NOAA Technical Memorandum NMFS F/NWC-25

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March 1982

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

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by

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ABSTRACT

Resource assessment surveys by the Northwest and Alaska Fisheries Center (NWAFC) have shown a substantial increase in abundance of Pacific cod in the eastern Bering Sea since 1977. This increase is primarily due to the emergence of the strong 1977 year-class. Because the life span of cod is relatively short and the current high abundance of the population is mainly the result of a single year-class, stock abundance may soon return to lower levels. It is important to predict these trends in abundance so that the fishing industry can anticipate the future harvest potential of the resource.

Abundance of the cod population was projected through 1986 using a numeric population simulator. The simulator projects numbers-at-age from given numbers-at-age in a base year using estimates of natural (M) and fishing (F) mortality and recruitment. Base year data used were from the 1979 NWAFC survey. Because counts of annual rings from cod scales have recently been shown to produce questionable age composition data, a modal analysis of size-frequency data was used to provide age specific population estimates. An estimate of natural mortality was derived by an iterative procedure starting, with the 1979 survey data and by adjusting M until population numbers from the 1980 and 1981 NWAFC surveys were approximated. The F values used in the simulator were based on various levels of exploitation (E) that were adjusted so that the effects of various options of exploitation on the population could be examined. Estimates of annual recruitment in 1982-86 were based on average levels of recruitment observed from survey data in 1976-81. One estimate included recruitment from the strong 1977 year-class; the second estimate excluded this year-class. Because a year-class of the magnitude of the 1977 year-class has only been observed once in the lo-year period of 1971-81, the probability is low that another year-class of this size will occur before 1986. The lower average

recruitment of 221 million fish was, therefore, considered to be the most reasonable estimate.

A number of simulations were run using various exploitation rates. The method of exploitation that would appear to provide the greatest cumulative catch in 1982-86 (and still maintain a parental stock size approximating that which produced the strong 1977 year-class) was the method using variable exploitation rates of 0.4 in 1982 and 1983 but 0.2 thereafter. Results of this simulation were as follows:

Year	Total population (1,000 t)	Fished population (1,000 t)	Recruits (millions of fish)	Catch (1,000 t)
1979	823.9	297.9	1,106	33.0
1980	919.9	709.6	442	43.4
1981	758.6	695.7	132	59.1
1982	599.7	494.3	221	197.7
1983	364.2	258.7	221	103.5
1984	294.1	188.6	221	37.7
1985	309.6	204.1	221	40.8
1986	317.9	212.4	221	42.5

This schedule of exploitation will: allow the fishery to increase harvests of cod while the strong 1977 year-class is still relatively abundant in the population. The surplus might otherwise be lost to natural mortality. This schedule will also maintain a, parental population size which is believed to be as large as or larger than the parental stock that produced the 1977 year-class.

The above projections of population abundance are believed to be conservative. Base year data used in the projections were from the 1979 NWAFC survey. Population estimates from the survey were based on an assumed catchability coefficient of 1.0, i.e., all cod in the path of the trawl were caught. If the catchability coefficient was less than 1.0, which seemed likely, then survey population estimates and those projected by the simulation model would underestimate the true abundance of cod. Values of natural mortality and recruitment used in the simulations are also believed to produce conservative estimates of population size. Thus, the exploitation rates resulting from the projected catches will probably be lower than indicated by the simulation model.

The simulation indicates that the contribution of the strong 1977 year-class will diminish substantially when it reaches age 7 in 1984. Catches will then have to be reduced to more historical levels. It is unlikely that catches will have to be reduced to the 38,000 to 42,000 metric ton (t) range in 1984-86 as shown by the simulation. Catches in the foreign fishery averaged 53,400 t in 1970-76 without harming the stock's capability to produce the strong 1977 year-class. There is also the safeguard provided by the Aleutian Islands population, estimated to be 299,000 t in 1980. A portion of the catches in 1982-86 would be expected to come from the Aleutian Islands region.

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INTRODUCTION

Resource assessment surveys by the Northwest and Alaska Fisheries Center (NWAFC) have shown a substantial increase in abundance of Pacific cod in the eastern Bering Sea since 1977. This increase is mainly due to the presence of a strong year-class in the population. Because the life span of cod is relatively short and the present high abundance is primarily due to a single year-class, abundance of the stock may soon return to lower levels. Increasing interest in Bering Sea cod by U.S. fishermen makes it important to provide information on expected population trends as the abundance of this strong year-class declines.,

Projections of abundance for Pacific cod are complicated by the relatively short time series of assessment data available for this species and the apparent difficulties of obtaining reliable ages from the reading of age structures, such as scales. We are observing a strong year-class in the population for the first time since NWAFC groundfish assessment surveys were initiated in 1971. Thus, there is no survey data base to forecast the longevity and contribution of this strong year-class to the fishable stock. However, an alternative method of aging fish populations and a numeric population simulator are used to predict levels of abundance through the mid-1980s.

RECENT HISTORY OF EXPLOITATION

During the early 1960s, a Japanese longline fishery targeted on cod for a frozen fish market. Catches in this period were relatively low compared to those in the 1970s (Table 1). In 1964, the Japanese trawl fishery began to target on walleye pollock (*Theragra chalcogramma*), and this fishery, later joined by other nations, expanded into one of the largest single species fisheries in the world. Pacific cod are an important component of the by-catch of

Table 1.--Catches of Pacific cod (t) in the eastern Bering Sea, 1954-80:

Year	Japan	U.S.S.R.	ROK	Taiwan	West Germany	Poland	U.S.1/	Total
1954	-2/							-
1955	-							-
1956	-							-
1957	-							-
1958	223	-						223
1959	3,632	-						3,632
1960	5,679	-						5,679
1961	6,883	-						6,883
1962	10,347	-						10,347
1963	13,641	-						13,641
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	-	-				33,318
1978	41,234	419	859	62				42,574
1979	28,532	1,956	2,446	38		9		32,981
19803/	29,524	11	6,404	200	552	628	8,456	45,775

1/ Catch by U.S. vessels delivering catches to Republic of Korea and U.S.S.R. processors in joint venture operations.

2/ Dash indicates fishing but catches of cod not reported.

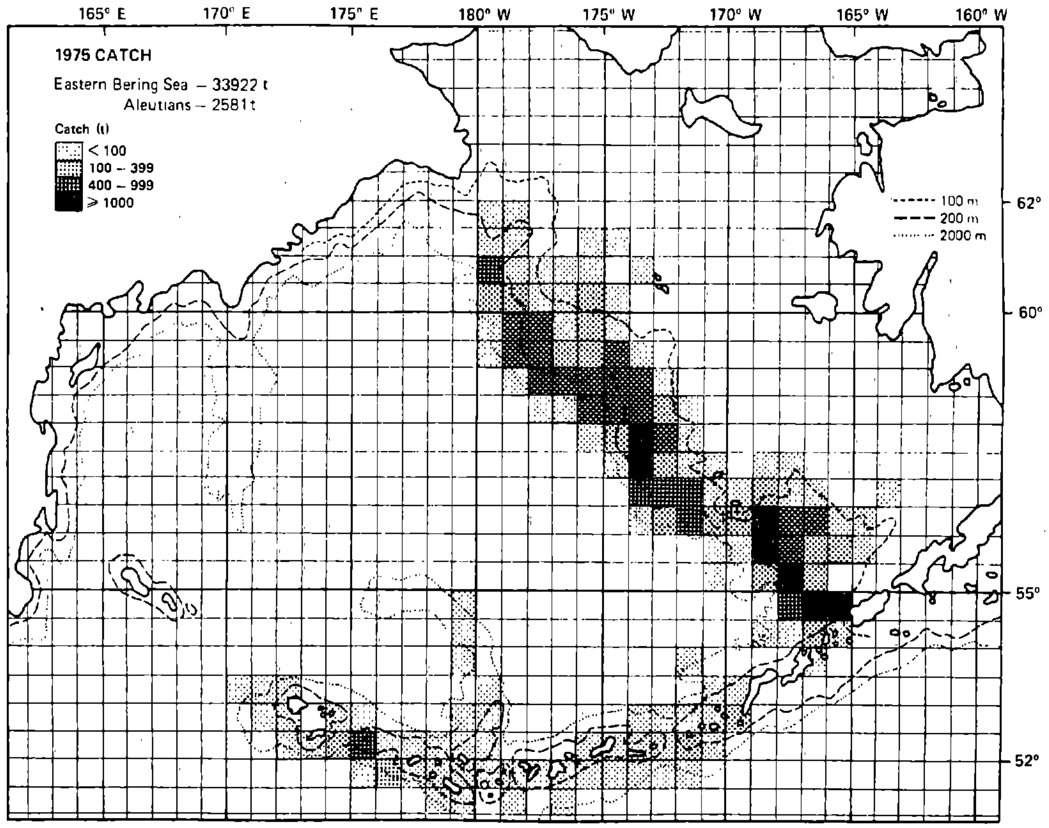
3/ Preliminary.

the pollock fishery, and catches of cod increased during the late 1960s as the pollock fishery expanded (Table 1). At present, cod are primarily taken as a by-catch in the foreign pollock fishery but are a target species when high concentrations are encountered. Cod is also a target species of the Japanese longline fishery at times. In 1980, about 5,700 t of the total Japanese cod catch of 29,500 t was taken by longliners; almost all of the longline catch was taken in the eastern Bering Sea.

Reported catches of cod by the foreign fisheries in the eastern Bering Sea increased from 13,400 metric tons (t) in 1964 to about 70,000 t in 1970 (Table 1). Since then catches have varied between 33,000 and 62,500 t. Most of the catch comes from the eastern Bering Sea; the maximum reported foreign catch in the Aleutians was 5,600 t in 1979. In 1981, the developing domestic fishery took 8,720 t in the Aleutian Islands area and southeastern Bering Sea; an additional 9,220 t were taken in joint venture fisheries between U.S. fishermen and foreign factory ships in the Bering Sea.

Fluctuations in catches give no indication of exceptionally strong year-classes in the cod population during the period of recorded catches (1958-80). Because of the unreliability of catch and effort data and insufficient information on the age composition of the catch, the presence of a strong year-class in the population may not have been apparent from catch data. Catches of cod since 1969 have fluctuated between 33,000 t and 70,000 t, suggesting some variation in population abundance.

The distribution of catches of cod in 1975 and 1977 by Japanese fisheries is illustrated in Figure 1. These data appear to typify two types of catch distribution that have been observed in the fishery. In 1975 catches came almost entirely from waters deeper than 100 m. In 1977 catches extended in-shore to waters much shallower than 100 m. These differences may result from



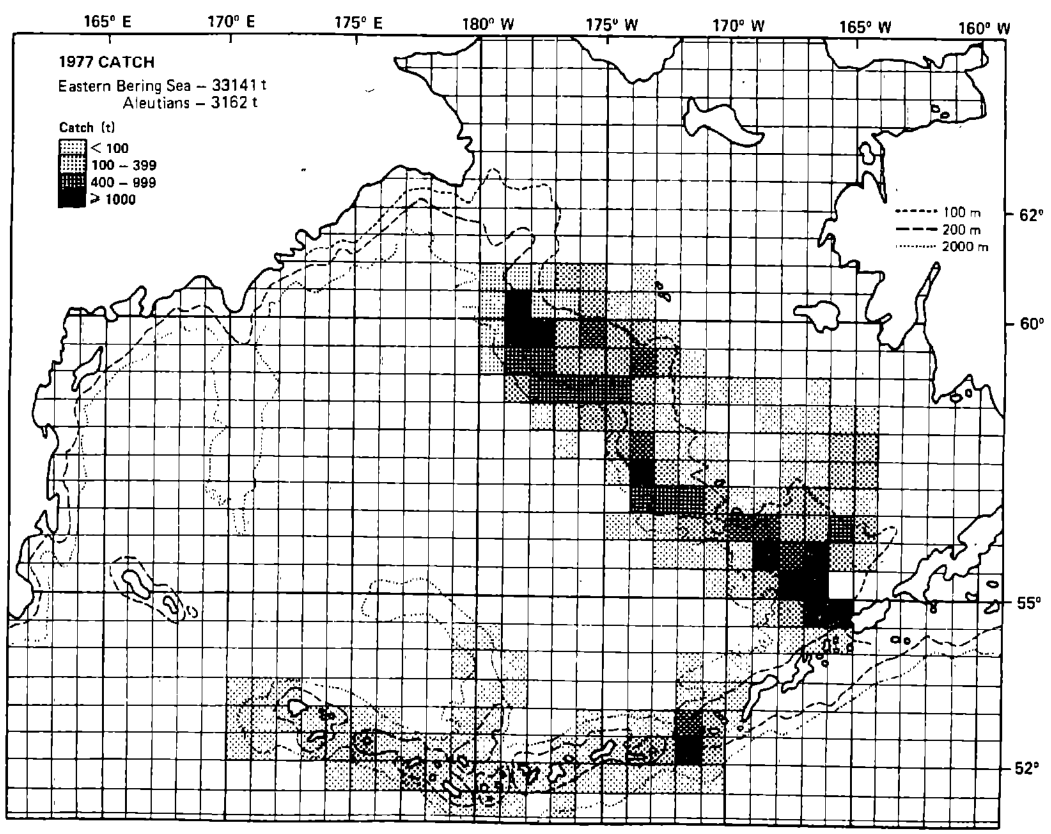


Figure 1.--Distribution of catches of Pacific cod by Japanese fisheries in 1975 and 1977.

a combination of factors such as changes in the distribution of pollock associated with variation in environmental conditions and strength of year-classes of cod. In years of colder bottom temperatures such as in 1975, the pollock fishery appears to operate mainly at depths greater than 100 m. By-catches of cod in the pollock fishery would, therefore, also come from this area. In years of warmer bottom temperatures, such as 1977, the pollock operations appear to extend into shallower water where cod are also taken. Cod located on the central shelf are mainly juveniles, and the magnitude of cod catches in these shallower waters is probably a function of the strength of year-classes.

Although cod catches appear to be more extensive geographically in warm years than in cold years, most of the cod catch comes from the outer continental shelf each year (Figure 1). Highest catches generally occur along the shelf edge in waters extending from near Unimak Pass to about 60°N. Catches are roughly equally divided between the areas southeast and northwest of the Pribilof Islands; in 1975, 48% of the total Japanese catch came from southeast of the Pribilofs and in 1977, 47%.

EVIDENCE OF INCREASED ABUNDANCE OF PACIFIC COD

Resource assessment surveys by the NWAFC have been the primary source of data used to follow trends in abundance of cod. Indices of relative abundance from the foreign fishery are not believed to provide reliable estimates of the abundance for cod because of the incidental nature of catches. Trends in abundance from Japanese pair trawl and stern trawl fisheries (which are believed to provide reliable indices of abundance of target species such as pollock and yellowfin sole) have simultaneously shown fluctuating and stable trends in abundance of cod from 1970 to 1979, neither of which are in agreement with trends shown by NWAFC resource assessment surveys (Figure 2).

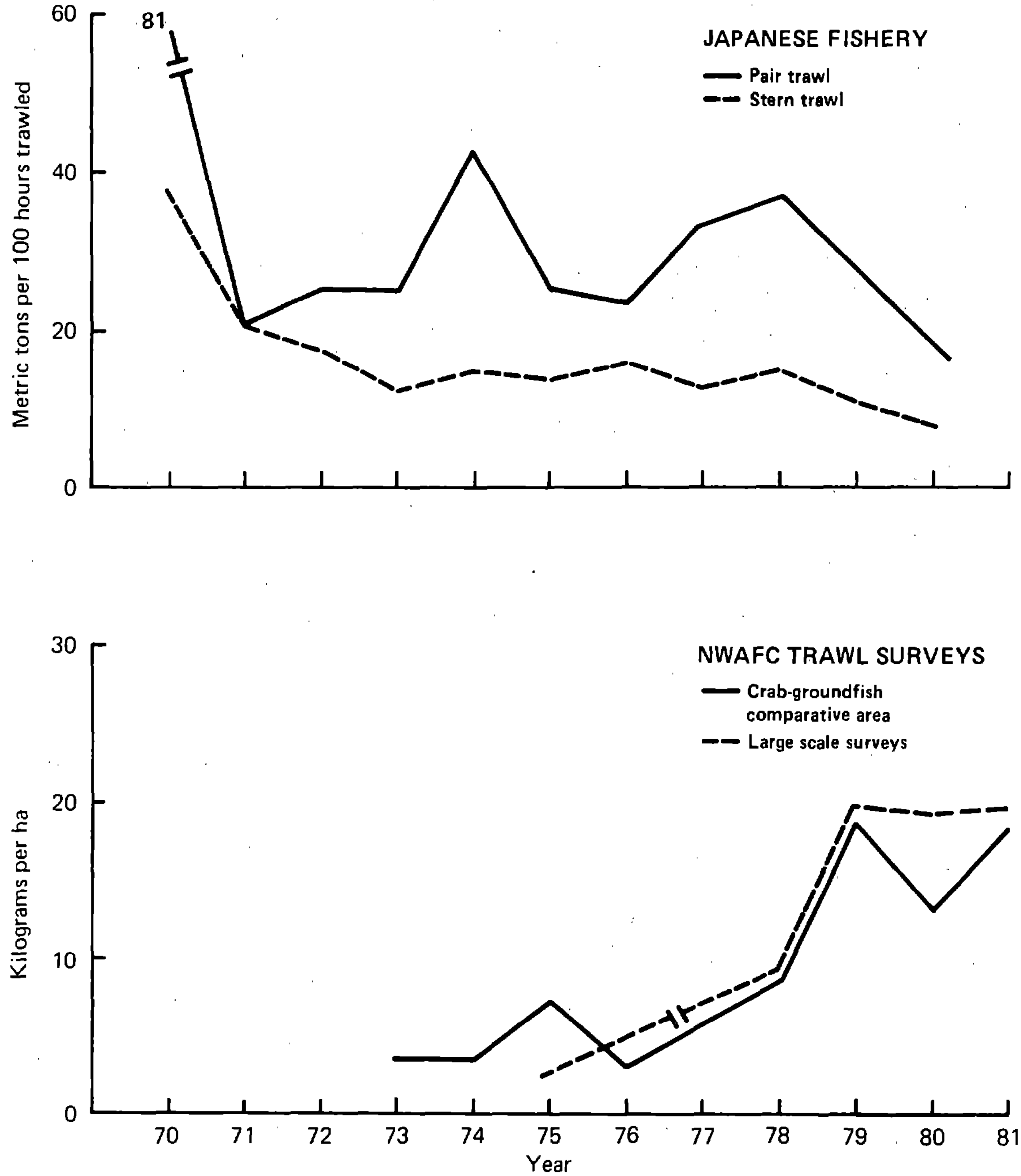


Figure 2. --Relative abundance of Pacific cod as shown by data from the Japanese commercial fishery and from NWAFC research vessel surveys.

Two sets of NWAFC survey data have been used to examine trends in abundance of cod. The first is from an area of the southeast Bering Sea (Figure 3) which has been consistently surveyed since 1973. The second is from larger scale NWAFC surveys in 1975-76 and 1978-81 that have sampled much of the eastern Bering Sea continental shelf north to the latitude of St. Matthew and Nunivak Islands. Trends from the two data sets have been similar (Figure 2) and indicate that abundance was relatively stable from 1973 to 1977 but increased substantially from 1977 to 1979. Abundance increased 7 to 10 times from levels observed in 1975-77 and has remained at the higher level through 1981.

Minimal estimates of biomass from only the large scale NWAFC surveys are shown below:

Year	Mean estimate (t)	95% confidence interval (t)
1975	64,500	51,500 - 77,500
1976	102,300	70,600 - 134,000
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

These estimates assume a catchability coefficient of l.0., i.e., all cod in the path of the trawl are caught. Because the catchability coefficient is probably less than 1.0, the true biomass of the stock may be larger than shown by these estimates.

The mean estimates suggest that abundance of the stock may have peaked in 1980 although the overlap in the 95% confidence intervals indicates that the estimates in 1979, 1980, and 1981 were not significantly different.

These estimates represent only the eastern Bering Sea population. Annual estimates are not available for the Aleutian Islands region except in 1980 when the NWAFC, in cooperation with the Fisheries Agency of Japan, conducted

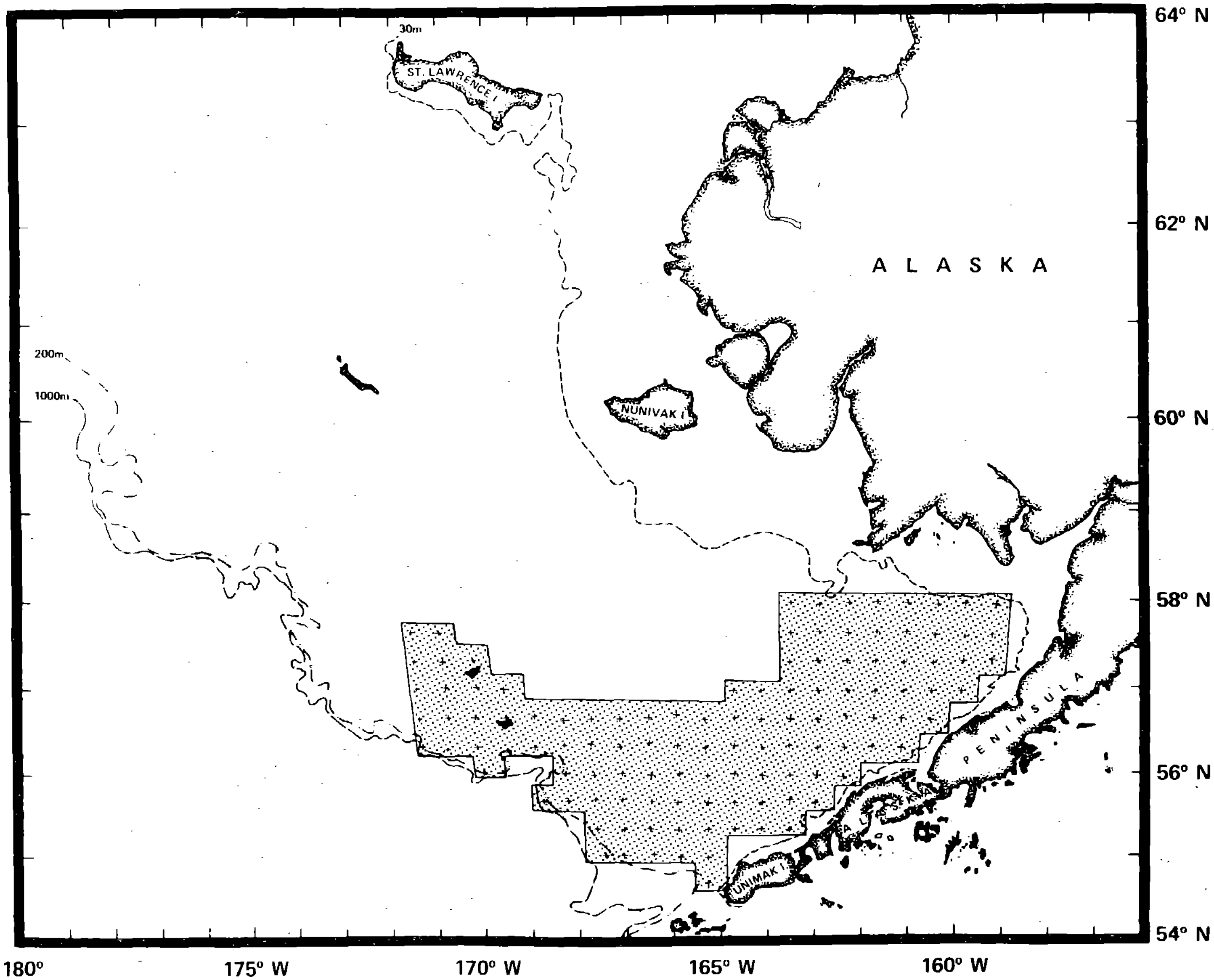


Figure 3. --NWAFC crab-groundfish comparative fishing area in the southeast Bering Sea.

an extensive demersal trawl survey in those waters. A preliminary biomass estimate of 299,000 t was derived for cod from this survey (Brown and Wilderbuer 1982). Of the total, 202,000 t or 68% was located in the eastern Aleutian Islands east of Amutka Pass (172°W). The relationship between the eastern Bering Sea and Aleutian Islands populations is unknown. Length measurements taken in 1980 illustrate substantial differences in the size distribution of the two sampled populations (Figure 4). The population in the eastern Bering Sea ranged in length from 11 to 87 cm, with a large mode centered at 41 cm. The Aleutian Islands population ranged in length from 29 to 102 cm with a mode peaking at 47 cm and relatively high proportions of large fish over 60 cm. The major differences in the length compositions suggest the possibility of independent stocks in the two regions.

AGE COMPOSITION AND YEAR-CLASS STRENGTH

Aging methods used for cod at the Northwest and Alaska Fisheries Center have been based on counts of annual rings from scales. Recent evidence from surveys indicate that scales may not be an appropriate structure for aging Bering Sea cod (Bakkala 1982).

An alternate method of estimating age composition was therefore examined. Survey data were analyzed using a computer program developed by MacDonald and Pitcher (1979) which iteratively fits normal curves to the modes in a length-frequency distribution to apportion the sampled population to age groups. Size-at-age and annual growth rates from this method were found to be comparable to those shown by the modal peak lengths formed by the abundant group of juvenile cod that were first observed in 1978 survey catches and have dominated catches through 1981 (Figure 5).

The length-frequency derived ages (Table 2) reveal that the span of eastern Bering Sea cod is greater than 10 years and that year-classes continue to

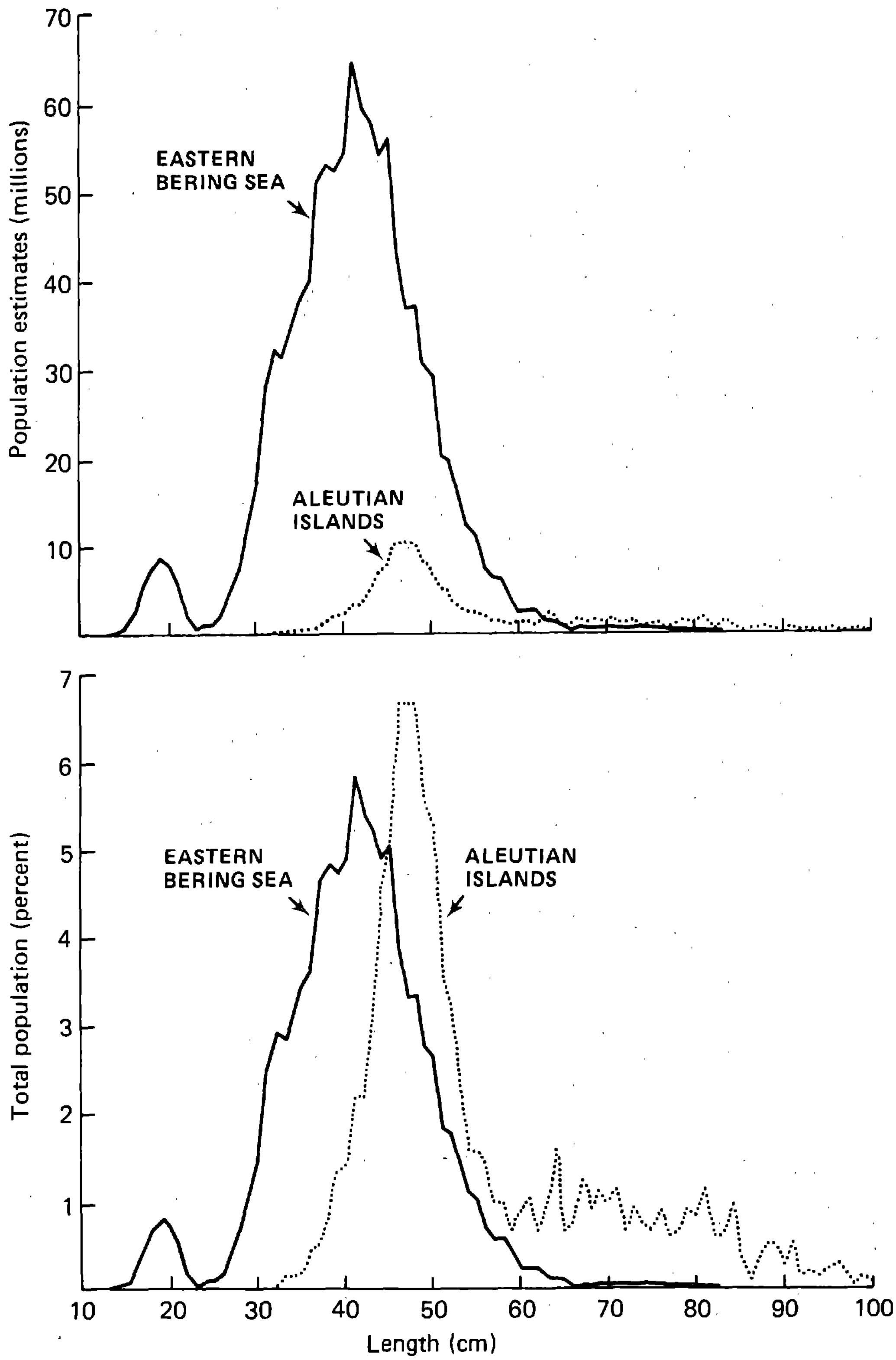


Figure 4.--Length composition of sampled populations of Pacific cod in 1980 from the eastern Bering Sea and Aleutian Islands regions.

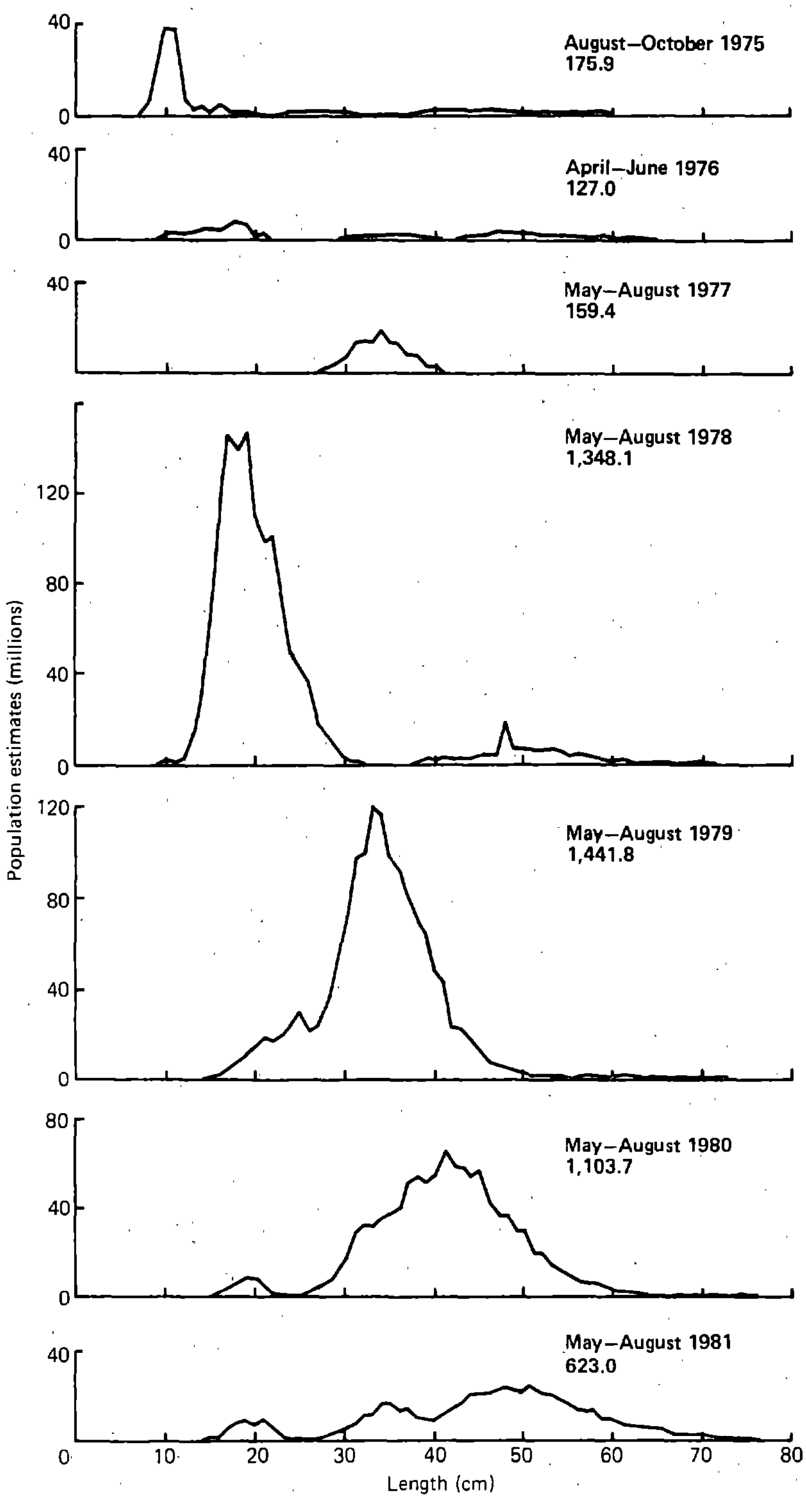


Figure 5 .--Length composition of Pacific cod in the eastern Bering Sea based on data from NWAFC resource assessment surveys, l975-1980. Numbers below dates of the surveys are estimated population numbers within the survey areas.

Table 2.--Estimated population numbers in millions of fish for Pacific cod of the eastern Bering Sea as determined by the method of MacDonald and Pitcher (1979). Population numbers for the 1977 year-class are underlined.

	Year					
	1976	1977[1]	1978	1979	1980	1981
1	55.4	0	1,268.2	158.4	42.7	62.0
2	23.9	486.0	24.2	1,106.6	442.4	132.3
3	24.5	14.0	32.8	213.5	477.4	145.4
4	11.1	24.4	24.8	12.0	93.6	166.4
5	3.7	8.6	23.1	10.6	30.9	49.9
6	3.6	4.5	9.8	6.4	6.5	32.5
7	2.8		2.8	6.3	2.1	22.1
8	0.3	2.8	4.2	2.4	3.3	9.0
9	1.2		2.1	0.7	3.4	1.1
≥ 10	0.4		1.8	1.1	1.4	3.1
Total	127.0	541.1	1,393.9	1,518.0	1,103.7	623.0

1/ The 1977 survey was limited to the southeast Bering Sea as shown in Figure 3. Population numbers shown here were expanded to approximate numbers that would have been available if the 1977 survey area was equivalent in area to the 1979 survey area.

contribute substantial numbers to the population through ages 5 or 6. The analysis also indicates that the substantial increase in abundance of the population is primarily due to a single year-class, the 1977 year-class.

The computer analysis may not completely separate population numbers to age groups accurately, especially in the case of age groups adjacent to an abundant age group such as the 1977 year-class. There is also the obvious problem of some fully recruited year-classes showing higher abundance at an older age such as shown by the 1980 and 1981 data although this could be a sampling problem. Regardless of these reservations, the results from the length-frequency method appear to reflect observed trends in age and growth of the Bering Sea cod population.

PROJECTIONS OF ABUNDANCE THROUGH 1986

Methods

Abundance of cod in 1982-86 was estimated using a numeric population simulator. The simulation model predicts age specific abundance in future years through a population decay function:

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

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

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

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

The starting population numbers-at-age used in the simulator were those estimated from the 1979 NWAFC survey (Table 2). These data were used for two reasons. First, numbers at age' were probably more accurately estimated in

1979 than in subsequent years because, in 1979, the length range of the strong 1977 year-class was still relatively narrow and had not begun to extensively overlap those of adjacent year-classes. This allowed better separation of population numbers among age groups with the length-frequency aging method. Secondly, using the 1979 survey data as a starting point provided a means of checking results of the simulations by comparing projected population estimates in 1980 and 1981 against survey estimates in those years.

Natural mortality was determined by first approximating its upper limit based on estimates of total mortality (Z), which was derived by regression analysis of 1976-81 survey age composition data. The regression of the natural log of average numbers at ages 2-9 resulted in a Z value of 0.71 (r^2 = 0.977). This estimate indicates that the average M for all ages is less' than 0.71. Another approximation of M was derived by using 1979 survey population estimates by age as a starting point and varying M between 0.6 and 0.8 to find a value that most closely approximated abundance estimates shown by the 1980 and 1981 surveys. The value derived (0.7) is slightly higher than the M of 0.6 reported for British Columbia cod (Ketchen 1964). It would be assumed that cod from more southern parts of its range would be faster growing, shorter lived, and have a higher natural mortality than more northern stocks. The estimate of 0.7 for the eastern Bering Sea stock may therefore be high, but using this relatively high value represents a conservative approach in that projections of population abundance will be underestimated.

Fishing mortality used in the simulation was derived from exploitation rates (E), defined as the harvested proportion of the exploitable population (ages 3-11). The total catch for each year of the simulation was converted from weight to numbers by a mean individual fish weight calculated as the sum of average weights-at-age, weighted by the population numbers-at-age. The ‘catch from each age was assumed to be proportional to the abundance of that age in the exploitable population. The resulting exploitation rate (catch in numbers/exploitable population in numbers) was used to calculate the F value which the population decay function used to project population numbers forward another year. The **F** value corresponding to E was arrived at iteratively from the catch equation ($E = [F\ (1-e^{-z})]/Z$) where Z = M + F. F was increased from 0 in steps of 0.001 until the E calculated in the catch equation was within + 0.5% of the actual E.

The data series for Pacific cod in the eastern Bering Sea is insufficient to determine whether a spawner-recruit relationship exists. Instead, two estimates of annual recruitment were used for 1982-86; for 1980 and 1981, survey estimates of recruitment were used. The estimates used in 1982-86 were: 369 million fish, the average number of age 2 cod in survey estimates in 1976-81, and 221 million fish, the average excluding the, strong 1977 year-class.

Age specific weights were calculated from mean lengths-at-age using a length-weight relationship derived from data collected during the 1981 NWAFC survey:

$$\text{Weight} = a\ L^b$$

where $a = 0.0166$

$b = 2.9311$

Mean lengths-at-age used to calculate age-specific weights were averages of values derived from 1976-81 survey data. Mean lengths used and the calculated weights were as follows:

Age	2	3	4	5	6	7	8	9	10	11
Length (cm)	35.0	44.4	51.7	57.5	62.3	66.4	70.9	75.7	81.7	86.7
Weight (kg)	0.48	0.96	1.49	2.04	2.58	3.11	3.76	4.56	5.70	6.79

Results

An example of projected numbers-at-age through 1986 from the simulation are shown in Table 3. These data illustrate the expected decline in abundance of the 1977 year-class (age 2 in 1979) and indicate that its contribution to the exploitable population will be considerably reduced by 1984.

Table 4 shows expected trends in total and exploitable population levels by weight from the simulation using various constant levels of catch in 1982-86 and the low average recruitment level (221 million fish at age 2). Table 5 shows the same simulation using the high average recruitment (369 million fish). The trends are similar, but as would be expected, the decline in biomass is lower with the higher level of recruitment. If the higher level of recruitment was realized, constant levels of catch of 120,000 t in 1982-86 would only reduce the population biomass to an estimated 454,000 t, well above the population biomass that was believed to produce the strong 1977 year-class. Because a year-class as strong as the 1977 year-class has only been observed once in the lo-year period of 1971-81, there is a low probability of another year-class of this magnitude occurring in the period under consideration. Thus, the lower average recruitment (221 million fish) is believed to represent the more likely situation in 1982-86. With this assumption, the exploitable population biomass would be expected to decline by 1986 to range from 349,000 t with no fishing to as low as 120,000 t with a constant annual catch of 120,000 t in 1982-86 (Table 4, Figure 6).

Results of simulations using different constant rates of exploitation (from 20% to 80%) and low average recruitment are given in Table 6. These simulations show, as is illustrated in Figure 6, that cumulative catches in 1982-86 would be maximized if catches were increased during the period that fish of the 1977 year-class were still contributing substantially to the

Table 3.--Projected numbers-at-age in millions of fish in 1980-86 from the population simulation using M = 0.7, E = 0.2 and recruitment = 221 million fish. Numbers. for the 1977 year-class are underlined.

AGE	YEAR							
	1979	1980	1981	1982	1983	1984	1985	1986
2	1106.6	442.4	132.3	221.9	221.9	221.9	221.9	221.9
3	213.5	549.5	219.7	65.7	110.2	110.2	110.2	110.2
4	12.0	90.5	251.7	97.0	23.9	40.1	40.1	40.1
5	10.6	5.1	41.5	111.1	35.3	8.7	14.6	14.6
6	6.4	4.5	2.3	18.3	40.4	12.9	3.2	5.3
7	6.3	2.7	2.1	1.0	6.7	14.7	4.7	1.2
8	2.4	2.7	1.2	0.9	0.4	2.4	5.4	1.7
9	0.7	1.0	1.2	0.5	0.3	0.1	0.9	2.0
10	1.1	0.3	0.5	0.5	0.2	0.1	0.0	0.3
11	0.0	0.5	0.1	0.2	0.2	0.1	0.0	0.0
SUM	1359.6	1099.2	652.6	517.1	439.5	411.3	401.0	397.3
F=	0.158	0.081	0.118	0.310	0.310	0.310	0.310	0.310
E=	0.021	0.037	0.068	0.114	0.099	0.092	0.089	0.088
CATCH=	28.0	40.2	44.2	59.1	43.5	37.9	35.8	35.1
MWT=	1.177	1.080	1.337	1.674	1.576	1.439	1.353	1.308

F = fishing mortality
Catch in million fish
MWT = Mean individual fish weight (kg) in catch

Table 4.--Forecast of Pacific cod abundance in thousand metric tons in the eastern Bering Sea, 1982-86 under varying levels of catch with M = .700. Recruitment in 1982-86 is the low average from 1976-81 survey data.

Year	Total Popn.	Fished Popn.	Recruits Millions	Catch	E	F	MWT
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	0.0	0.000	0.000	1.674
1983	535.1	429.6	221.0	0.0	0.000	0.000	1.673
1984	492.3	386.8	221.0	0.0	0.000	0.000	1.627
1985	468.1	362.6	221.0	0.0	0.000	0.000	1.589
1986	454.6	349.1	221.0	0.0	0.000	0.000	1.562
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	58.0	0.117	0.169	1.674
1983	484.6	379.1	221.0	58.0	0.153	0.228	1.620
1984	410.1	304.6	221.0	58.0	0.190	0.293	1.503
1985	364.9	259.4	221.0	58.0	0.224	0.354	1.400
1986	336.8	231.4	221.0	58.0	0.251	0.407	1.324
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	78.0	0.158	0.236	1.674
1983	466.9	361.4	221.0	78.0	0.216	0.339	1.599
1984	381.4	275.9	221.0	78.0	0.283	0.472	1.451
1985	328.5	223.0	221.0	78.0	0.350	0.622	1.319
1986	294.9	189.4	221.0	78.0	0.412	0.780	1.220
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	120.0	0.243	0.391	1.674
1983	430.1	324.6	221.0	120.0	0.370	0.670	1.551
1984	321.7	216.2	221.0	120.0	0.555	1.252	1.323
1985	254.0	148.6	221.0	120.0	0.808	2.000	1.114
1986	225.5	120.0	221.0	120.0	1.000	2.000	1.007

F = fishing mortality
E = exploitation rate for fished population (ages 3-11)
MWT = Mean individual fish weight (kg) in catch

Table 5.--Forecast of Pacific cod abudance in thousand metric tons in the eastern Bering Sea, 1982-86 under varying levels of catch with M = .700. Recruitment in 1982-86 is the high average from 1976-81 survey data.

Year	Total Popn.	Fished Popn.	Recruits Millions	Catch	E	F	MWT
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	669.9	494.3	369.0	0.0	0.000	0.000	1.674
1983	675.1	499.5	369.0	0.0	0.000	0.000	1.513
1984	686.6	511.0	369.0	0.0	0.000	0.000	1.471
1985	699.2	523.6	369.0	0.0	0.000	0.000	1.472
1986	708.8	533.2	369.0	0.0	0.000	0.000	1.481
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	669.9	494.3	369.0	58.0	0.117	0.169	1.674
1983	624.7	449.1	369.0	58.0	0.129	0.188	1.462
1984	603.2	427.6	369.0	58.0	0.136	0.198	1.380
1985	594.0	418.4	369.0	58.0	0.139	0.203	1.351
1986	589.3	413.7	369.0	58.0	0.140	0.206	1.339
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	669.9	494.3	369.0	78.0	0.158	0.236	1.674
1983	606.9	431.3	369.0	78.0	0.181	0.276	1.441
1984	573.7	398.1	369.0	78.0	0.196	0.303	1.344
1985	556.0	380.4	369.0	78.0	0.205	0.319	1.303
1986	545.7	370.1	369.0	78.0	0.211	0.330	1.281
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	669.9	494.3	369.0	120.0	0.243	0.391	1.674
1983	570.1	394.5	369.0	120.0	0.304	0.518	1.396
1984	512.2	336.6	369.0	120.0	0.356	0.638	1.261
1985	477.2	301.6	369.0	120.0	0.398	0.743	1.190
1986	454.5	278.9	369.0	120.0	0.430	0.831	1.146

F = fishing mortality
E = exploitation rate for fished population (ages 3-11)
MWT = Mean individual fish weight (kg) in catch

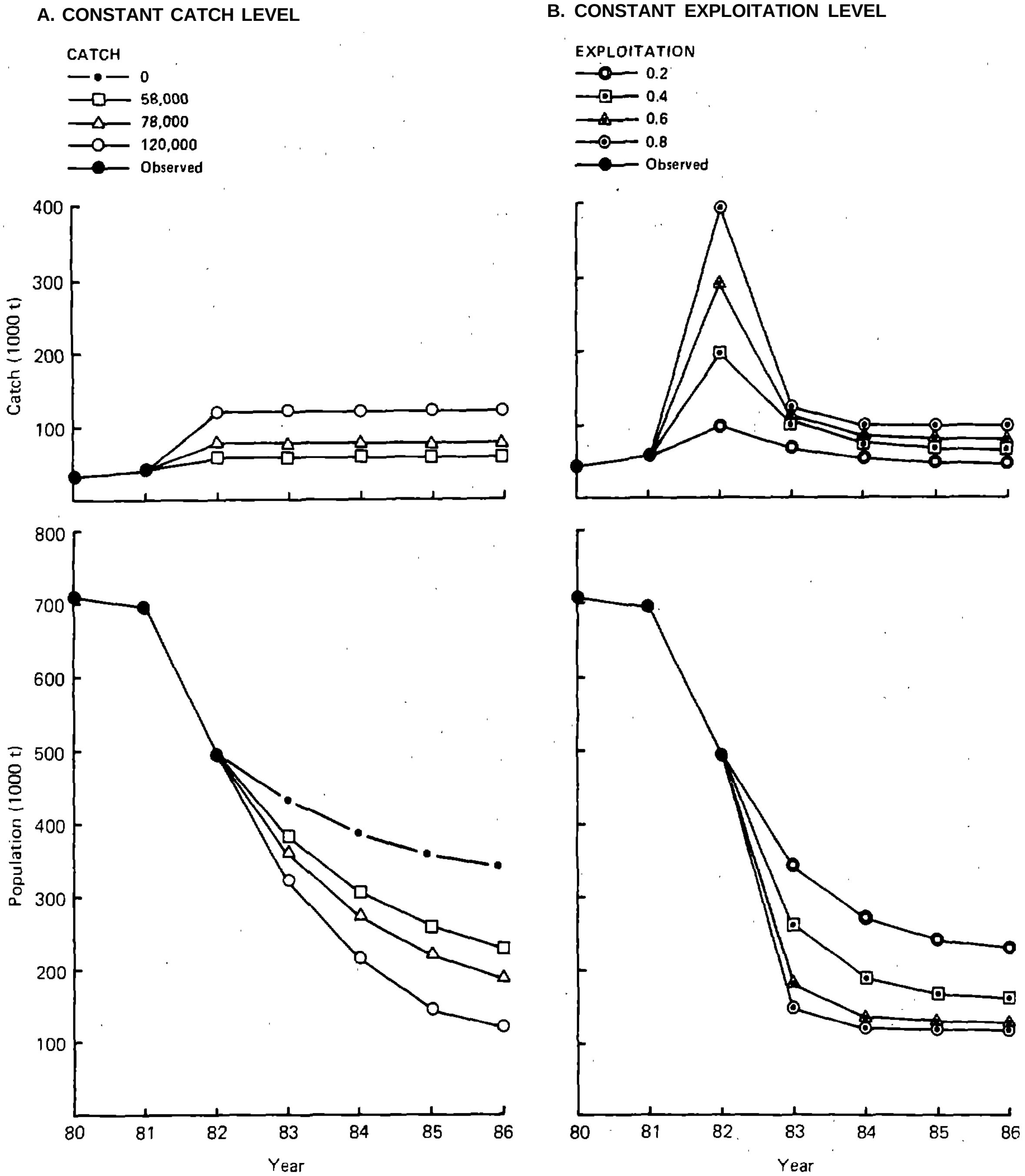


Figure 6. --Comparison of Pacific cod population trends in the eastern Bering Sea, 1980-86 under: A. different levels of catch, B. 'different levels of exploitation. Population projections in 1982-86 assume M = 0.7 and recruitment is 221 million fish at age 2.

Table 6.--Forecast of Pacific cod abundance in thousand metric tons in the eastern Bering Sea, 1982-86 under varying levels of exploitation (E) with M = .700. Recruitment in 1982-86 is the low average form 1976-81 survey data.

Year	Total Popn.	Fished Popn.	Recruits Millions	Catch	E	F	MWT
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	98.9	0.200	0.310	1.674
1983	448.6	343.1	221.0	68.6	0.200	0.310	1.576
1984	378.1	272.6	221.0	54.5	0.200	0.310	1.439
1985	347.9	242.4	221.0	48.5	0.200	0.310	1.353
1986	334.9	229.4	221.0	45.9	0.200	0.310	1.308
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	197.7	0.400	0.748	1.674
1983	364.2	258.7	221.0	103.5	0.400	0.748	1.441
1984	294.1	188.6	221.0	75.5	0.400	0.748	1.238
1985	274.5	169.0	221.0	67.6	0.400	0.748	1.158
1986	269.0	163.5	221.0	65.4	0.400	0.748	1.132
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	296.6	0.600	1.446	1.674
1983	287.1	181.6	221.0	109.0	0.600	1.446	1.255
1984	241.0	135.5	221.0	81.3	0.600	1.446	1.066
1985	234.5	129.1	221.0	77.4	0.600	1.446	1.032
1986	233.6	128.2	221.0	76.9	0.600	1.446	1.027
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	395.4	0.800	2.000	1.674
1983	254.6	149.1	221.0	119.3	0.800	2.000	1.147
1984	225.4	119.9	221.0	95.9	0.800	2.000	1.008
1985	223.0	117.6	221.0	94.0	0.800	2.000	0.995
1986	222.8	117.4	221.0	93.9	0.800	2.000	0.993

F = fishing mortality
E = exploitation rate 'for fished population (ages
MWT = Mean individual fish weight (kg) in catch

exploitable population. A possible option for maximizing cumulative catches would be to use variable exploitation rates such as shown in Table 7. Catches could be increased to as much as 198,000 t in 1982 and 103,000 t in 1983 before they would need to be reduced to lower levels in 1984 as population abundance declined. The simulation model indicates that this approach would not reduce the exploitable population by 1986 any lower than constant annual catches of 58,000 t in 1982-86. However, cumulative catches in 1982-86 could reach 422,000 t with the variable exploitation rates shown in Table 7 compared to 290,000 t with constant catches of 58,000 t. The variable exploitation rates would allow the fishery to take cod that would otherwise be lost to natural mortality.

Discussion

It should be emphasized that the projections of abundance of cod are highly dependent on a number of assumptions. Abundance estimates derived from surveys assume a catchability coefficient of 1.0 for cod and other species. If the catchability coefficient were less than 1.0, which seems likely, then the population abundances were underestimated. Because the simulation model uses survey data as a starting point, the resulting projections of population abundance may also be underestimated. For example, if the catchability coefficient of survey vessels for cod were only 0.5, then the population biomass would be twice that shown by survey estimates and the simulation model. The estimates of natural mortality and recruitment would also significantly influence the accuracy of the projections. Other less critical assumptions were those that natural mortality was constant over all ages, catches from given age groups were proportional to the abundance of those age groups in the exploitable population, and that exploitation was limited to ages 3 and above. The three major assumptions having the greatest influence on the projections are believed

Table 7.--Forecast of Pacific cod abundance in thousand metric tons in the Bering Sea, 1982-86, under varying levels of exploitation (E) with M = .700. Recruitment in 1982-86 is the low average from 1976-81 survey data.

Year	Total population	Fished population	Recruits (millions)	Catch	E	F	MWT
1979	823.9	297.9	1106.0	33.0	0.111	0.158	1.177
1980	919.9	709.6	442.0	43.4	0.061	0.081	1.080
1981	758.6	695.7	132.0	59.1	0.085	0.118	1.337
1982	599.7	494.3	221.0	197.7	0.400	0.748	1.674
1983	364.2	258.7	221.0	103.5	0.400	0.748	1.441
1984	294.1	188.6	221.0	37.7	0.200	0.310	1.238
1985	309.6	204.1	221.0	40.8	0.200	0.310	1.232
1986	317.9	212.4	221.0	42.5	0.200	0.310	1.245

E = exploitation rate for fished population (ages 3-11)
F = fishing mortality
MWT = mean individual fish weight (kg) in catch

to produce conservative results. The natural mortality (0.7) and catchability coefficient (1.0) values used are probably higher than the actual values and therefore underestimate the true population in future years. The estimate of recruitment excludes the strong 1977 year-class and may also produce conservative abundance estimates in 1982-86. Catch levels projected therefore probably represent lower exploitation rates than those indicated by results of the simulation model.

Cushing (1975) observed that cod-like fish are highly fecund and, because of their high egg production, have a capacity to stabilize abundance under conditions of fluctuating recruitment and high levels of fishing. He further stated that variations in recruitment are governed more by environmental conditions than parental stock size. Nevertheless, caution seems desirable in reducing the parental stock. How far the parental stock can be reduced without harming its reproductive capability is unknown, but the adults producing the strong 1977 year-class might be used as a guide. The size of the parental stock producing the 1977 year-class is also unknown. The area surveyed in 1977 by the NWAFC research vessel was limited to the southeast Bering Sea (Figure 3) and, therefore, did not provide an estimate of abundance for the overall eastern Bering Sea population. Some approximation of the total population size in 1977 may be provided by expanding the biomass estimate from the southeast Bering Sea. This may produce a reasonable estimate because there is a good relationship between relative abundance estimates from the southeast Bering Sea and those from large-scale NWAFC surveys that sampled major portions of the eastern Bering Sea (Figure 2). Using 1979 survey data, the biomass of cod in the southeast Bering Sea represented 36.6% of 'the biomass in the total area surveyed in 1979. Applying this ratio to the 1977 survey, biomass estimate of 92,900 t produces an estimate for the major portion of the eastern Bering Sea of about 254,000 t. This approximation is less than the 318,000 t that was projected for 1986 from the simulation using variable exploitation rates (Table 7). Catch levels approximating those in Table 7 would, therefore, not appear to be detrimental to the stock.

The simulation indicates that the contribution of the strong 1977 year-class would diminish substantially when it reaches age 7 in 1984. Catches would then have to be reduced to more historical levels. Catches in 1984-86 could probably exceed the 38,000 to 42,000 t range shown by the simulation model (Table 7). From 1970 to 1976, the foreign fishery harvested an average 53,400 t annually in the eastern Bering Sea without harming the stocks' capability to produce the 1977 year-class. Also to be considered is the safeguard provided by the Aleutian Islands population (estimated at 299,000 t in 1980) which would sustain some portion of the catches in 1982-86.

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