tr	4,700
1981	1,221	--	1	1,222	3,618	--	4	3,622
1982	212	9	3	224	1,012	--	2	1,014
1983	116	8	97	221	272	--	8	280
1984	156	1,279	134	1,569	356	2	273	631
1985	35	717	32	784	Tr	93	215	308
1986	16	716	117	849	Tr	178	160	338

[a]The 1960-76 catches may have contained rockfish other than S. alutus; the 1977-86 catches are S. alutus only.
[b]Catch data may differ from earlier status of stocks reports. The data used here, however, are believed to be the most reliable presently available.
[c]Domestic Annual Processing.
[d]Joint Venture Processing.

Sources: 1960-76--Ito (1987); 1977-86 non-U.S. and U.S. joint ventures--Nelson et al. (1980, 1981a, 1981b, 1982, 1983a), Berger et al. (1984, 1985b, 1986, 1987b); 1980-86 U.S. domestic--Pacific Fishery Information Network (PacFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. Fifth Avenue, Portland, OR 97201.

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 1970s, CPUE values had dropped in excess of 90% from those of the early 1960s. Since the late 1970s, these values have declined to (and remain 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 was 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 about 4,500 t in 1979 to 9,800 t in 1981 and then decreased to 5,500 t in 1982 (Table 2). In 1985, this estimate jumped to about 32,400 t and this sixfold increase from 1982 to 1985 raises the question whether the biomass of Pacific ocean perch can be adequately estimated from trawl surveys. The 95% confidence interval about the 1985 point estimate is extremely wide (Fig. 2) and points to the problems of sampling this species. The trawl gear may not adequately sample scattered schools of Pacific ocean perch, 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 (165°W to 170°W) portion of the eastern Bering Sea management area. This area, however, was sampled during the 1980, 1983, and 1986 U.S.-Japan trawl surveys of the Aleutian Islands region which provided biomass estimates of approximately 6,000 t, 97,500 t, and 49,600 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 1980-86 average 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 about 64,100 t.

Cohort and Virtual Population Analyses--Commercial CPUE data have become increasingly difficult to interpret. Standardizing and partitioning total groundfish effort into effort directed solely toward Pacific ocean perch is

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

Year	Mean estimates*: Population numbers (millions)	Mean estimates*: 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

*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).

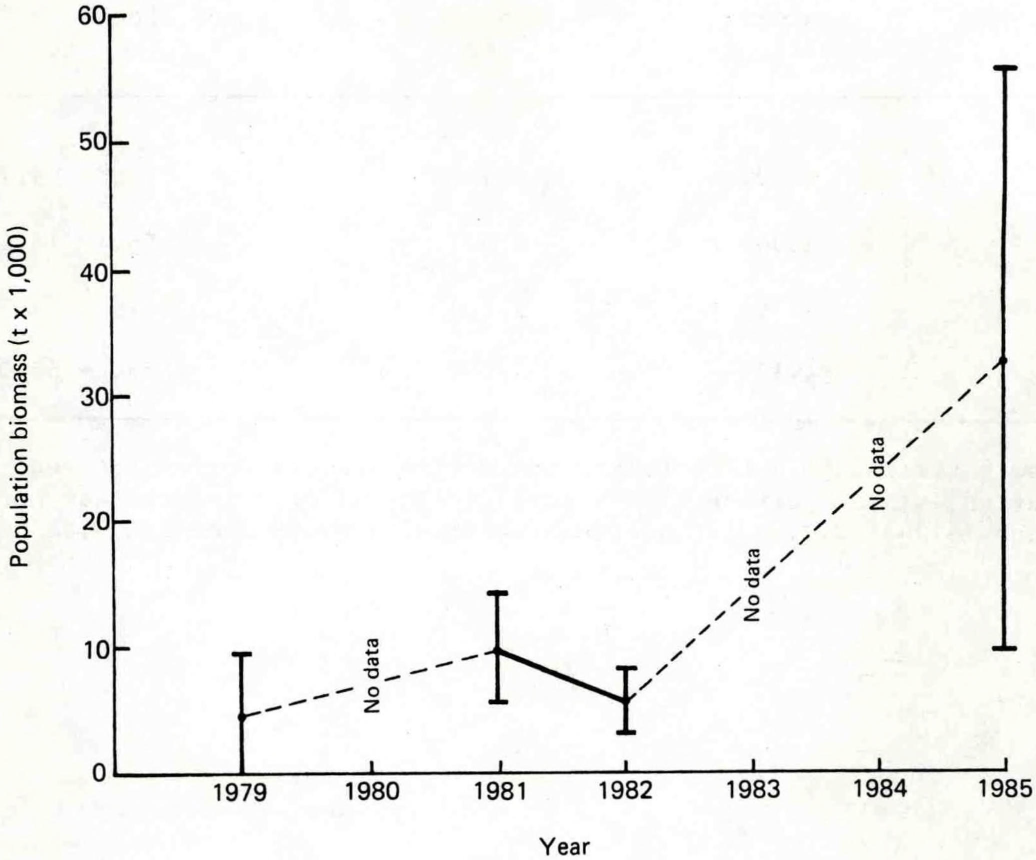


Figure 2.--Biomass estimates and 95% confidence intervals for Sebastes alutus along the continental slope of the eastern Bering Sea as shown by U.S.-Japan cooperative bottom trawl surveys, using Japanese data only.

extremely 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 commercial CPUE and trawl survey stock assessments is cohort and virtual population analyses (VPA). Cohort and VPA techniques have been developed to circumvent the need for reliable effort statistics and to describe stock changes in terms of absolute values rather than as an index. These techniques estimate past population numbers at age and age-specific rates of instantaneous fishing mortality.

Cohort and virtual population analyses were applied to the eastern Bering Sea Pacific ocean perch stock to examine trends in absolute abundance (Ito 1982; Balsiger et al. 1985). The results of these analyses indicate that the eastern Bering Sea Pacific ocean perch stock underwent a sharp decline in abundance after the onset and during the period of heavy foreign fishing. Depending on the parameters selected for the analyses, the results indicate that stock biomass may have declined 60-99% during the 16-year period from 1963 to 1979.

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)--Stock reduction analysis (Kimura and Tagart 1982; Kimura et al. 1984; Kimura 1985; Kimura, In press) was employed to examine trends in biomass and potential long-term production. This assessment technique, which incorporates Schnute's (1985) version of the delay-difference equation, is a biomass-based method of stock assessment that links the exponential form of the catch equations when age data are insufficient or unavailable. The input requirements for the SRA model used in the present analysis includes: catch data (in biomass), an estimate of instantaneous natural mortality (M), the delay-difference growth coefficients (RHO, OMEGA), the age at recruitment (k), the Beverton-Holt recruitment coefficient (A), (Kimura, In press) and an estimate of current biomass.

Catch data used in the SRA model spanned the period from 1960 to 1986 (Table 1). It was assumed that the stock was at or close to its virgin biomass level in 1960 when the catch statistics started. The natural mortality rate of M = 0.05 from Archibald et al. (1981) was employed, as this parameter was consistent with the older ages derived from sectioned and break and burn otoliths. The delay-difference growth coefficients (RHO = 0.936 and OMEGA = 0.820) were estimated based on weight-at-age data from Chikuni (1975). The age of recruitment has varied with time and is related to a variety of factors such as growth, fishing mortality, year-class strength, and year-to-year variations in availability. For purposes of this study, however, it was assumed that the age at recruitment was k = 9 years.

Two recruitment scenarios were used in the current SRA approach. The first scenario employed constant recruitment (i.e., a Beverton-Holt coefficient of A = 1.0). When A = 1.0, recruitment is constant and the population is highly resilient; that is, no matter what the population size is at the end of any year, a constant number of fish will recruit to the stock at the beginning of the next year. The second recruitment scenario was based on a Beverton-Holt causal stock-recruitment relationship (A = 0.889). Under this scenario, recruitment was structured so that 90% of virgin recruitment occurred when the stock was reduced to 50% of its virgin biomass level.

An estimate of current biomass is also needed with the SRA approach used in this study. The mean of the 1979-85 eastern Bering Sea slope biomass estimates and the mean biomass from the 1980-86 Aleutian Islands portion of the eastern Bering Sea were summed and used to tune the SRA analysis. This estimate of biomass was 64,100 t.

The SRA results indicate that virgin biomass in the eastern Bering Sea region ranged from 247,800 to 266,600 t and that this stock is now at about 24-26% of virgin levels (Fig. 3). The biomass trace from SRA indicates that the stock underwent a sharp decline in abundance throughout the 1960s and the early 1970s. Since 1977, however, the SRA results indicate that the eastern Bering Sea stock has been increasing. This increase may be due in part to the North Pacific Fishery Management Council's efforts to rebuild this resource by reducing Pacific ocean perch harvests through quota management.

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. 4). 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 1960s and 1970s. 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. As in the eastern Bering Sea region, more recent CPUE data may not be a good index of stock abundance because much of the trawl effort was directed to species other than Pacific ocean perch.

Estimates of Absolute Abundance

Trawl Surveys--During the summer-fall of 1980, 1983, and 1986, 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

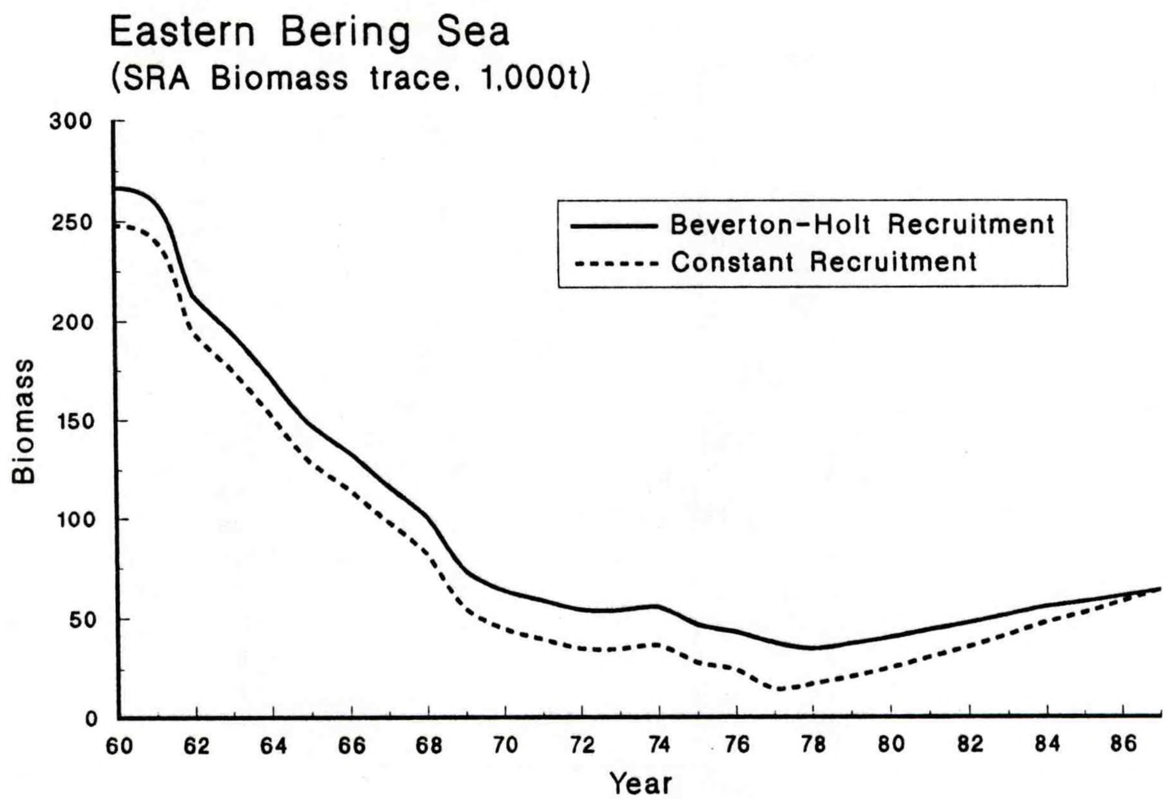


Figure 3.--Estimated population biomass of Pacific ocean perch from the eastern Bering Sea region, based on stock reduction analysis (SRA) with two recruitment scenarios.

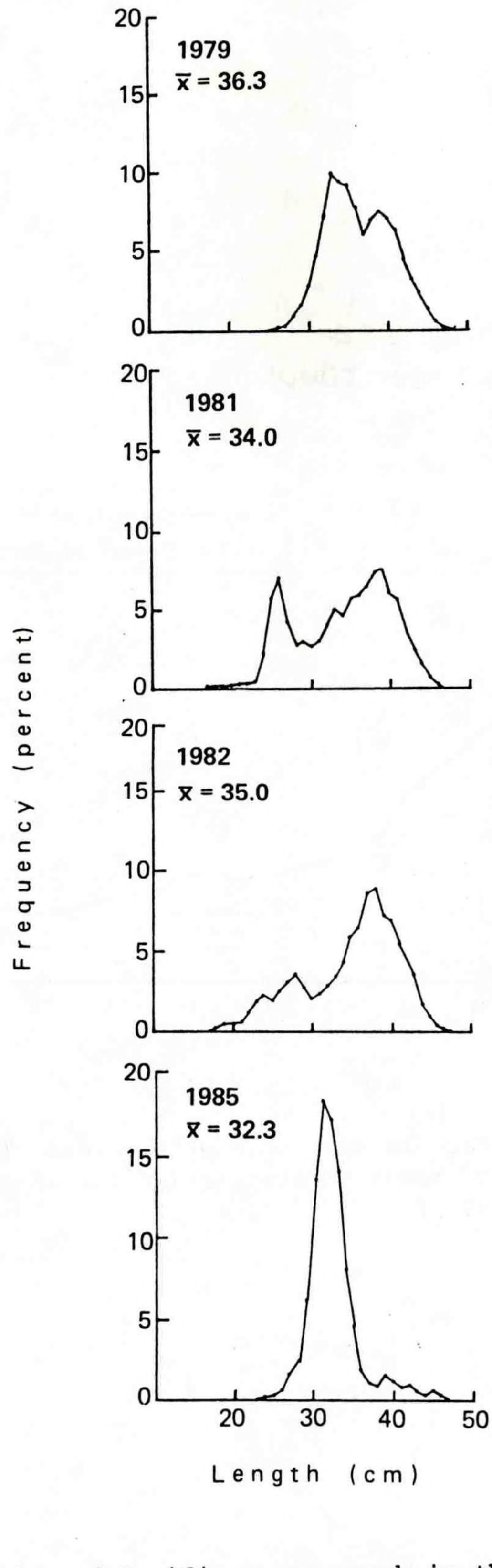


Figure 4.--Size composition of Pacific ocean perch in the eastern Bering Sea as shown by data collected during the cooperative U.S.-Japan demersal trawl surveys in 1979, 1981, 1982, and 1985.

first comprehensive resource assessment surveys of groundfish in the Aleutian Islands region.

The exploitable biomass of Pacific ocean perch in the Aleutian Islands region (170°E to 170°W) was estimated at about 109,000 t in 1980 and increased to 144,100 t in 1983 and 220,600 t in 1986. Although there appears to be an increasing trend in biomass, the overlapping confidence intervals between the point estimates (Fig. 5) indicate that these estimates may not be statistically different.

Cohort and Virtual Population Analyses--Cohort and virtual population analyses were applied to the Aleutian Islands Pacific ocean perch stock to examine trends in absolute abundance (Ito 1982; Balsiger et al. 1985). Similar to the results from the eastern Bering Sea analyses, the Aleutian Islands stock apparently underwent a sharp decline in abundance after the onset and during the period of heavy Japanese and U.S.S.R. fishing. Depending on the parameters selected for the analyses, the results indicate that stock biomass may have declined 77-98% from 1964 to 1979. These trends closely parallel the cohort and VPA results from the eastern Bering Sea analyses.

Stock Reduction Analysis (SRA)--The same SRA methodology and parameters used for the eastern Bering Sea stock were applied to the Aleutian stock; the only difference was the estimate of current biomass used to tune the SRA model. The estimate of current biomass was taken as the mean of the 1980, 1983, and 1986 survey point estimates--157,900 t.

The SRA results indicate that virgin biomass in the Aleutian region ranged from 565,000 t to 606,000 t and that this stock is now at about 26-28% of virgin levels (Fig. 6). The biomass trace from SRA shows that the stock underwent a sharp decline in abundance throughout the 1960s and early 1970s. Since 1977, however, the SRA results indicate that the stock has been increasing. These trends parallel the SRA results from the eastern Bering Sea analyses. In light of the North Pacific Fishery Management Council's goal of rebuilding the Pacific ocean perch resource, the recent increasing trend in abundance is encouraging. It suggests that the council's current management practices of restricting harvests are appropriate.

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 7). 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 during the 1980, 1983, and 1986 Aleutian Islands surveys, it appears that one or more strong year classes have entered the population (Fig. 8). The mean size dropped from 31.2 cm in 1980 to 29.5 cm in 1983 and then increased to 32.8 cm in 1986. A shift in the dominant length

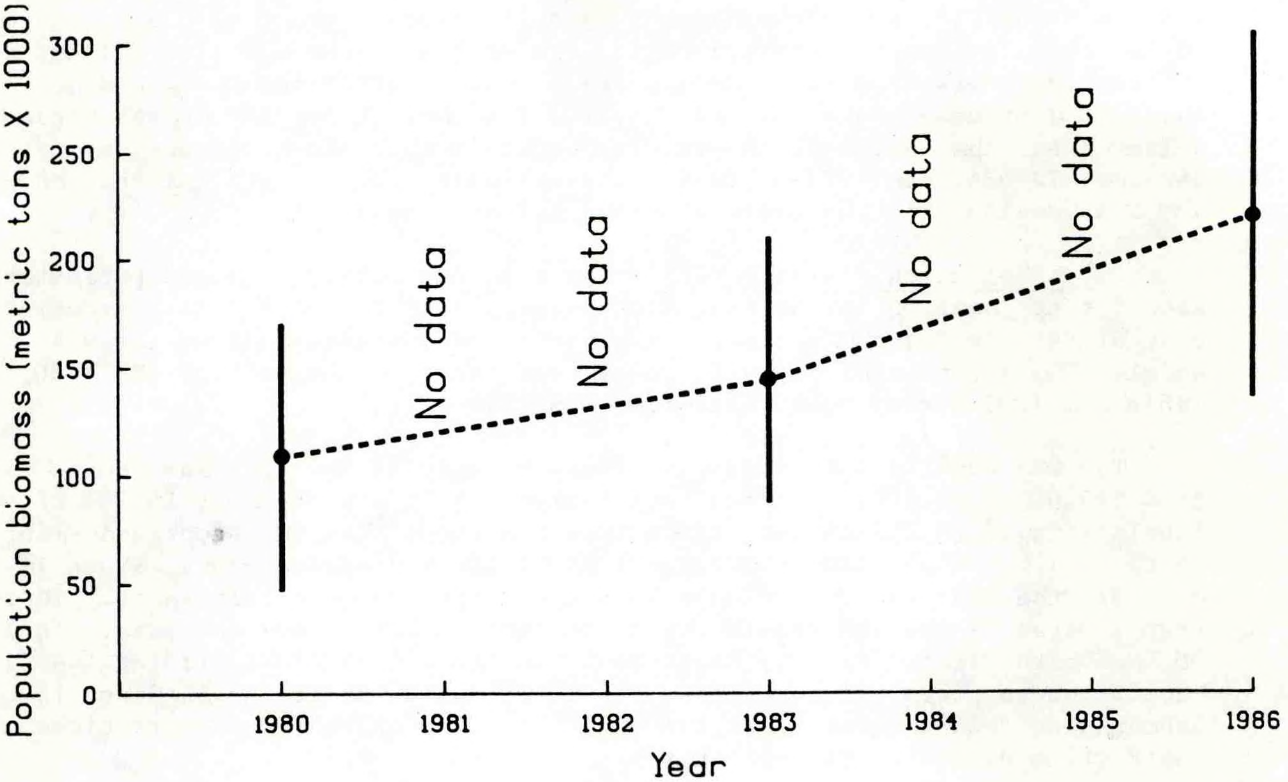


Figure 5.--Biomass estimates and 95% confidence intervals for Pacific ocean perch in the Aleutian Islands region as shown by U.S.-Japan cooperative bottom trawl surveys.

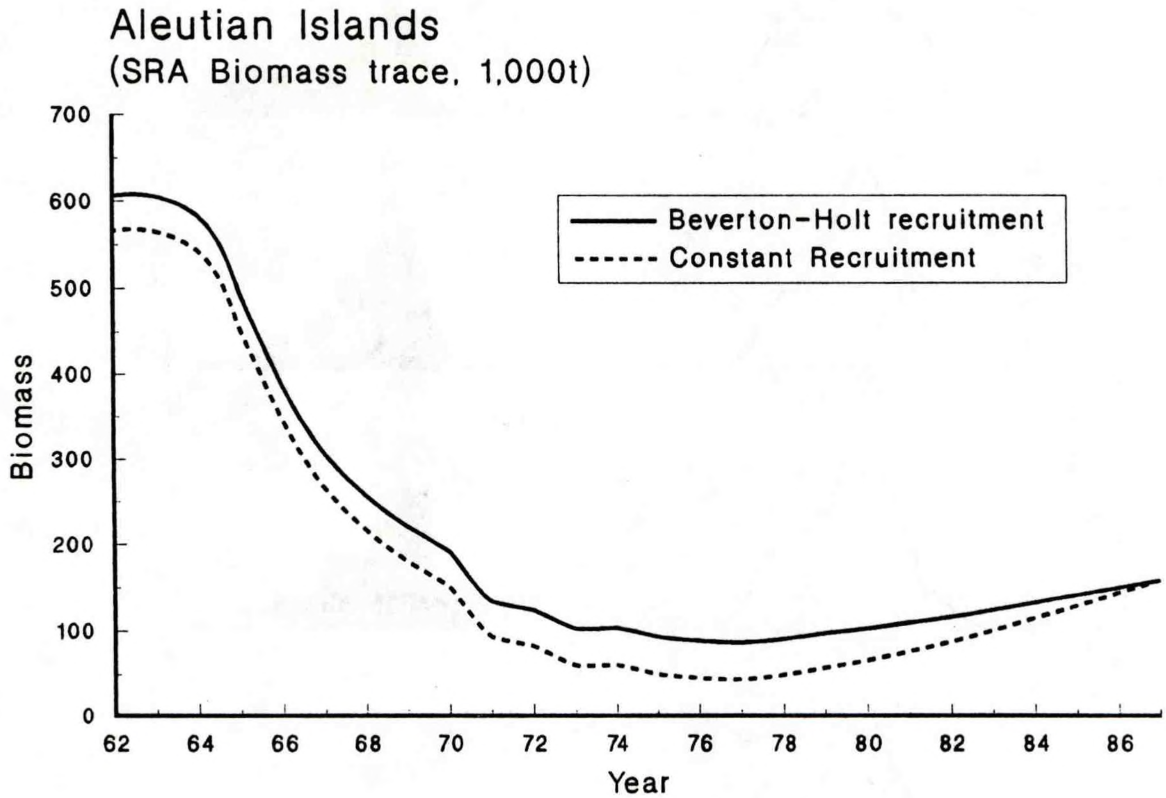


Figure 6.--Estimated population biomass of Pacific ocean perch from the Aleutian Islands region, based on stock reduction analysis (SRA) with two recruitment scenarios.

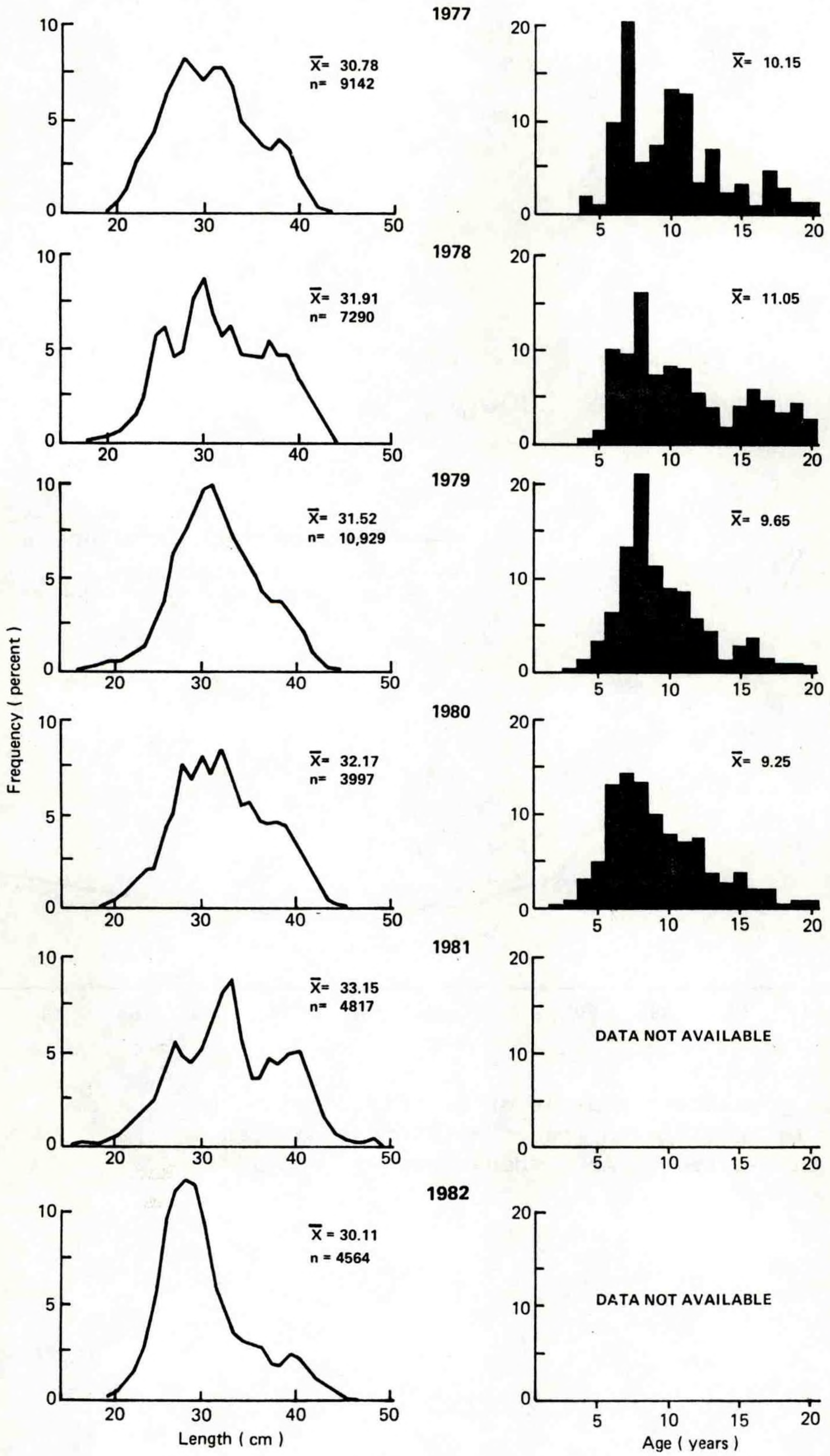


Figure 7.--Length and age composition of Pacific ocean perch in the Aleutian region as shown by data taken by U.S. observers from catches aboard Japanese small stern trawlers, 1977-82.

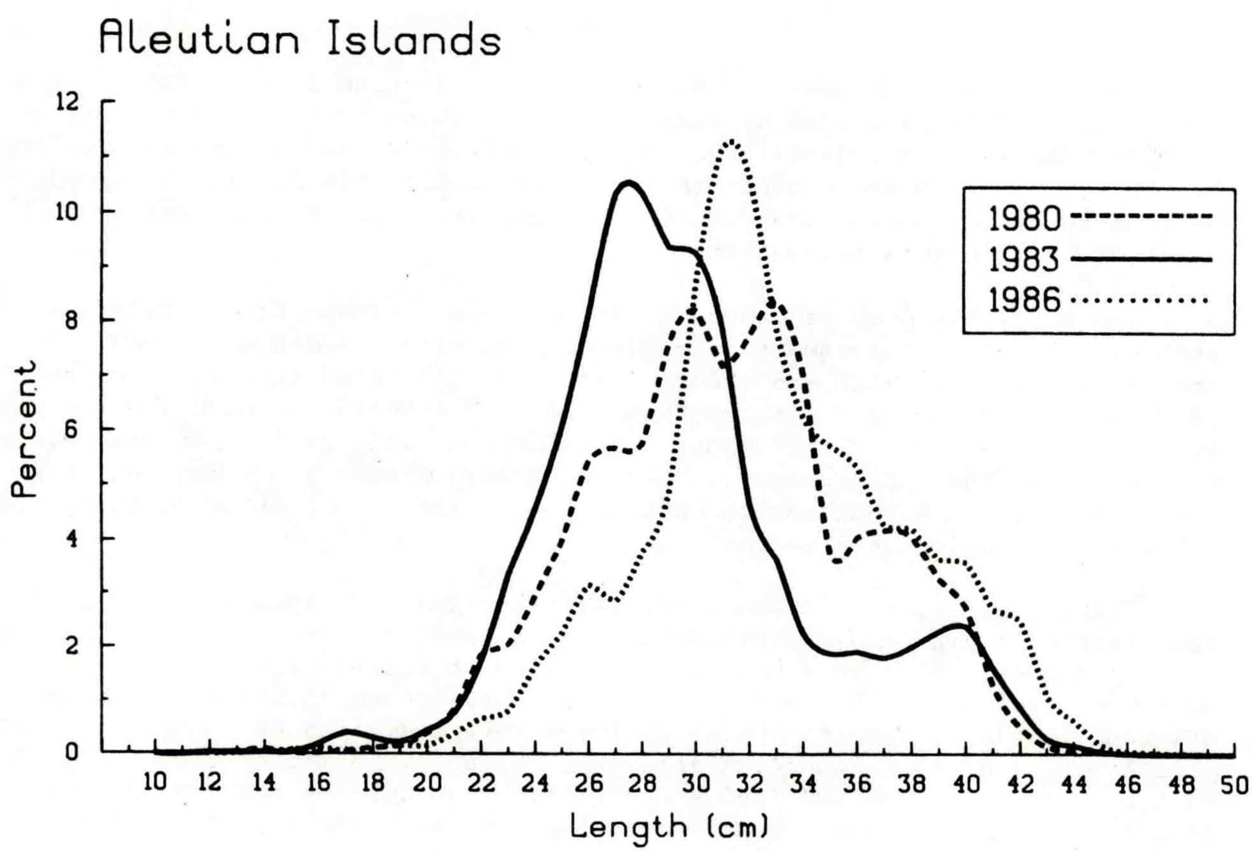


Figure 8.--Size composition of Pacific ocean perch in the Aleutian Islands as shown by data collected during the cooperative U.S.-Japan demersal trawl surveys in 1980, 1983, and 1986.

frequency mode was evident based on the last two surveys. The dominant mode shifted from 27-28 cm in 1983 to 32 cm in 1986.

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. 9). 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. Otoliths were collected during the 1986 Aleutian survey; however, the ages were not available for analysis at the time of this writing.

Condition of Stocks Summary

In this report the eastern Bering Sea and Aleutian Islands Pacific ocean perch stocks were evaluated by examining the results from 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 from commercial fishery catch and effort statistics indicated that Pacific ocean perch stocks in both the eastern Bering Sea and Aleutian Islands regions underwent sizable reductions throughout the 1960s and early 1970s. As previously mentioned, however, the use of CPUE data in more recent years may not be a good index of stock abundance. 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 the three models show that both stocks underwent sizable reductions in abundance from the 1960s to the mid-1970s. Reductions in biomass of 60 to 98% from levels present in the early 1960s were indicated by cohort, virtual population, and stock reduction analyses. Recent information from the 1985 eastern Bering Sea and the 1983 and 1986 Aleutian Islands surveys, however, indicate increased abundance and recruitment to both stocks. This is an encouraging sign and may indicate that the stocks are in the process of rebuilding.

MAXIMUM SUSTAINABLE YIELD

Estimates of maximum sustainable yield (MSY) from SRA ranged from about 4,400 to 5,900 t for the eastern Bering Sea stock and 9,900 to 13,400 t for the Aleutian stock (Table 3, Fig. 10), depending on the recruitment scenario employed. The biomass producing the eastern Bering Sea MSY levels ranged from approximately 40,600 to 77,000 t. For the Aleutian stock the biomass at MSY ranged from 92,600 to 175,100 t.

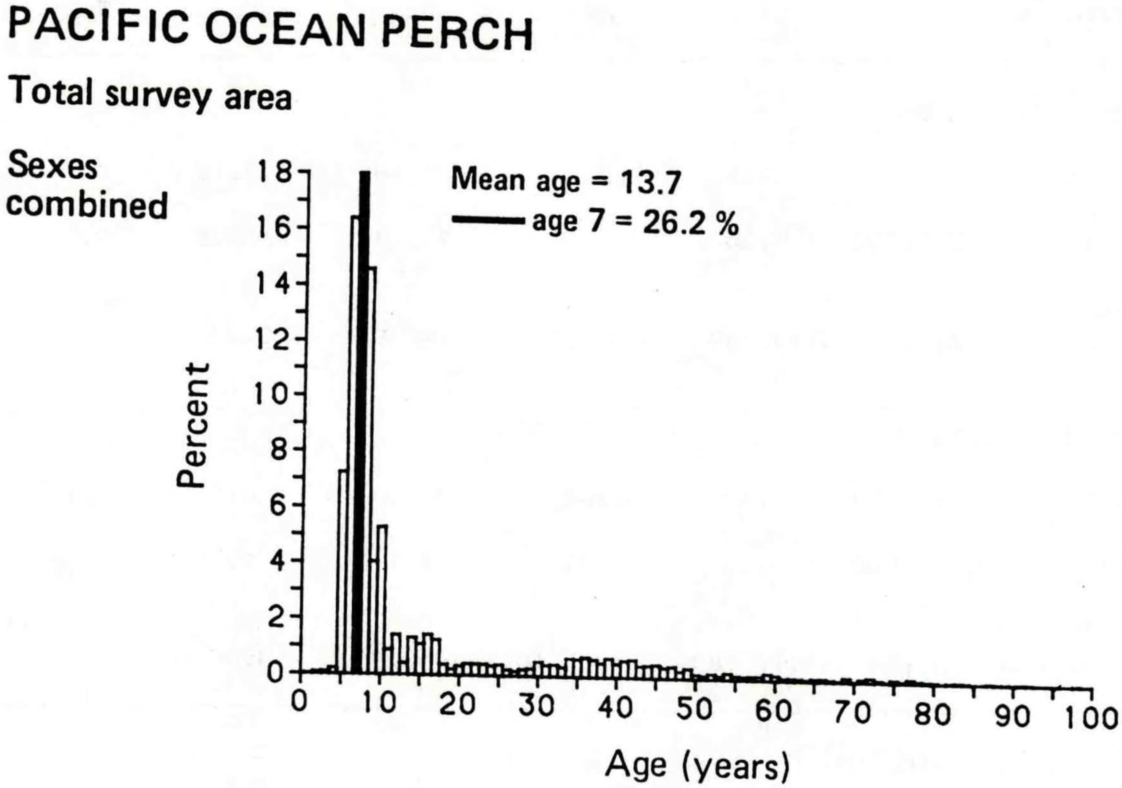


Figure 9.--Age composition of the Pacific ocean perch population in the Aleutian Islands as shown by data collected during the cooperative U.S.-Japan demersal trawl survey in 1983.

Table 3.--Results of stock reduction analysis for the eastern Bering Sea and Aleutian Islands populations of Pacific ocean perch assuming a Beverton-Holt stock recruitment relationship.

Recruitment coefficient	B_1	P	MSY	B_{msy}	F_{msy}	E_{msy}
Eastern Bering Sea						
A=1.000	247,800	0.26	5,857	40,582	0.16	0.14
A=0.889	266,600	0.24	4,377	77,032	0.06	0.06
A=1.000 Constrained ($F_{0.1}$):		EY=5,180	EB=91,167	F=0.06	E=0.06	
Aleutian Islands						
A=1.000	565,700	0.28	13,369	92,636	0.16	0.14
A=0.889	606,000	0.26	9,950	175,113	0.06	0.06
A=1.000 Constrained ($F_{0.1}$):		EY=11,183	EB=208,106	F=0.06	E=0.06	

B_1 - Virgin Biomass.
P - $B_{current}/B_1$.
MSY - Maximum Sustainable Yield.
B_{msy} - Biomass which produces MSY.
F_{msy} - Instantaneous Fishing Mortality Rate at MSY.
E_{msy} - Exploitation Rate at MSY.
EY - Equilibrium Yield.
EB - Equilibrium Biomass.
F - Instantaneous Fishing Mortality Rate.
E - Exploitation Rate.

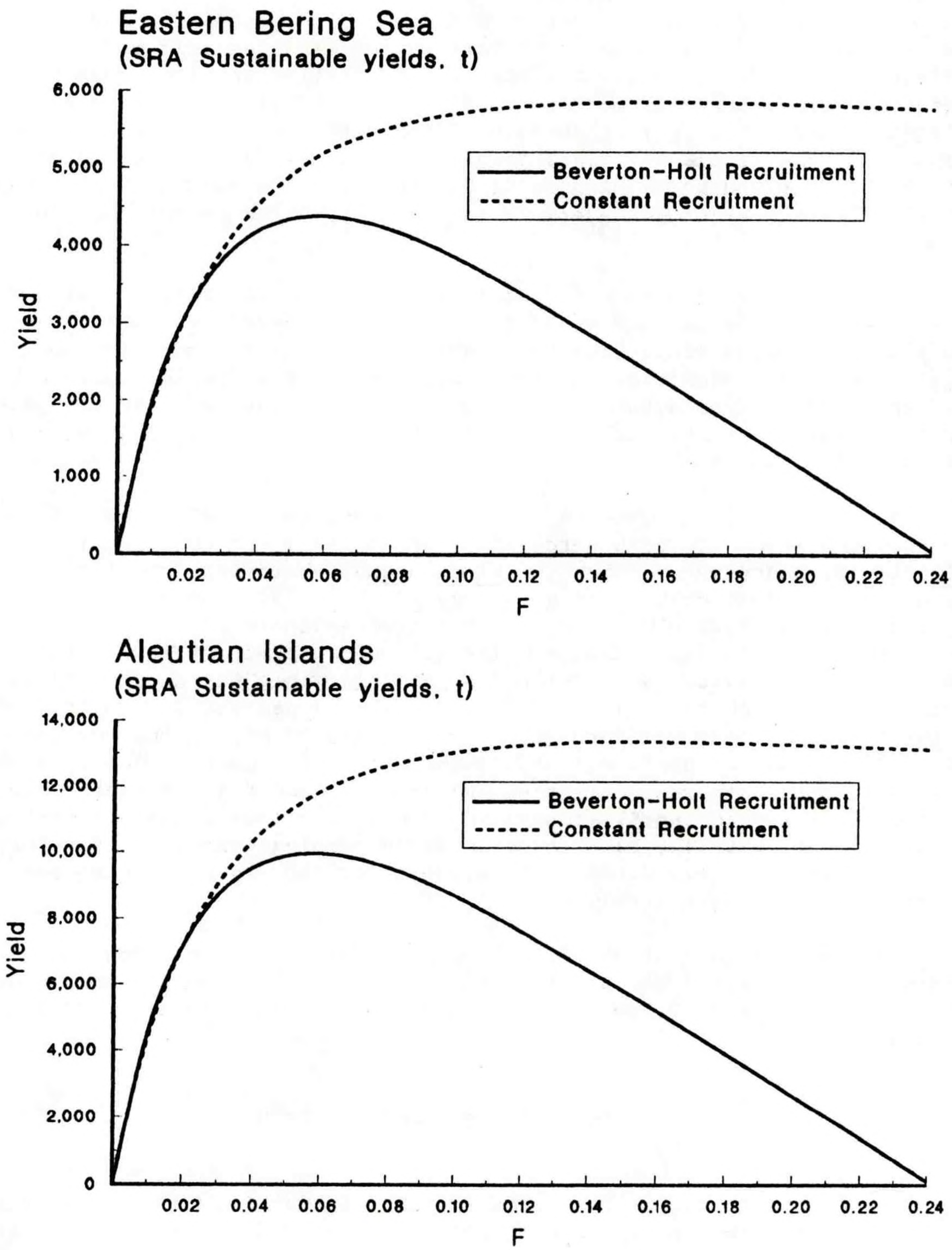


Figure 10.--Estimates of equilibrium yield for Pacific ocean perch in the eastern Bering Sea and Aleutian Islands regions based on results from stock reduction analysis (SRA) with two recruitment scenarios.

The high estimates of MSY were based on the assumption of constant recruitment (i.e., A = 1.0). That is, recruitment to the fishable biomass will be the same year after year regardless of the population size. As such, the estimate of MSY based on a constant recruitment scenario may be overly optimistic. A more conservative approach for estimating long-term production under this type of recruitment is to determine the yield under an $F_{0.1}$ policy. Using this approach, $F_{0.1}$ is about 0.06 for both the eastern Bering Sea and Aleutian stocks (Table 3). This translates into a long-term equilibrium yield (EY) of 5,200 t and an EY biomass of 91,200 t for the eastern Bering Sea stock. For the Aleutian stock long-term EY is 11,200 t, which corresponds to an EY biomass of 208,100 t.

The best point estimate of MSY for each stock was taken as the midpoint of the range of the maximum yield from the Beverton-Holt recruitment scenario and the equilibrium yield from the constant recruitment scenario under an $F_{0.1}$ policy. To summarize, the best estimates of MSY for the eastern Bering Sea stock ranged from 4,400 t to 5,200 t, with a point estimate of 4,800 t. For the Aleutian stock, the MSY ranged from 9,900 t to 11,200 t, with a point estimate of 10,600 t.

In practice, Pacific ocean perch is managed as a complex comprising five species--Pacific ocean perch (S. alutus), northern rockfish (S. polyspinis), rougheye rockfish (S. aleutianus), shortraker rockfish (S. borealis), and sharpchin rockfish (S. zacentrus). Because SRA could not be applied to these four other species, a direct estimate of MSY for the Pacific ocean perch complex (excluding S. alutus) could not be obtained. A first approximation, however, was obtained by assuming that the production of the Pacific ocean perch complex (excluding S. alutus) was similar to that of S. alutus. The ratio of the current point estimate of MSY to the current estimate of biomass for S. alutus was about 0.07 for both regions. This ratio was applied to the current estimate of biomass for the Pacific ocean perch complex (excluding S. alutus) in each region (see below) to arrive at an estimate of MSY. The Pacific ocean perch complex (excluding S. alutus) MSY values were roughly 2,600 t and 8,300 t for the eastern Bering Sea and Aleutian stocks, respectively.

The best estimate of MSY for the entire Pacific ocean perch complex (all five species combined) amounts to 7,400 t (4,800 t + 2,600 t) for the eastern Bering Sea stock and 18,900 t (10,600 t + 8,300 t) for the Aleutian Islands stock (Table 4).

ACCEPTABLE BIOLOGICAL CATCH

A range of acceptable biological catches (ABCs) for both stocks were estimated by multiplying the exploitation rate at MSY by the current estimate of biomass. The exploitation rates for both stocks under constant and Beverton-Holt recruitment were 0.14 and 0.06, respectively. Current biomass was estimated at about 64,100 t for the eastern Bering Sea stock and 157,900 t for the Aleutian stock. Applying the above approach, ABC estimates ranged from 3,800-9,000 t for the eastern Bering Sea stock and 9,500-22,100 t for the Aleutian stock. The high estimates of ABC were based on the constant recruitment scenario with an exploitation rate of 0.14.

Table 4.--Best estimates of current biomass, maximum sustainable yield (MSY), and acceptable biological catch (ABC) in thousands of metric tons for the Pacific ocean perch complex in the eastern Bering Sea/Aleutian Islands region.

Region	Estimated biomass	MSY	ABC
Eastern Bering Sea			
Pacific ocean perch complex	101.1	7.4	6.0
(Pacific ocean perch *Sebastes alutus*)	(64.1)	(4.8)	(3.8)
(Other species in complex)	(37.0)	(2.6)	(2.2)
Aleutian Islands			
Pacific ocean perch complex	276.5	18.9	16.6
(Pacific ocean perch *S. alutus*)	(157.9)	(10.6)	(9.5)
(Other species in complex)	(118.6)	(8.3)	(7.1)

A conservative and perhaps best approach for estimating ABC is to employ the MSY exploitation rate under the Beverton-Holt recruitment scenario or the exploitation rate under the constant recruitment $F_{0.1}$ policy. Both approaches yield exploitation rates of about 0.06. This exploitation rate produces ABCs for Pacific ocean perch in the eastern Bering Sea and Aleutian regions of 3,800 t (0.06 x 64,100 t) and 9,500 t (0.06 x 157,900 t), respectively.

As previously mentioned, Pacific ocean perch is managed as a complex of five species. From the 1979-85 eastern Bering Sea slope surveys, the mean estimated biomass of the Pacific ocean perch complex (excluding *S. alutus*) was 4,600 t. For the Aleutian Islands portion of the eastern Bering Sea region, the 1980-86 surveys provide a mean biomass estimate of 32,400 t. Therefore, the best estimate of current biomass for the Pacific ocean perch complex (excluding *S. alutus*) in the entire eastern Bering Sea region is about 37,000 t (4,600 + 32,400 t). The 1980-86 Aleutian Islands surveys provided a mean biomass for the Pacific ocean perch complex (excluding *S. alutus*) in the total Aleutian area of 118,600 t.

The ABC estimates for the other four species in the Pacific ocean perch complex were estimated by multiplying the appropriate exploitation rate (0.06, see above) by the estimates of current biomass (Table 4). For the eastern Bering Sea region the estimate of ABC for the Pacific ocean perch complex (excluding *S. alutus*) was estimated at 2,200 t; and for the Aleutian Islands region this estimate amounted to 7,100 t.

Under the assumption that 0.06 is the most appropriate exploitation rate for estimating ABC, the estimates of ABC for the Pacific ocean perch complex (all five species combined) totaled 6,000 t (3,800 t + 2,200 t) for the eastern Bering Sea region and 16,600 t (9,500 + 7,100 t) for the Aleutians (Table 4).

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 non-U.S. fisheries in the Bering Sea-Aleutian Islands region. Toward the end of that period, however, catches had declined sharply. The catch in 1976 was roughly only one-quarter the catch in peak year 1965. Catches were variously reported as a single category (Pacific ocean perch, Sebastes alutus--by far the most abundant species) or as two categories (Pacific ocean perch and "other rockfish"). It is probable that under either system, the reported catches of Pacific ocean perch included other species of rockfish--particularly northern rockfish, S. polyspinis; rougheye rockfish, S. aleutianus; shortaker rockfish, S. borealis; and sharpchin rockfish, S. 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 U.S. observers aboard non-U.S. fishing vessels, that catch and effort data have become available for individual species of rockfish, thus making it possible for the North Pacific Fishery Management Council (NPFMC) to manage species or groups of species separately.

Even with the 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 "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 were placed in the separate category "other rockfish."

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 1977-86 estimated catches of all rockfish from the eastern Bering Sea and Aleutian Islands regions are listed in Tables 2 and 3, respectively.

Table 1.--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 non-U.S. and U.S. joint venture fishing vessels, 1977-86.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Non-U.S. fisheries										
POP[a] complex:	4,021	11,759	9,707	1,946	2,000	788	332	339	77	32
Pacific ocean perch	2,654	2,211	1,718	1,050	1,221	212	116	156	35	16
Northern rockfish	322	119	126	58	31	68	10	19	5	6
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99	16	8
Sharpchin rockfish	--	--	6	3	4	4	tr[b]	0	0	0
Shortraker rockfish	1	8,792	2,726	652	444	354	148	65	21	2
Other rockfish	311	2,607	2,059	456	332	262	212	123	37	4
Subtotal	4,332	14,366	11,766	2,402	2,332	1,050	544	462	114	36
U.S. Joint ventures										
POP complex:	--	--	--	59	1	17	121	147	34	156
Pacific ocean perch	--	--	--	47	1	3	97	134	32	117
Northern rockfish	--	--	--	11	0	2	24	13	2	36
Rougheye rockfish	--	--	--	tr	0	tr	tr	tr	tr	1
Sharpchin rockfish	--	--	--	1	0	0	0	0	0	0
Shortraker rockfish	--	--	--	0	0	12	tr	tr	tr	2
Other rockfish	--	--	--	3	0	6	8	8	1	12
Subtotal	--	--	--	62	1	23	129	155	35	168
Combined										
POP complex:	4,021	11,759	9,707	2,005	2,001	805	453	486	111	188
Pacific ocean perch	2,654	2,211	1,718	1,097	1,222	215	213	290	67	133
Northern rockfish	322	119	126	69	31	70	34	32	7	42
Rougheye rockfish	1,044	637	5,131	183	300	150	58	99	16	9
Sharpchin rockfish	--	--	6	4	4	4	tr	0	0	0
Shortraker rockfish	1	8,792	2,726	652	444	366	148	65	21	4
Other rockfish	311	2,607	2,059	459	332	273	220	131	38	16
Grand Total	4,332	14,366	11,766	2,464	2,333	1,078	673	617	149	204

[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 non-U.S. and U.S. joint venture fishing vessels, 1977-86.

	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Non-U.S. fisheries										
POP[a] complex:	14,625	13,102	15,513	5,645	4,684	1,690	371	414	2	tr
Pacific ocean perch	8,080	5,286	5,487	4,700	3,618	1,012	272	356	tr	tr
Northern rockfish	5,311	3,782	997	374	138	193	28	12	tr	tr
Rougheye rockfish	1,128	2,938	4,538	469	477	159	22	19	tr	tr
Sharpchin rockfish	3	1	73	tr[b]	tr	14	1	0	0	0
Shortraker rockfish	103	1,095	4,418	102	451	312	48	27	1	0
Other rockfish	3,042	921	4,517	416	328	2,114	1,041	42	2	tr
Subtotal	17,667	14,023	20,030	6,061	5,012	3,804	1,412	456	4	tr
U.S. Joint ventures										
POP complex:	--	--	--	tr	7	2	11	451	420	362
Pacific ocean perch	--	--	--	tr	4	2	8	273	215	160
Northern rockfish	--	--	--	0	2	0	tr	173	196	200
Rougheye rockfish	--	--	--	0	1	0	2	5	9	2
Sharpchin rockfish	--	--	--	0	0	0	tr	0	0	0
Shortraker rockfish	--	--	--	0	0	0	1	tr	tr	tr
Other rockfish	--	--	--	0	0	0	4	14	8	15
Subtotal	--	--	--	tr	7	2	15	465	428	377
Combined										
POP complex:	14,625	13,102	15,513	5,645	4,691	1,692	382	865	422	362
Pacific ocean perch	8,080	5,286	5,487	4,700	3,622	1,014	280	629	215	160
Northern rockfish	5,311	3,782	997	374	140	193	28	185	196	200
Rougheye rockfish	1,128	2,938	4,538	469	478	159	24	24	9	2
Sharpchin rockfish	3	1	73	tr	tr	14	1	0	0	0
Shortraker rockfish	103	1,095	4,418	102	451	312	49	27	1	tr
Other rockfish	3,042	921	4,517	416	328	2,114	1,045	56	10	15
Grand Total	17,667	14,023	20,030	6,061	5,019	3,806	1,427	921	431	377

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

These catches were separated into two major rockfish categories, Pacific ocean perch complex and "other rockfish." Catches of "other rockfish," by individual species, are presented in Tables 4 and 5 for the eastern Bering Sea and Aleutian Islands regions, respectively.

Total rockfish catches by non-U.S. and U.S. 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. In 1986, total rockfish catches increased to 204 t, due mainly to the increase in joint venture catches. The "other rockfish" catches follow this trend, peaking in 1978 at about 2,600 t and then dropping to an all time low of 16 t in 1986 (Table 4). The average catch of "other rockfish" during the period of observer coverage was 645 t and averaged only about 17% of the total rockfish catch during this period.

Shortspine thornyheads, *Sebastolobus alascanus*, have consistently dominated the "other rockfish" catches in the eastern Bering Sea (Table 4). This species alone composed over 80% of the "other rockfish" catch from 1977 to 1985. Darkblotched rockfish, *Sebastes crameri*; dusky rockfish, *Sebastes ciliatus*; and redstripe rockfish, *Sebastes proriger*, have also made up significant portions of the "other rockfish" catch during the past 10 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 377 t in 1986. The catches of "other rockfish" averaged 1,246 t during the period from 1977 to 1986 (Table 5). 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.

BIOMASS ESTIMATES

Data from the 1979-86 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.

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, 1983, and 1986 cooperative U.S.-Japan surveys of the Aleutian region indicated an average of about 2,659 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 165°W and 170°W). Thus, an overall estimate for the eastern

Table 4.--Catches (t) of "other rockfish" in the eastern Bering Sea groundfish fishery, 1977-86.[a]

Common name	Non-U.S. fishery										U.S. joint venture fishery						
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1980	1981	1982	1983	1984	1985	1986
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	0.3						tr	tr
Dusky rockfish	3.1	56.5	92.4	18.9	13.7	13.9	4.8	18.1	6.5	2.8	1.2	tr	1.3	6.6	5.1	0.5	10.5
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	0.1			4.6		1.2	0.1	0.7
Shortspine thornyhead	292.2	2,288.8	1,585.6	389.2	195.9	219.4	178.4	91.4	28.6	1.1			4.9	0.3	0.4	0.3	
Silvergray rockfish		0.8								0.1							
Splitnose rockfish						4.8	10.6										tr
Misc. rockfish	12.0	149.3	247.3	1.3	3.1	3.7	3.9	3.5	0.8	tr	1.4	—	tr[b]	0.5	1.7	0.3	0.3
Total	310.9	2,614.4	2,108.4	456.4	331.3	261.8	212.0	121.4	36.9	4.4	2.6	tr	10.8	8.4	8.4	1.2	11.5

[a]Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a; Berger et al. 1984, 1985b, 1986, 1987b.
[b]tr = trace amounts.

Table 5.--Catches (t) of "other rockfish" in the Aleutian Islands groundfish fishery, 1977-86.[a]

Common name	Non-U.S. fishery										U.S. joint venture fishery						
	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1980	1981	1982	1983	1984	1985	1986
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								7.0
Dusky rockfish	2,932.9	11.3	54.8	2.8	10.6	3.8	1.0	2.6	0.3	tr		tr[b]		0.9	8.3	8.2	6.8
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	1.4
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	—	tr	—	—	5.0	0.2	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	tr	0.0	4.3	14.1	8.5	15.4

[a]Data sources: Nelson et al. 1980, 1981a, 1981b, 1982, 1983a; Berger et al. 1984, 1985b, 1986, 1987b.
[b]tr = trace amounts.

Bering Sea region, based on the mean of the 1980-86 Aleutian estimates and the mean of the 1979-85 eastern Bering Sea survey data, is 7,092 t.

Biomass estimates of "other rockfish" from the 1980, 1983, and 1986 U.S.-Japan cooperative trawl surveys of the Aleutian Islands region indicate a decrease from 19,078 t in 1980 to 15,995 t in 1983. Based on the 1986 survey, the biomass increased to 20,336 t. 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 (18,470 t) indicates a much larger biomass than that found in the eastern Bering Sea.

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 direct estimate of maximum sustainable yield (MSY) for the "other rockfish" stocks in the eastern Bering Sea or Aleutian Islands regions. However, if one assumes that the exploitation and productivity patterns of the "other rockfish" group is similar to that of the POP complex, one can arrive at a gross approximation of MSY. The same conversion ratio (0.07) used to estimate the MSY for the four other species in the POP complex (refer to the MSY section in the POP section of this report) was applied to the current biomass estimates of "other rockfish." This procedure yielded estimates of MSY of about 500 t for the eastern Bering Sea stock and 1,300 t for the Aleutian Islands stock.

ACCEPTABLE BIOLOGICAL CATCH

Acceptable biological catches (ABCs) for both stocks of "other rockfish" were estimated in a manner similar to that used to estimate the ABCs for the POP complex. It was assumed that the exploitation rate used to estimate the POP complex ABC was applicable to the "other rockfish" group. By multiplying this exploitation rate (0.06) by the current estimates of biomass, the estimated ABCs for "other rockfish" were about 400 t for the eastern Bering Sea stock and 1,100 t for the Aleutian Islands stock.

ATKA MACKEREL

by

Daniel K. Kimura and Lael L. Ronholt

INTRODUCTION

Atka mackerel in the North Pacific Ocean are comprised of two species, *Pleurogrammus azonus* and *P. monopterygius*. *P. azonus* is limited to the Asian coast from the Kuril-Sakhalin area to northern Japan, where catches have fluctuated in the 100,000 to 200,000 metric ton (t) range over the last 25 years (Chikuni 1985). *P. monopterygius* is widely distributed in the North Pacific from the Asian coast to the North American coast. The center of abundance of *P. monopterygius* is in the Aleutian Islands, particularly in the Atka Island and Seguam Pass areas (Fig. 1). Gorbunova (1962) considered the adults of the two species to be geographically separated. It can, therefore, be assumed that all landings of Atka mackerel in the U.S. exclusive economic zone are *P. monopterygius*.

Levada (1979) conducted a study of morphological and meristic characteristics of Atka mackerel in the Gulf of Alaska and Aleutian Islands regions and concluded that they were separate stocks. However, the dramatic decline of Atka mackerel in the gulf region suggests that gulf fish are at the extreme limit of their geographic range which is only populated during periods of favorable environmental conditions. An analysis of growth data presented in this paper demonstrates that Atka mackerel populations appear to be localized once they assume the demersal phase in their life history. The growth characteristics of subpopulations appear to be largely determined by the availability of food.

CONDITION OF STOCK

Catch Statistics

The total annual landings of Atka mackerel in the Bering Sea and Aleutians region increased during the 1970s reaching an initial peak of 24,250 t in 1978 (Table 1). 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. From 1984 to 1986 Atka mackerel catches have been at record high levels, averaging 35,302 t annually. Although significant landings came from the eastern Bering Sea area during 1978-81, the vast majority of the catches since then have been from the Aleutian Islands region (Table 2).

Historically, Atka mackerel have been pursued by non-U.S. and U.S. joint venture fisheries. From 1970 to 1979, Atka mackerel landings were made almost exclusively by the U.S.S.R. (Table 1). Japan and the Republic of

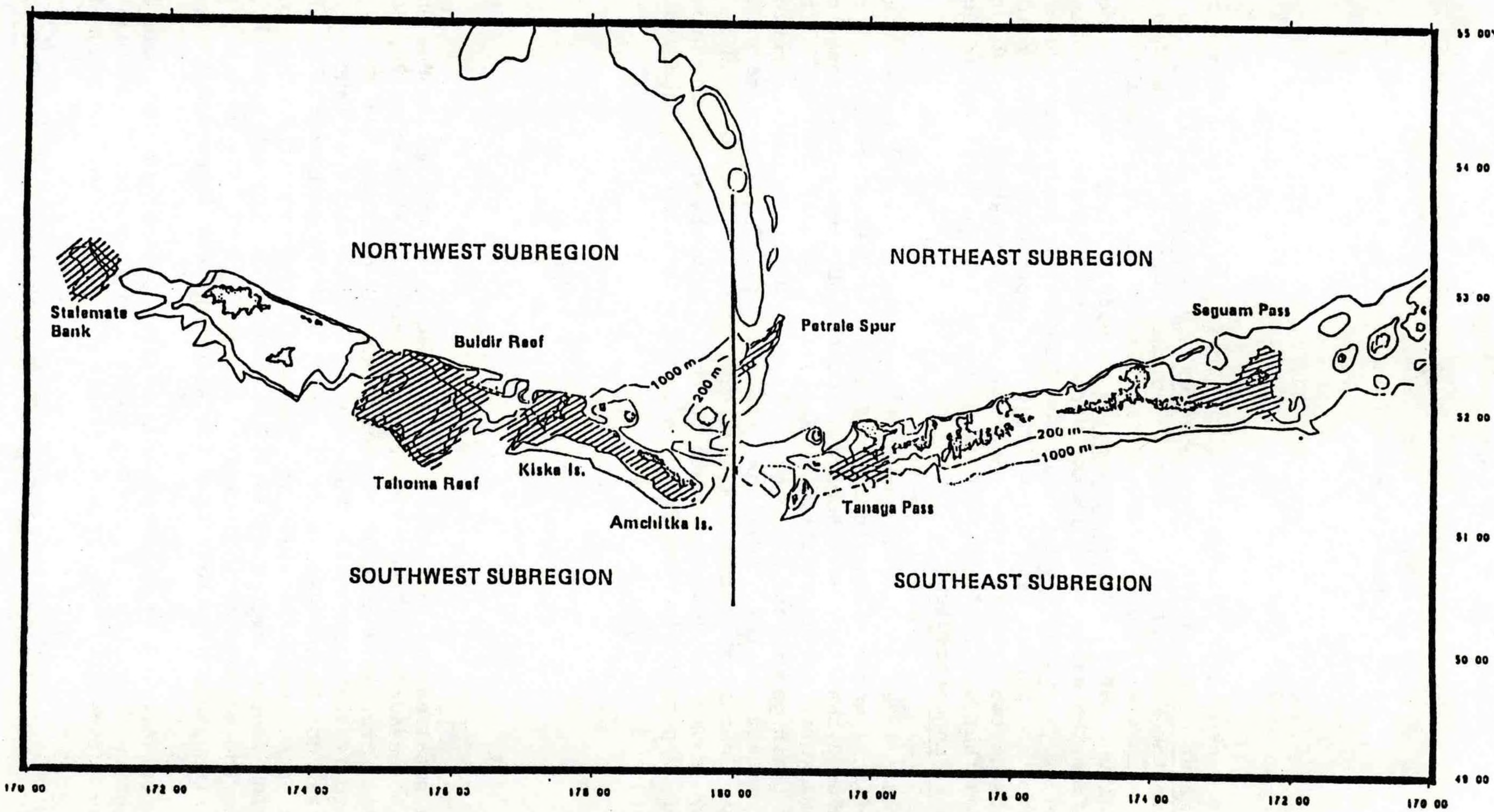


Figure 1.--Map of the Aleutian Islands region with the four subregions used in the discussion of survey results. Also shown are the major concentrations of Atka mackerel.

Table 1.--Atka mackerel catches in metric tons, by nation, in the eastern Bering Sea and Aleutian Islands regions, 1971-86.

Year	U.S.S.R.	Japan	R.O.K.[a]	W. Germany	Poland	U.S.J.V.[b]	Total
1971	--	--	--	--	--	--	--
1972	4,907	--	--	--	--	--	4,907
1973	1,712	--	--	--	--	--	1,712
1974	1,377	--	--	--	--	--	1,377
1975	13,326	--	--	--	--	--	13,326
1976	20,737	--	--	--	--	--	20,737
1977	20,975	788	--	--	--	--	21,763
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	20,489
1981	--	5,615	12,385	38	18	1,633	19,689
1982	--	888	6,385	126	--	12,475	19,874
1983	--	280	910	25	--	10,512	11,726
1984	--	104	8	--	tr[c]	35,943	36,055
1985	--	1	tr[c]	--	tr[c]	37,859	37,860
1986	--	1	5	--	tr[c]	31,984	31,990

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

Sources of catch data: 1971-76, Forrester et al. 1983; 1979, Murai et al. 1981; 1978-1986 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 International North Pacific Fisheries Commission areas in the Bering Sea and Aleutian Islands regions, 1978-86.

Year	Eastern Bering Sea (I)	Eastern Bering Sea (II)	Central Bering Sea (III)	Aleutians (V)	Total
1978	422	409	0	23,418	24,250
1979	1,653	332	0	21,279	23,264
1980	4,493	462	0	15,533	20,489
1981	2,307	720	0	16,661	19,689
1982	155	173	0	19,546	19,874
1983	21	120	0	11,585	11,726
1984	24	33	0	35,998	36,055
1985	3	1	0	37,856	37,860
1986	11	1	0	31,978	31,990

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.

Korea (R.O.K.) made significant landings from 1978 to 1982. U.S. joint venture fisheries which began in 1980 have dominated the catches since 1982.

In the early 1970s, most Atka mackerel catches occurred in the western Aleutian Islands, west of 180° long. During 1978 and 1979 the fishing effort moved progressively eastward (Tables 3a and 3b), with significant landings in the central and eastern portions of the Aleutian Islands region. Since 1980, the majority of the landings of Atka mackerel (74-99%) have occurred east of 180° long., primarily between 171°W and 174°W (Table 3). In 1984 and 1985 the majority of total landings came from a single 0.5° lat. by 1° long. block bounded by lat. 52° 30'N, 53°N, 172°W, and 173°W (73% in 1984, 52% in 1985).

Overview of Available Assessment Data

Because Atka mackerel occur in large localized concentrations they are an especially difficult species to assess. Their shoaling behavior makes the species difficult to survey with trawls, and since they are poor acoustic targets they are also difficult to survey with hydroacoustic gear. This behavior also makes catch per unit effort (CPUE) data from the commercial fleet difficult to interpret. Considering the transient nature of the fleets that have fished Atka mackerel, commercial CPUE data are meaningless.

One problem should be noted concerning the age determination of Atka mackerel. In the Aleutian Islands region, Atka mackerel is a summer-fall spawning fish that 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 age data more consistent with data obtained from tail ossicles by Gorbunova (1962). All age data presented in this report have been corrected in this way.

Despite its shortcomings, we felt that the survey data from the U.S.-Japan cooperative surveys in 1980, 1983, and 1986 were valuable. These data provide absolute abundance estimates, and also a good sampling of size at age from throughout the Aleutian Islands region. These survey data were used to estimate growth parameters and a weight-length relationship.

In addition to the survey data, biological data were collected from commercial catches by the Foreign Fisheries Observer program. However, age composition data from commercial catches were not available for 1980 and 1981 and these had to be generated using 1980 survey data, age-length keys, and distribution mixture methods (Kimura and Chikuni 1987). These estimates of catch in numbers at age were then used to perform Virtual Population Analysis (Pope 1972) and its least squares counterpart (Doubleday 1976; Deriso et al. 1985).

Results from Resource Assessment Surveys

Estimated Biomass and Size and Age Composition

Groundfish resource assessment surveys have been conducted in the Aleutian Islands and southern Bering Sea by the Resource Assessment and Conservation

Table 3a.--Annual catches of Atka mackerel in metric tons by 1° of longitude in the western Aleutian Islands.[a]

	East longitude								
Year	170°	171°	172°	173°	174°	175°	176°	177°	178°
1977	81	143	112	141	385	13,058	3,789	327	195
1978	426	0	0	0	400	11,684	275	0	41
1979	58	34	6,694	4,236	30	121	111	18	65
1980	125	26	110	35	95	171	107	56	121
1981	268	68	104	84	180	490	250	163	210
1982	53	28	37	26	33	74	86	42	31
1983	15	4	21	3	13	32	17	17	18
1984	0	0	11	1	tr[b]	0	0	1	167
1985	0	0	103	0	0	0	0	0	2,988
1986	0	0	0	0	0	0	0	17	723

[a] These data based on non-U.S. and U.S. joint venture landings when U.S. observers were aboard the fishing or processing vessels.

[b] tr = trace

Table 3b.--Annual catches of Atka mackerel in metric tons by 1° of longitude in the eastern Aleutian Islands.[a]

	West longitude								
Year	179°	178°	177°	176°	175°	174°	173°	172°	171°
1977	557	34	0	393	0	0	2	34	34
1978	6,703	0	0	0	955	0	0	21	1,509
1979	770	20	8	1	1,919	1	42	4,972	1,941
1980	185	119	26	52	41	98	449	10,867	2,635
1981	283	108	35	10	60	69	303	7,968	1,874
1982	92	49	0	0	7	34	66	5,147	7,346
1983	159	5	4	2	0	1	2,753	5,492	737
1984	4,951	235	16	9	0	204	2,507	23,892	361
1985	6,462	0	tr[b]	0	0	0	541	17,356	332
1986	7,481	0	0	0	0	0	880	8,333	tr[b]

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

Engineering (RACE) Division of the NWAFC; the Far Seas Fisheries Research Laboratory, Shimizu, Japan; and the Pacific Research Institute of Fisheries and Oceanography, Vladivostok, U.S.S.R. Although the U.S.-U.S.S.R. cooperative surveys provided useful biological data, they were too limited to provide useful biomass estimates of the resources. The U.S.-Japan triennial surveys in 1980, 1983, and 1986 have been multispecies in nature and have covered both sides of the Aleutian Islands from 170°E to 170°W, and the north side of the Aleutian Islands from 170°W to 165°W (i.e., the southern Bering Sea portion of International North Pacific Fisheries Commision (INPFC)statistical area I).

The initial Aleutian Islands survey of 1980 used a systematic sampling scheme which guaranteed a wide geographic and bathymetric distribution of sampling effort since no previous resource assessment surveys had been conducted in this region. For the 1983 and 1986 surveys, data from previous surveys were used to develop a stratified random sampling design based on the abundance of the principal species in an attempt to reduce the variance of the biomass estimates. For the 1983 survey the 1980 survey data were used, and for the 1986 survey the data from both the 1980 and 1983 surveys were used. The main change in the survey design since 1980 has been a shift of sampling effort to shallower water and to areas which have a higher abundance of the principal species.

Because of their dense schooling behavior, Atka mackerel are one of the most difficult fish species for estimating biomass and mean CPUE using trawl survey techniques. It is extremely easy to miss concentrations, particularly with the limited sampling effort available for these surveys. Also, Atka mackerel live in a shallow water habitat with extremely hard, rough, and rocky bottom which makes sampling with otter trawls very difficult. In some areas it has been impossible to sample Atka mackerel concentrations that were visible hydroacoustically, even though the otter trawls were equipped with roller gear. Despite these problems, the U.S.-Japan cooperative surveys have located major concentrations of Atka mackerel in the Aleutian Islands region (Fig. 1; i.e., Stalemate Bank, Buldir-Tahoma Reefs, Kiska Island, Amchitka Island, Petrale Spur, Tanaga Pass, and Seguam Pass).

The Japanese research vessels were assigned a higher percentage of the deeper water sampling stations and their shallow water sampling was restricted by the U.S. 3-mile limit. Because Atka mackerel are most abundant in shallower water, the biomass estimates for the 1980 and 1983 surveys may have a downward bias.

Biomass estimates of Atka mackerel have increased from 197,529 t in 1980 to 306,780 t in 1983, and 544,754 t in 1986 (Table 4). However, the high value for 1986 should not be directly compared with previous surveys. During the 1980 survey no successful sampling occurred in shallow waters around Kiska and Amchitka Islands, and during the 1983 survey very few stations were successfully trawled. However, during the 1986 survey several stations were successfully trawled in waters less than 100 m, and most produced extremely large catches of Atka mackerel. For 1986 the biomass estimate from this one depth interval alone totaled 418,000 t (Table 4), or 76.5% of the total biomass of Atka mackerel in the Aleutian Islands. This was also a 403,000 t increase over the 1983 biomass estimate for the same stratum-depth interval.

Table 4.--Estimated biomass in metric tons by subregion, depth interval, and survey year in the Aleutian Islands region.

Area	Depth (m)	Biomass 1980	Biomass 1983	Biomass 1986	Coefficient of variation 1980	Coefficient of variation 1983	Coefficient of variation 1986
Aleutian subregions combined	1-100	48,306	140,552	450,869	0.996	0.257	0.758
	101-200	144,431	162,399	93,501	0.458	0.248	0.297
	201-300	4,296	3,656	331	0.593	0.420	0.572
	301-500	483	172	16	0.769	1.003	0.866
	501-900	13	1	37	0.750	1.000	1.001
	Total	197,529	306,780	544,754	0.415	0.215	0.629
Southwest	1-100	95	15,321	418,271	0.000	0.612	0.815
	101-200	75,857	120,991	51,312	0.576	0.405	0.390
	201-300	619	2,304	122	0.607	0.574	0.829
	301-500	105	172	14	0.765	1.003	0.982
	501-900	9	1	0	0.962	1.000	0.000
	Total	76,685	138,789	469,719	0.570	0.359	0.727
Southeast	1-100	0	65,814	33	0.000	0.000	0.419
	101-200	21,153	854	89	0.865	0.919	0.897
	201-300	115	202	3	0.138	0.857	0.882
	301-500	16	0	0	0.000	0.000	0.000
	501-900	0	0	0	0.000	0.000	0.000
	Total	21,284	66,870	125	0.860	0.012	0.640
Northwest	1-100	0	41,235	32,564	0.000	0.723	0.651
	101-200	382	5,571	211	0.712	0.688	0.543
	201-300	2,524	34	0	0.962	0.690	0.000
	301-500	0	0	0	0.000	0.000	0.000
	501-900	4	0	0	1.118	0.000	0.000
	Total	2,910	46,840	32,775	0.839	0.642	0.647
Northeast	1-100	48,211	18,182	1	0.998	1.000	1.000
	101-200	47,039	34,983	44,889	0.983	0.707	0.459
	201-300	1,038	1,116	206	0.653	0.688	0.778
	301-500	362	0	2	1.001	0.000	0.707
	501-900	0	0	37	0.000	0.000	1.001
	Total	96,650	54,281	42,135	0.691	0.566	0.456

Therefore, when comparing between years, the biomass estimate for 1986 should perhaps be reduced to reflect the difference in survey coverage. If 403,000 t is removed from the 1986 survey estimate, the total biomass from 1980 to 1983 increased from 198,000 t to 307,000 t, and then dropped to 142,000 t in 1986, a 74% decrease since 1983. The same trend is indicated in three of the four subregions: the Southwest, Southeast, and Northwest. In the Northeast, which has produced most of the Atka mackerel landings since 1983, the biomass estimate decreased in both 1983 and 1986 (Table 4).

Survey data indicate a general shift of Atka mackerel toward shallower water since 1980. Because sampling in shallower waters less than 100 m was not as thorough in the early surveys as in the later surveys, it is difficult to know if the population was previously inhabiting deeper water or a wider depth interval. However, it is evident that the number of deeper stations producing significant catches has decreased, indicating either a movement of a portion of the population to shallower water, or a mortality on those fish in deeper water, either natural or fishing.

An interpretation of the length frequencies of Atka mackerel is made difficult by the geographic stratification of the stock by size. During the 1980 U.S.-Japan trawl survey, fish in the two subregions of the western Aleutian Islands averaged 32.3 and 35.3 cm, and fish in the eastern Aleutians 30.9 and 32.0 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 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 32-cm range is also evident. In the southwest, a large number of younger fish less than 30-cm in size is apparent, with fewer of the over 36-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. During the 1986 U.S.-Japan survey, the 1983 pattern is again evident with recruitment appearing in the west (32.2 and 30.8 cm) and the larger fish appearing in the east (37.6 and 41.1 cm). Examining the Aleutian summary plots with all areas combined (Fig. 2) shows the growth of large year classes in 1980 and 1983, with the large year classes apparently absent in 1986.

Overall age distributions from the U.S.-Japan trawl surveys (Fig. 3) show the dominant 1975 year class in 1980, and the dominant 1977 year class in 1983. Although the 3-year-olds from the 1983 year class were dominant in the 1986 survey, it is too early to know if this is really a strong year class, or just an indication of a lack of older aged fish.

Analysis Of Growth

Since our previous stock assessment of Atka mackerel, it has been brought to our attention that many fish caught were larger than L_{inf} previously estimated from the von Bertalanffy growth curve. Large annual and geographic variability in length at age was found to be the cause of this anomaly.

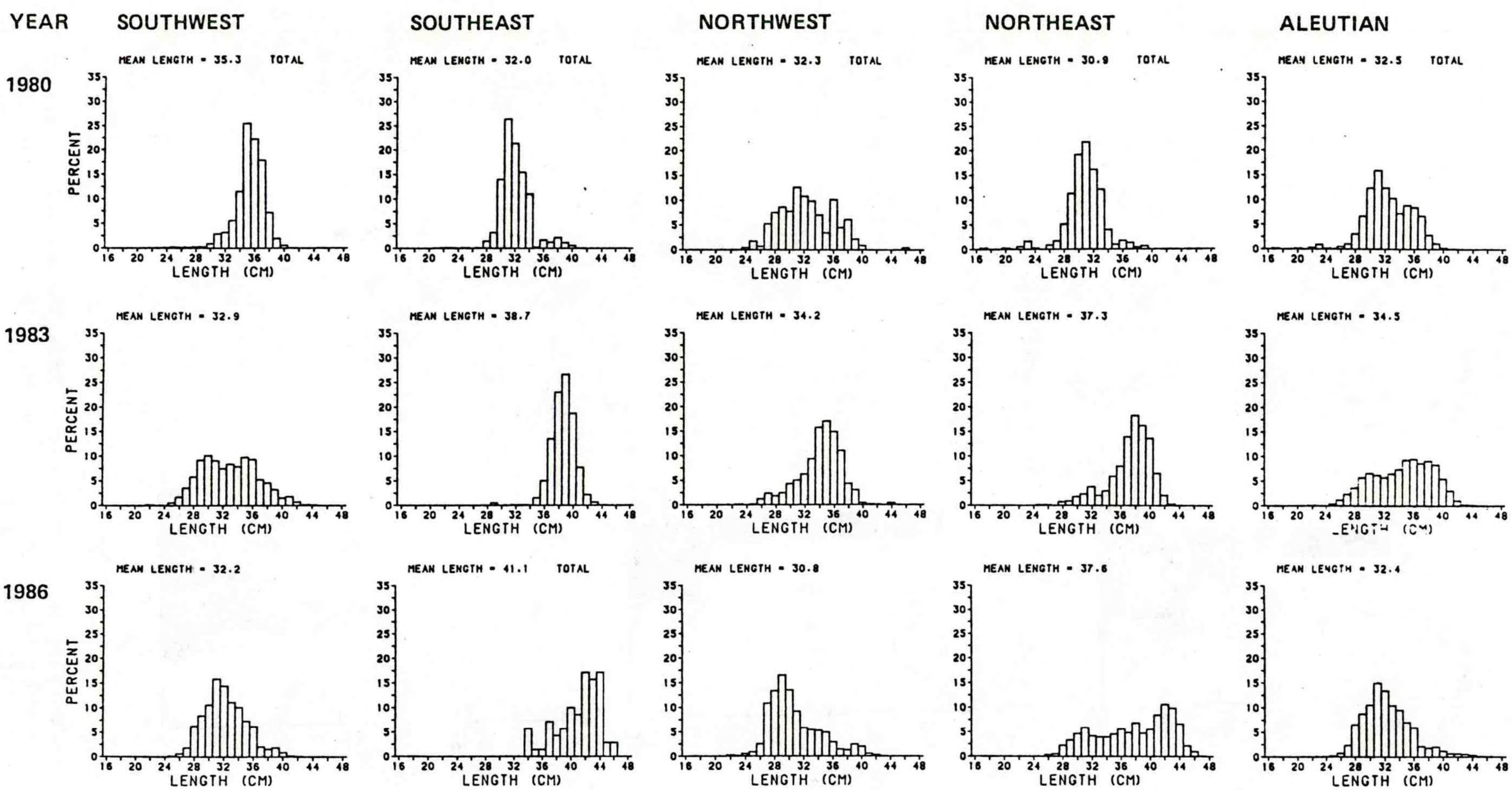


Figure 2.--Length frequency distributions by subregion (Fig. 1) of the Aleutian Islands region for U.S.-Japan trawl surveys in 1980, 1983, and 1986.

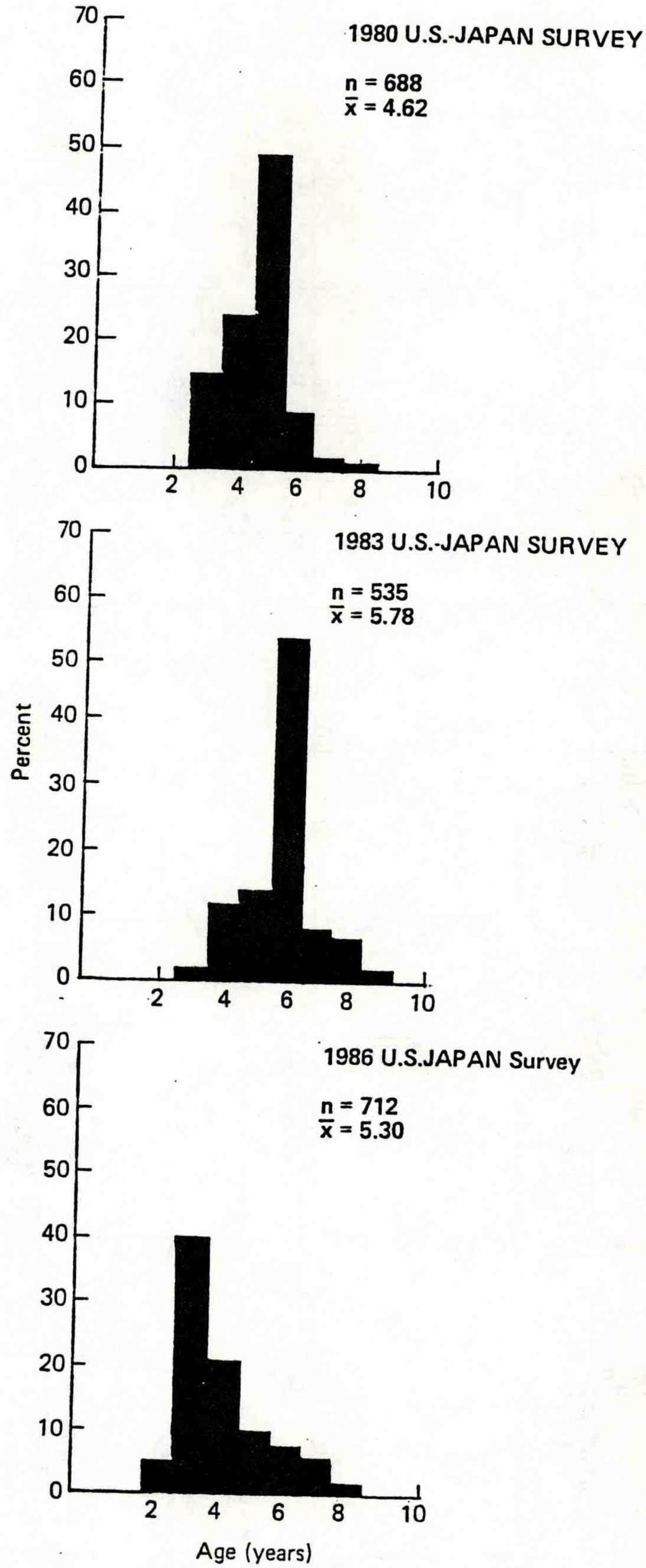


Figure 3.--Overall age distributions from the Aleutian Islands region based on data from U.S.-Japan trawl surveys in 1980, 1983, and 1986.

Because survey data provide the most uniform sampling of the Aleutian Islands region, data from these surveys have been used to evaluate variability in growth. Length-at-age data from the 1980, 1983, and 1986 U.S.-Japan trawl surveys, and the U.S.-U.S.S.R. surveys in 1982 and 1985 were analyzed by six areas (Table 5, Fig. 1). It appears that length at age is smallest in the west and largest in the east.

Analysis of variance (ANOVA) was used to evaluate these differences statistically. Preliminary analyses indicated that length at age did not differ significantly by sex, so the sex factor was ignored in further analyses. Also, the results were similar using either length or log (length) as the response variable, so we present only the results using length. The results treating these data as a fixed effects factorial design are shown in Table 6. For this model the AREA and AGE effects are both significant, but the YEAR effect is not quite significant. The AREA effect appears much stronger than the AGE effect and all interactions appear significant.

However, a more interesting question might be whether the AREA effect is significant if YEAR is assumed to be a random effect. In other words, whether the area differences can be expected to remain over the years. For this analysis we used a classic "split-plot" design where AREA is the whole plot factor, YEAR is the main sampling unit, and age within year is the subunit. The results (Table 6) show that the AREA effect is still significant. This demonstrates that the differences in growth between areas is probably a real phenomenon rather than just a chance sampling of years.

Estimating Growth and Mortality Parameters

Because the survey data represent a broad sampling of the Aleutian Islands population, we have used these data from all years and areas in our analysis. Curves were fit to mean lengths at age weighted by sample size (Table 5) which should be equivalent to using individual data points. It is important to recall that the growth of Atka mackerel differ greatly by area and year, so our estimates are average figures, which may not apply to a given time and area.

Because sex was not an important differentiating variable for growth in Atka mackerel, we present curves for the sexes combined. Using nonlinear least squares, our fit for the von Bertalanffy growth curve is:

von Bertalanffy parameters: L_{inf} = 41.4 (cm), K = 0.311, and t_o = -1.23 (yr).

Similarly, the nonlinear least squares fit for the weight-length relationship is:

$$\text{weight (kg)} = .0000049761 \text{ length (cm)}^{3.2403}.$$

These curves are graphed in Figure 4 along with plots of observed values.

Another useful set of growth parameters are the delay difference growth parameters RHO and OMEGA (Schnute 1985; Kimura 1985). Assuming an age at recruitment of k = 3 years, and using the weight-at-age data averaged over all years and areas (Table 5), least squares estimates of these parameters are RHO = 0.983 and OMEGA = 0.731.

Table 5.--Length at age and weight at age for Atka mackerel sampled in six areas (Fig. 1) of the Aleutian Islands region. Data are from survey samples taken from 1980 to 1986.

Area	Age (yr)	Length at age: Sample size	Length at age: Length (cm)	Weight at age: Sample size	Weight at age: Weight (kg)	Area	Age (yr)	Length at age: Sample size	Length at age: Length (cm)	Weight at age: Sample size	Weight at age: Weight (kg)
Stalemate Bank	2	5	25.8	3	.257	Amchitka Island	2	8	26.5	8	.246
	3	83	29.2	71	.287		3	35	31.8	31	.429
	4	112	30.3	48	.311		4	41	33.6	21	.472
	5	104	32.1	43	.374		5	77	35.3	11	.541
	6	76	34.1	20	415		6	20	36.5	7	.604
	7	29	33.9	17	.391		7	4	37.8	4	.617
	8	27	34.8	4	.428		8	3	38.0	3	.698
	9	5	36.2	2	.512		9	1	35.0	1	.418
	10	7	35.1	0	.000		10	1	37.0	1	1.010
						Petrale Spur	2	28	24.3	28	.156
Buldir and Tahoma reefs	3	28	31.9	0	.000		3	82	29.4	57	.282
	4	77	33.8	8	.496		4	55	33.5	33	.457
	5	152	35.3	20	.604		5	51	35.4	36	.568
	6	80	35.5	13	.55		6	70	36.6	32	.582
	7	42	36.6	28	.621		7	34	36.5	18	.613
	8	28	36.5	16	.580		8	13	37.6	6	.630
	9	6	37.7	1	.650		9	8	38.0	6	.637
	10	1	40.2	0	.000		10	4	41.5	1	1.010
Kiska Island	2	20	27.4	20	.257						
	3	69	30.6	68	.349	Seguam Pass	3	20	33.1	2	.540
	4	108	34.8	21	.453		4	51	36.4	14	.819
	5	155	36.3	13	.556		5	83	38.8	9	.926
	6	62	37.2	5	.690		6	116	39.5	23	.967
	7	38	38.4	18	.669		7	44	40.4	15	.968
	8	20	38.3	9	.632		8	86	41.4	36	.946
	9	5	39.6	2	.690		9	47	42.6	31	.991
	10	1	43.0	1	.940		10	14	42.4	11	.983
							11	4	43.5	3	1.017
						All Areas	2	61	25.7	59	.208
							3	317	30.3	229	.326
							4	444	33.4	145	.447
							5	622	35.5	132	.531
							6	424	36.8	100	.642
							7	191	37.5	100	.641
							8	177	38.9	74	.765
							9	72	41.0	43	.884
							10	27	40.2	14	.952
							11	5	42.8	3	1.017

Table 6.--Analysis of variance of survey length-at-age data from the Aleutian Islands region. The analysis was for ages 5 to 8 years and the areas shown in Figure 1, and the response variable (fish length) was in centimeters. The upper part of the table show the results treating the data as a fixed effects factorial design. The lower part of the table show the results treating the data as a "split-plot" design. In this design, area was the whole plot factor, year was the whole plot main sampling unit, and age was the split-unit factor.

Source	SS	DF	MS	F	P-value
Factorial analysis					
Within cells	7448.98	2072	3.60		
Area	753.79	5	150.76	41.93	0.000
Year	32.28	4	8.07	2.25	0.062
Age	123.26	5	24.65	6.86	0.000
Area by year	305.97	9	34.00	9.46	0.000
Area by age	206.49	25	8.26	2.30	0.000
Year by age	211.42	20	10.57	2.94	0.000
Area by year by age	301.01	34	8.85	2.46	0.000
Split-plot analysis					
Whole plot					
Residuals	340.51	13	26.19		
Areas	761.46	5	152.29	5.81	0.005
Within plot					
Residuals	593.74	54	11.00		
Age	615.00	5	123.00	11.19	0.000
Area by age	219.07	25	8.76	0.80	0.728

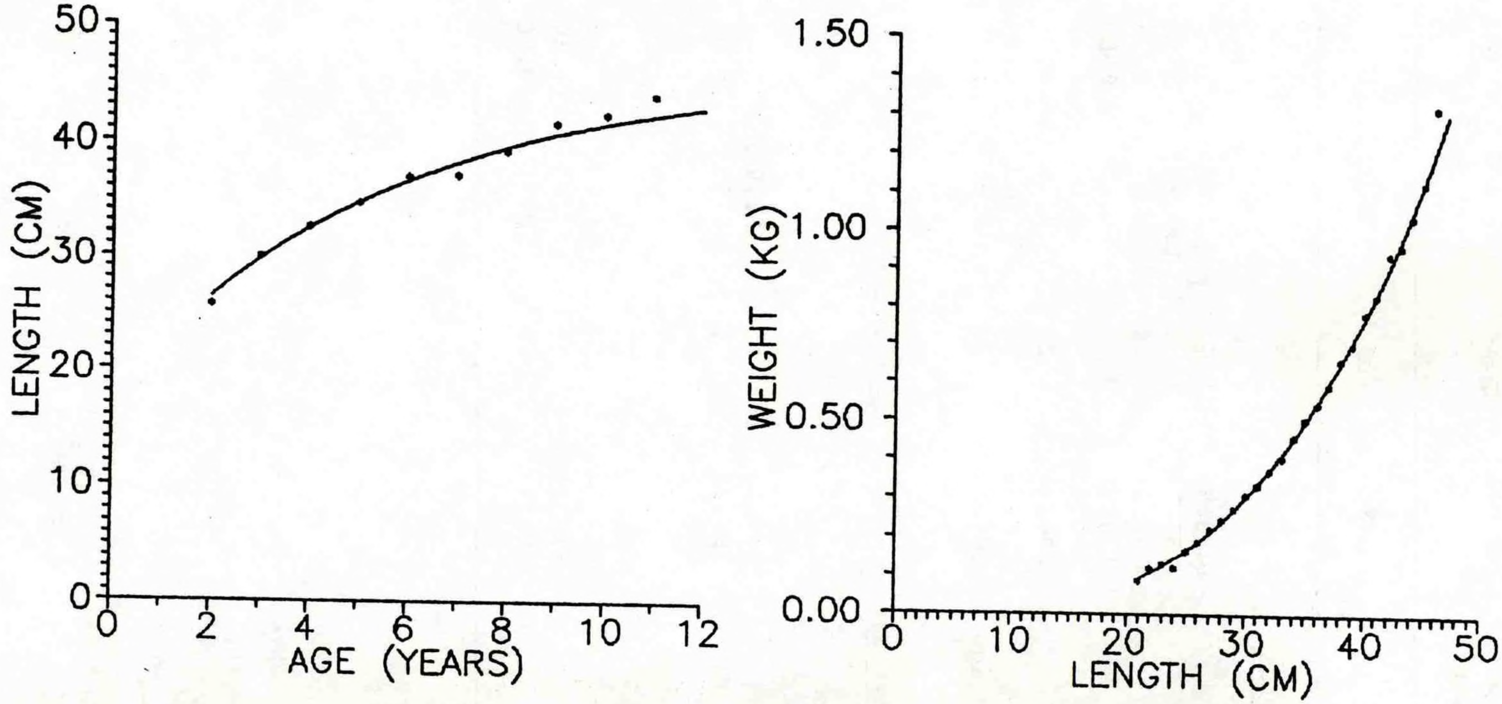


Figure 4.--Plots of the von Bertalanffy growth curve and length-weight relationship for Atka mackerel in the Aleutian Islands region. Curves were fit using survey data from all areas and years.

In earlier status of stock documents we estimated natural mortality using the Alverson-Carney (1975) method. However, this method used von Bertalanffy growth parameter estimates which are quite tenuous for this species. Therefore, in the present paper we use the regression model of Hoenig (1983) to estimate the total instantaneous mortality rate Z, which is an upper bound for the natural mortality rate M. Assuming a maximum age of t_{max} = 11 years Hoenig's regression equation estimates a Z of 0.38. Since M = Z-F, a natural mortality rate anywhere below 0.38, depending on our estimate of F, is consistent with this estimate. In our modeling, M = 0.2, M = 0.3, and M = 0.4 have been used as estimates of natural mortality, which is consistent with the observed maximum age.

Length and Age Distributions from Commercial Catches

From 1977 to the present, commercial catches have been sampled for length and age data by the U.S. Foreign Fisheries Observer Program. In 1980 and 1981 the U.S. observer length sample sizes were small, so these data were supplemented with length samples taken by R.O.K. fisheries personnel from their commercial landings. These data (Fig. 5) show an increase in the size of fish taken in the commercial fishery. In 1977 most of the fish were under 30 cm, but by 1979 nearly all were over 30 cm. Mean size increased from 33.0 cm in 1980 to 37.8 cm in 1984, and was 37.4 cm in 1985, and 37.5 cm in 1986. An interpretation of the length frequencies of Atka mackerel is made difficult by the geographic stratification of the stock by size. Estimates of catch in numbers at age were estimated using the length frequencies described above and age-length keys. The formulas used are described by Kimura (1987). As with the length frequencies, the age data for 1980 and 1981 presented problems. The commercial catches in 1980 and 1981 were not sampled for age structures. Therefore, the 1980 survey age-length key was used to estimate 1980 commercial catch age distributions and these data were further used to estimate the 1981 commercial catch age distribution using a mixture model (Kimura and Chikuni 1987).

The most salient feature of the estimated catch in numbers at age (Table 7) is the strong 1975 and 1977 year classes. The 1975 year class appeared strong as 3-and 4-year-olds in 1978 and 1979. The 1977 year class has appeared strong since they entered the fishery as 3-year-olds in 1980. The extraordinary strength of the 1977 year class led us to believe that catches would decline sharply as this year class aged, and there are some indications that this may have occurred in the 1987 fishery.

Age-Structured Modeling

Methods

In previous documents (e.g., Ronholt and Kimura 1987) Stock Reduction Analysis (SRA) was used to estimate levels of sustainable yield. In the present analysis we use virtual population analysis (VPA) and its least squares counterpart (Doubleday 1976; Deriso et al. 1985). These appear to be the simplest models from which reasonable inferences can be made concerning Atka mackerel. Because input data exist only for the Aleutian Islands region, all modeling results refer only to that region.

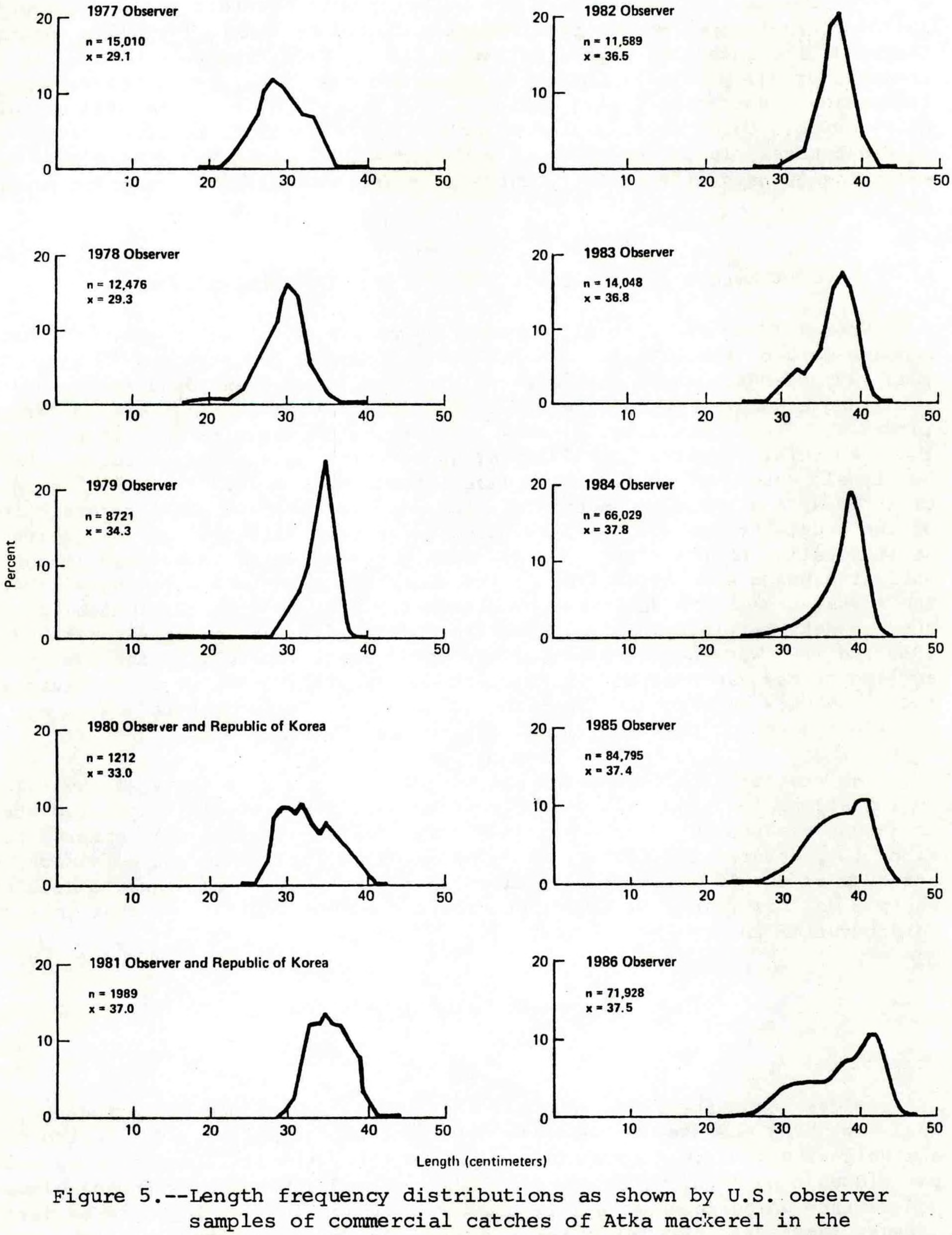


Figure 5.--Length frequency distributions as shown by U.S. observer samples of commercial catches of Atka mackerel in the Aleutian Islands region. Observer samples were augmented by samples taken by the Republic of Korea in 1980 and 1981.

Table 7.--Estimated catch in numbers at age (in millions) for Atka mackerel in the Aleutian Islands region. Estimates for 1980 and 1981 used 1980 survey age data and length frequency analysis. Therefore, these estimates may be inaccurate. Estimated coefficients of variation are shown below the catches. For 1980 and 1981 the average coefficients of variation from the other years were used.

	Year									
Age (yr)	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
2	6.827	2.712	0.011	-	-	-	-	0.094	0.627	0.369
3	31.522	60.155	4.477	12.681	5.393	0.188	1.900	0.977	15.971	11.454
	0.046	0.028	0.088	0.135	0.135	0.446	0.074	0.299	0.055	0.040
4	20.056	15.573	26.778	5.920	17.106	2.629	1.433	7.295	8.787	6.457
	0.075	0.093	0.053	0.112	0.112	0.176	0.189	0.104	0.105	0.098
5	15.113	9.221	13.000	7.220	0.002	25.828	2.535	7.070	9.428	4.423
	0.072	0.109	0.105	0.107	0.107	0.031	0.194	0.125	0.103	0.113
6	1.223	3.750	2.197	1.665	1.612	3.861	10.596	10.793	6.010	5.335
	0.305	0.157	0.265	0.164	0.164	0.150	0.062	0.092	0.143	0.137
7	0.393	0.592	1.109	0.591	8.104	0.676	1.587	21.775	5.453	4.531
	0.436	0.390	0.477	0.277	0.277	0.307	0.253	0.056	0.154	0.144
8	0.197	0.343	-	0.240	-	-	-	2.212	11.685	5.841
9	-	0.106	-	0.131	-	-	-	0.957	1.263	9.912
10	-	-	-	-	-	-	-	-	0.269	1.036
11	-	-	-	-	-	-	-	-	-	0.846

Based on our previous discussions we use natural mortality rates of $M = 0.2$, $M = 0.3$, and $M = 0.4$; catch-at-age data from Table 7; and weight-at-age estimates averaged over all years and areas (Table 5). As with all modeling of catch-at-age data, the model needs to be constrained with ancillary information (see Deriso et al. 1985). Although the survey data have severe limitations, they provide the only data available to constrain our model. Survey biomass estimates from the Aleutian Islands region (Table 4) were used to tune the catch-at-age models.

Virtual population analysis was carried out using Gulland's classic method (see Pope 1972). Only ages 3 to 7 years were used because catches were available for these ages in all years (Table 7). Ages 6 and 7 were assumed to be equally fished, so that the instantaneous fishing mortality rate in years previous to the final catch year could be "linked" to provide initial F values for earlier cohorts. Furthermore, initial Fs for all ages in the final year were assumed to be equal (i.e., knife-edged recruitment at age 3 yr was assumed). Preliminary fits and an examination of Table 7 indicate that the assumption of knife-edged recruitment at age 3 appears reasonable. In our analysis VPA was used to provide initial estimates to the least squares model.

It should be recognized from the outset that the survey biomass estimates and the catch-at-age data are contradictory. The catch-at-age data are dominated by the strong 1977 year class, which strongly suggests that the biomass should first grow and then decay. On the contrary, the survey biomass estimates show an increase in biomass over time. We reconciled this in our least squares modeling by weighting the fits by the coefficients of variation of the estimates. These include the coefficients of variation of both the catches at age (Table 7) and biomass estimates (Table 4). Since the variance of the log is roughly equivalent to the coefficient of variation, the sum of squares to be minimized is

$$\Sigma((\log(c_{ij})-\log(\hat{c}_{ij})/cv(\hat{c}_{ij}))^2 + \Sigma((\log(b_t)-\log(\hat{b}_t))/cv(\hat{b}_t))^2,$$

where C_{ij} is the catch in numbers of j year olds in year i, and b_t is the survey biomass estimate in year t. In the least squares modeling, we again assumed that Atka mackerel were fully recruited to the fishery at age 3.

Results

The most useful role catch-at-age analysis plays in our assessment of Atka mackerel in the Aleutian Islands region is in inference concerning the present (1986) biomass. Catch-at-age data clearly show the dominance of the 1977 year class. As pointed out earlier, this strongly suggests that biomass should increase and then decline in accord with the growth and decay of this year class. However, the biomass estimates from the 1980 and 1983 surveys were similar, and the estimate from the 1986 survey much higher, placing some doubt as to the accuracy of the 1986 estimate.

Since the weighted least squares catch-at-age analysis takes into account the variability of these estimates, our model makes a somewhat objective statement concerning this matter. Using the coefficients of variation estimated from the survey data (Table 8), catch-at-age analysis indicates an extremely

Table 8.--Estimated biomass (in thousands of metric tons) and recruitment of 3-year-old fish (in millions) for Atka Mackerel in the Aleutian Islands region from least squares catch-at-age analysis.

	Coefficients of variation of survey biomass estimates							
	E[a]		0.25[b]		0.10[b]		0.01[b]	
Year	Biom.[c]	Recr.[d]	Biom.	Recr.	Biom.	Recr.	Biom.	Recr.
M = 0.20								
1977	106	135	123	158	111	142	82	106
1978	163	262	200	321	174	279	114	183
1979	133	19	172	25	144	22	80	14
1980	335	744	466	1,038	393	890	206	485
1981	386	212	555	309	472	284	257	212
1982	390	90	565	137	494	152	311	196
1983	352	83	524	128	467	133	310	137
1984	320	60	484	97	448	125	385	330
1985	149	87	242	145	262	184	387	414
1986	106	82	192	151	237	203	528	624
M = 0.30								
1977	151	193	185	236	154	198	95	123
1978	232	371	298	477	240	385	125	203
1979	185	27	249	37	193	30	83	16
1980	450	999	644	1,439	514	1,173	211	510
1981	480	264	708	397	573	357	266	273
1982	439	102	654	162	550	184	329	290
1983	361	86	553	136	477	143	306	150
1984	297	56	463	95	420	132	385	407
1985	124	72	210	128	233	172	394	442
1986	75	58	148	117	195	171	526	672
M = 0.40								
1977	228	292	295	378	226	289	112	144
1978	343	549	461	739	340	547	141	228
1979	263	38	368	54	262	41	88	18
1980	609	1,354	899	2,013	673	1,552	216	528
1981	599	330	908	514	696	450	273	332
1982	497	116	762	192	614	222	357	415
1983	372	89	586	147	489	154	304	159
1984	277	53	446	94	396	139	394	509
1985	103	61	185	113	209	162	396	465
1986	52	41	115	92	161	144	523	726

[a]Estimated coefficient of variation of survey biomass estimates: 0.415 in 1980, 0.215 in 1983, and 0.629 in 1986.

[b]Other possible coefficients of variation for survey biomass estimates.

[c]Biomass estimates.

[d]Recruitment of age 3 fish.

low current biomass ranging from 52,000 to 106,000 t depending on the natural morality rate used and averaging 78,000 t over all natural mortality rates. In other words, the coefficient of variation of the 1986 survey estimate is so large (0.629), the analysis largely discounts this survey estimate.

To see if this result was due mainly to the relative weighting of the survey biomasses, the model was rerun using a coefficient of variation of 0.25 for all survey biomasses. The resulting estimate of current biomass was 152,000 t (again averaged over all natural mortality rates), which is still much less than the 545,000 t survey biomass estimate for 1986.

Because the coefficient of variation for the catch-at-age data is based only on the sampling error of the biological data, it is likely that this variation was underestimated. Therefore the coefficient of variation of the survey biomass estimates was purposely underestimated in order to weight our results toward the survey biomass estimates as much as would seem reasonable. We reran the model using a coefficient of variation of 0.10 for all survey biomass estimates. This resulted in a 1986 survey biomass estimate of 198,000 t, again averaged over all natural mortality rates. Clearly when the variability estimates of the data are taken into consideration, the catch-at-age analysis does not support a 1986 biomass of 545,000 t, but clearly suggests a much lower biomass.

In order to demonstrate that our model is capable of reproducing the survey biomass estimates, the model was rerun using a coefficient of variation of 0.01 for all survey biomass estimates. Although these are obviously unrealistic estimates of survey accuracy, the estimated biomasses follow the survey results for all estimates of natural mortality.

MAXIMUM SUSTAINABLE YIELD

Maximum sustainable yield (MSY) was estimated from the average recruitment of 3-year-olds estimated from the catch-at-age analysis. This average was calculated from the values in Table 8, excluding the extraordinarily strong 1977 year class because it has already passed through the fishery, and no other year classes appear as strong.

Two methods were used: the classic Beverton and Holt yield-per-recruit model, and Schnute's delay-difference equation with RHO = 0.983, and OMEGA = 0.731 as calculated earlier. Kimura (1987 In press) describes how the delay-difference equation can be used to estimate sustainable yield. Both models assume constant recuitment and that MSY occurs either when F = M, or at the point when F = F(0.1). Kimura (1987 In press) gives an example where F = M approximates the MSY for a variety of stock-recruitment curves, when higher levels of fishing might cause recruitment failure. Gulland and Boerema (1973) argue that fishing beyond the level of F(0.1) is not economically practical.

Table 9.--Estimates of maximum sustainable yield in metric tons for Atka mackerel in the Aleutian Islands region using the Beverton and Holt yield-per-recruit model. Estimates in the upper half of the table assume F = M at the point of maximum sustainable yield; those in the bottom half assume F = F(0.1) at the point of maximum sustainable yield. Estimates in parentheses are based on 1982-86 recruitment estimates.

Natural mortality (M)	Coefficients of variation of survey biomass estimates			
	E[a]	0.25[b]	0.10[b]	0.01[b]
	Estimates of MSY assuming the Beverton and Holt Yield Per Recruit Model and F=M			
0.20	30,666 (21,520)	43,847 (35,508)	45,461 (42,771)	66,174 (91,460)
0.30	33,565 (18,375)	48,510 (31,360)	48,265 (39,200)	70,070 (96,040)
0.40	39,846 (16,488)	59,082 (29,312)	54,731 (37,556)	76,257 (104,195)
Average	34,692 (18,794)	50,480 (32,060)	49,486 (39,842)	70,834 (97,232)
	Estimates of MSY assuming the Beverton and Holt Yield Per Recruit Model and F=F(0.1)			
0.20 F(0.1)=0.271	33,972 (23,840)	48,574 (39,336)	50,362 (47,382)	73,308 (101,320)
0.30 F(0.1)=0.413	37,264 (20,400)	53,856 (34,816)	53,584 (43,520)	77,792 (106,624)
0.40 F(0.1)=0.569	45,066 (18,648)	66,822 (33,152)	61,901 (42,476)	86,247 (117,845)
Average	38,767 (20,963)	56,417 (35,768)	55,282 (44,459)	79,116 (108,596)
Grand average	36,730 (19,879)	53,447 (33,914)	52,384 (42,151)	74,975 (102,914)

[a]Estimated coefficient of variation of survey biomass estimates: 0.415 in 1980, 0.215 in 1983, and 0.629 in 1986.

[b]Other possible coefficients of variation for survey biomass estimates.

Estimates of MSY using the Beverton and Holt yield-per-recruit model are given in Table 9, assuming F = M, F = F(0.1), and all scenarios used in the catch-at-age least squares analysis. These MSY estimates range from 35,000 t to 79,000 t (averaging over all natural mortality rates). Estimates of MSY using Schnute's (1985) delay-difference equation are given in Table 10, assuming F = M, F = F(0.1), and all scenarios used in the catch-at-age least squares analysis. These MSY estimates range from 31,000 t to 66,000 t (again averaging over all natural mortality rates). The assumed natural mortality rate, and the choice between the assumptions F = M, or F = F(0.1), have little influence on calculated yield. The choice of model (Beverton and Holt versus Schnute's) does have a moderate influence on the MSY estimates. However, the assumed coefficient of variation of survey biomass estimates has the greatest influence on estimates of MSY.

Because they are based on actual data, we believe the MSY estimates assuming the estimated coefficients of variation for survey biomasses are the best. This would suggest a long-term MSY of around 31,000 t to 39,000 t. However, as argued earlier, scenarios using survey biomass coefficients of variation of 0.25 and 0.10 might also have credibility. These levels of variability suggest an MSY of approximately 44,000 t to 55,000 t.

Estimates of MSY using the Beverton and Holt yield per recruit model (Table 9), estimated coefficients of variation, and assuming F = F(0.1) provide MSY estimates which range from 34,000 t to 45,000 t depending on the natural mortality rate used. Averaging over the natural mortality rates gives our best estimate of long-term MSY for the Aleutian Islands region of 38,800 t.

ACCEPTABLE BIOLOGICAL CATCH

The lack of knowledge concerning Atka mackerel in the Aleutian Islands region make it difficult to estimate an equilibrium sustainable yield. Therefore, only acceptable biological catch is estimated.

The 1987 fishery had difficulty reaching the 1987 quota of 30,739 t. The catch-at-age analysis indicates that recruitment has been relatively weak in 1982-86 (Table 8, coefficient of variation "E"). Thus, it may be more appropriate to estimate ABC based on these most recent levels of recruitment. This would suggest an ABC of 20,963 t (Table 9, coefficient of variation "E") again averaged over all natural mortality rates.

Table 10.--Estimates of maximum sustainable yield in metric tons for Atka mackerel in the Aleutian Islands region using Schnute's (1985) delay-difference equation. Estimates in the upper half of the table assume F = M at the point of maximum sustainable yield; those in the bottom half assume F = F(0.1) at the point of maximum sustainable yield. Estimates in parentheses are based on 1982-86 recruitment estimates.

Natural mortality (M)	Coefficients of variation of survey biomass estimates: E[a]	0.25[b]	0.10[b]	0.01[b]
	Estimates of MSY assuming Schnute's Delay-difference Model and F=M			
0.20	28,239 (19,817)	40,376 (32,697)	41,863 (39,386)	60,936 (84,221)
0.30	29,368 (16,077)	42,444 (27,439)	42,230 (34,298)	61,308 (84,031)
0.40	34,398 (14,234)	51,004 (25,304)	47,247 (32,421)	65,830 (89,948)
Average	30,668 (16,709)	44,608 (28,480)	43,780 (35,368)	62,691 (86,067)
	Estimates of MSY assuming Schnute's Delay-difference Model and F=F(0.1)			
0.20 F(0.1)=0.20	28,239 (19,817)	40,376 (32,697)	41,863 (39,386)	60,936 (84,221)
0.30 F(0.1)=0.35	30,868 (16,898)	44,612 (28,840)	44,387 (36,050)	64,440 (88,323)
0.40 F(0.1)=0.53	37,836 (15,656)	56,102 (27,833)	51,970 (35,662)	72,410 (98,939)
Average	32,314 (17,457)	47,030 (29,790)	46,073 (37,033)	65,929 (90,494)
Grand average	31,491 (17,083)	45,819 (29,135)	44,927 (36,201)	64,310 (88,281)

[a]Estimated coefficient of variation of survey biomass estimates: 0.415 in 1980, 0.215 in 1983, and 0.629 in 1986.
[b]Other possible coefficients of variation for survey biomass estimates.

SQUID

by

Richard G. Bakkala

INTRODUCTION

Assessment data are not available for squid from Northwest and Alaska Fisheries Center surveys because of their mainly pelagic distribution over deep water. Information on the distribution, abundance, and biology of squid stocks in the eastern Bering Sea and Aleutian Islands region is generally lacking. Berryteuthis magister predominates in commercial catches in the eastern Bering Sea and Onychoteuthis borealijaponicus is the principal species encountered in the Aleutian Islands region.

CATCH STATISTICS

Squid are generally taken incidentally in target fisheries for groundfish but have been the target of Japanese and Republic of Korea trawl fisheries in the past. Distribution of catches shows that the major fishing area for squid is on the continental slope of the eastern Bering Sea (Table 1). Reported catches reached a peak of 9,000 metric tons (t) in 1978. Since 1978, squid catches have steadily declined to only about 900 t in 1986. The squid stocks are believed to be large and have probably only been lightly exploited even during years of highest catches.

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. 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.

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[a]

Year	Aleutian Islands Region						Eastern Bering Sea						Regions Combined
	Japan	R.O.K.[b]	Other non-U.S. fisheries[c]	U.S. joint ventures[d]	U.S. domestic[e]	Total	Japan	R.O.K.	Other non-U.S. fisheries	U.S. joint Ventures	U.S. domestic	Total	
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		4,183	5,945
1982	1,177	11	13			1,201	3,308	484	45	5		3,842	5,043
1983	452	52	4	1		509	3,346	104	11	9		3,470	3,979
1984	325		10	7		342	2,614	110	74	27		2,825	3,167
1985	1		4	4		9	1,469	15	99	27		1,610	1,619
1986			1	15	4	20	819	4	6	19		848	868

[a]Catches in 1977-79 from data submitted to the United States by fishing nations and available Northwest and Alaska Fisheries Center, 7600 Sand Point Way N.E., Seattle, WA 98115. Catches in 1980-86 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986, 1987a.
[b]Republic of Korea.
[c]Taiwan, Federal Republic of Germany, Poland, U.S.S.R., and People's Republic of China.
[d]U.S. Fishing vessels delivering catches to non-U.S. processing vessels.
[e]U.S. Fishing vessels processing their own catch or delivering catches to U.S. processors.

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, species 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.

During cooperative U.S.-Japan surveys in 1979 and 1980, 34 species of sculpins were identified in the eastern Bering Sea and 22 species in the Aleutian Islands region (Bakkala et al. 1985a; Ronholt et al. 1985). During these same surveys, 15 species of skates were identified but inadequate taxonomic keys for this family may have resulted in more species being identified than actually exists. Species that have been consistently identified during these surveys are the Alaska skate, *Raja parmifera*; big skate, *R. binoculata*; longnose skate, *R. rhina*; starry skate, *R. stellulata*; and Aleutian skate, *R. aleutica*. Sharks are rarely taken during demersal trawl surveys in the Bering Sea; spiny dogfish, *Squalus acanthias*, is the species usually caught, but the Pacific sleeper shark, *Somniosus pacificus*, has also been been taken on occasion. Two species of octopus have been recorded, with *Octopus dofleini* the principal species and *Opisthoteuthis californiana* appearing intermittently in catches.

CONDITION OF STOCKS

Catch statistics

The composition of catches reported as "other groundfish" species is unknown and likely includes species from both the "other species" group discussed here and the "nonspecified species" category as defined in Table 1 on page 3 of this report. Reported catches of other groundfish increased during the 1960s and early 1970s and reached a peak of 133,000 t in 1972 (Table 1) which was the year when total catches of all species of groundfish reached a maximum of 2.2 million t. The "other groundfish" catch in 1972 represented 6% of the total groundfish catch. Following 1972, catches remained relatively high fluctuating within the range of 33,000-74,000 t annually until 1981. Since 1981 reported catches declined further to a range of 10,000-14,000 t in 1984-86. In these latest years the reported catches of other groundfish have only represented about 1% of the total catches of all groundfish.

Table 1.--All-nation catches in metric tons of "other species" in the eastern Bering Sea and Aleutian Islands regions.[a]

	Eastern Bering Sea				Aleutian Islands region				
Year	Non-U.S. fisheries[b]	U.S. Joint ventures[c]	U.S. domestic[d]	Total	Non-U.S. fisheries	U.S. Joint ventures	U.S. domestic	Total	Regions combined
1964	736			736	66			66	802
1965	2,218			2,218	768			768	2,986
1966	2,239			2,239	131			131	2,370
1967	4,378			4,378	8,542			8,542	12,920
1968	22,058			22,058	8,948			8,948	31,006
1969	10,459			10,459	3,088			3,088	13,547
1970	15,295			15,295	10,671			10,671	25,966
1971	33,496			33,496	2,973			2,973	36,469
1972	110,893			110,893	22,447			22,447	133,340
1973	55,826			55,826	4,244			4,244	60,070
1974	60,263			60,263	9,724			9,724	69,987
1975	54,845			54,845	8,288			8,288	63,133
1976	26,143			26,143	7,053			7,053	33,196
1977	35,902			35,902	16,170			16,170	52,072
1978	61,537			61,539	12,436			12,436	73,973
1979	38,767			38,767	12,934			12,934	51,701
1980	33,955	678		34,633	13,028			13,028	47,661
1981	32,363	3,188	100	35,651	7,028	246		7,274	42,925
1982	17,480	720		18,200	4,781	386		5,167	23,367
1983	11,062	1,139	3,264	15,465	3,193	439	43	3,675	19,140
1984	7,349	1,159		8,508	184	1,486		1,670	10,178
1985	6,243	4,365	895	11,503	40	1,978	32	2,050	13,553
1986	4,043	6,115	313	10,471	1	1,442	66	1,509	11,980

[a]Catches in 1964-79 from data submitted to the United States by fishing nations. Catches in 1980-86 from French et al. 1981, 1982; Nelson et al. 1983b, 1984; Berger et al. 1985a, 1986, 1987a.
[b]Japan, U.S.S.R., Republic of Korea, Taiwan, Federal Republic of Germany, Poland and Peoples Republic of China.
[c]U.S. Fishing vessels delivering catches to non-U.S. processing vessels.
[d]U.S. Fishing vessels processing their own catch or delivering catches to U.S. processors.

Biomass Estimates

Data from Northwest and Alaska Fishery Center surveys of the eastern Bering Sea in 1975 and 1979-87, and the Aleutian Islands region in 1980, 1983, and 1986 provide abundance estimates for the "other species" category and show the relative importance of the various species comprising this category (Table 2). The estimates illustrate that sculpins have generally been the major component of this group, but skates have become increasingly important and in 1987 the biomass of skates (350,100 t) exceeded that of sculpins (194,800 t).

Survey abundance estimates for the "other species" complex have shown general trends but have been irregular at times. Biomass estimates for the complex as a whole increased between 1975 and 1982 (with the exception of 1981) reaching an initial peak of 533,100 t in 1982 (Table 2). The estimates then declined to 334,250 t in 1985, but increased sharply to 573,100 t in 1986. The 1987 estimate of 556,700 t was similar to that in 1986.

The periodic major fluctuations in abundance estimates from the survey data may be the result of changes in availability of certain species in the survey area. Sculpins have been the principal cause of the large fluctuations in abundance of the total complex. The species mainly responsible for the variability in biomass estimates for sculpins has been the butterfly sculpin, Hemilepidotus papilio. This species has a relatively large biomass and is a cold water species distributed on the northern fringes of the survey area. Changes in the north-south distribution of this species, which moves farther south in cold water years, can substantially alter the annual biomass estimates for the sculpin complex. For example, the estimate for butterfly sculpin was 54,000 t in 1985, 159,000 t in 1986, and 9,300 t in 1987 which accounts for most of the changes in biomass of the sculpin complex between 1985 and 1987.

It should be pointed out that smelts and possibly sharks may be poorly sampled by demersal trawls because species in those groups primarily inhabit pelagic waters. The abundance of these groups are, therefore, assumed to be substantially underestimated.

Survey estimates indicate that the biomass of "other species" may be from 7 to 13% as large in the Aleutian Islands region as they are in the eastern Bering Sea.

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 maximum sustainable yield (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 Aleutians surveys approximated virgin biomass and 2) a natural mortality coefficient of 0.2, the Alverson and Pereyra (1969) yield equation would indicate that MSY (i.e., MSY = 0.5 x 0.2 x 589,800 t) is 59,000 t. The validity of the assumptions used to derive this estimate are obviously questionable and the estimate should be considered a rough approximation.

Table 2.--Biomass estimates (in metric tons) of "other species" from Northwest and Alaska Fisheries Center demersal trawl surveys.*

Area	Year	Species group: 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
	1987	194,800	350,800	2,900	200	8,000	556,700
Aleutian Islands Region	1980	39,400	13,700	0	800	2,800	56,700
	1983	20,500	12,100	0	0	200	32,800
	1986	39,200	19,100	2,400	0	900	61,600

*The biomass estimates for the eastern Bering Sea are from a standard survey area of the continental shelf. The 1979, 1981, 1982, and 1985 data includes 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 (618,300 t) from the 1987 eastern Bering Sea and 1986 Aleutian Islands surveys, the MSY of 59,100 t would represent an exploitation rate of 10%. The biomass estimates from the eastern Bering Sea in 1986 and 1987 were similar, which provides some confidence in the magnitude of these latest estimates. There appears to be no reason to reduce acceptable biological catch (ABC) below the MSY value. Thus, ABC is estimated to equal MSY or 59,000 t. Recent by-catches of the "other species" group (10,000-14,000 t) have been well below the ABC estimate.

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