Northwest and
Alaska Fisheries
Center

National Marine
Fisheries Service

U.S. DEPARTMENT OF COMMERCE

NWAFC PROCESSED REPORT 85-05

Pacific Cod in the Eastern Bering Sea:
A Synopsis

February 1985

PACIFIC COD IN THE EASTERN BERING SEA: A SYNOPSIS

By

Reynold A. Fredin

Institute for Marine Studies
University of Washington
Seattle, Washington 98125

and

Natural Resources Consultants
4055 21st Avenue West
Seattle, Washington 98199

Report to RU 643
National Ocean Service
Office of Oceanography and Marine Services
Anchorage, Alaska

Resource Ecology and Ecosystem Simulation Task
Resource Ecology and Fisheries Management Division
Northwest and Alaska Fisheries Center
Building 4, BIN C15700
7600 Sand Point Way N. E.
Seattle, WA 98115

TABLE OF CONTENTS

Table of Contents (cont'd.)

INTRODUCTION

Pacific cod (*Gadus macrocephalus*) is a relatively abundant and an economically important species of fish in the eastern Bering Sea. It ranked third in biomass among all species of fish in comprehensive demersal trawl surveys of the area in 1979 and 1980, exceeded only by walleye pollock and yellowfin sole. It was the first species of demersal fish to be commercially utilized in eastern Bering Sea, the original fishery having been a fleet of North American based sailing schooners accompanied by dory catcher boats which commenced handline fishing on a regular annual basis about 100 years ago and continued until 1950. Since the mid-1950's there has been, first, a widespread development of foreign trawl fishing activity for groundfish in the area, with catches of Pacific cod, although not a target species, reaching record highs by the early 1970's, and, within the past five years, a rapidly expanding U.S. trawl fishery, with vessels catching increasingly larger quantities of cod each year for domestic and foreign processing, the latter under joint venture arrangements. The species serves as the foundation for building a strong domestic fishery and processing industry around the groundfish resources of the eastern Bering Sea and Aleutian Islands.

Compared to the century of commercial fishing for Pacific cod in the eastern Bering Sea, biological research on the species in the area has a very brief history and, moreover, is lacking in comprehensiveness in certain respects. Little direct information is available regarding some important biological and life history aspects of Pacific cod in eastern Bering Sea. Thus, in preparing a synopsis of information on the species in the area, it is necessary to draw on findings from studies of Pacific cod throughout their range in the North Pacific Ocean and, where relevant, from studies of Atlantic cod, a closely related species. Even so, many gaps in our knowlege remain.

1. IDENTITY

The Pacific cod (Class Osteichthyes, Order Gadiformes, Family Gadidae, Genus *Gadus*, Species *macrocephalus*) is the only member of its genus represented in the eastern Bering Sea (Salveson and Dunn, 1976). It is distinguished from other North Pacific gadids (cod fishes) by the presence of three separate dorsal fins, anus located below the second dorsal fin, and a barbel below the lower jaw as long as or longer than the width of the eye (Hart, 1973). A detailed description of the species is given by Hart.

Several decades ago taxonomists disagreed as to whether the Pacific cod and Atlantic cod were different species or simply subspecies of the same species (Schultz and Welander, 1935; Svetovidov, 1948), but it is now generally accepted by researchers on North Pacific fish populations that the two are separate species, G. *macrocephalus* and G. *morhua*.

Other common names frequently used for Pacific cod are "cod," "true cod" and "gray cod."

2. DISTRIBUTION

a. Overall Distribution in the North Pacific Ocean.

On the North American coast Pacific cod inhabit waters over the continental shelf and the upper portion of the continental slope from Santa Monica Bay, California (about lat. 34°N), north to St. Lawrence Island in the northern Bering Sea (about lat. 63°N at long. 170°W) and throughout the Aleutian Islands (Figure 1). Cod also inhabit Norton Sound, but apparently only in small numbers (Wolotira et al, 1977). Along the coast of mainland Asia, they inhabit continental shelf and upper slope waters from the Gulf of Anadyr to the southern end of the

Korean Peninsula and along the west coast of Korea in the Yellow Sea to Port Arthur in China. They also occupy shelf and upper slope waters off the Kurile and Sakhalin Islands, the west coast of Japan in the Sea of Japan, and the Pacific coast of Japan from northern Hokkaido to Tokyo Bay (Bakkala et al, 1984). Moiseev (1953) indicates that an arc connecting the southernmost limits of the species' distribution in North America and Asia covers a distance of approximately 10,000 kilometers.

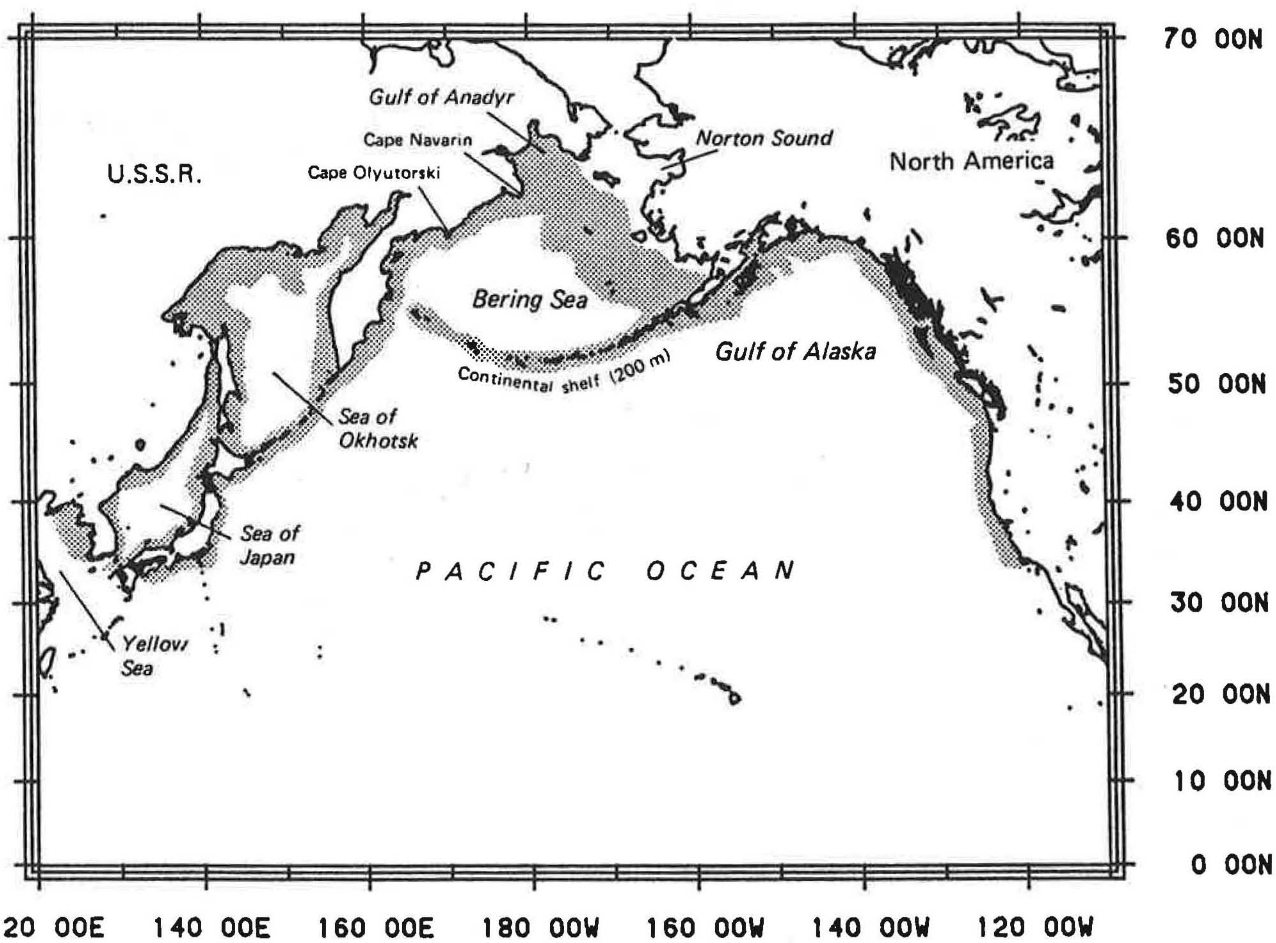


Figure 1.--Overall distribution of Pacific cod in the North Pacific Ocean. (From Bakkala et al., 1984.)

Average annual regional catches during 1968-77 suggest that the abundance of Pacific cod increases from south to north along both the Asian and North American sides of the North Pacific Ocean, peaking in the eastern Bering Sea (Figure 2). Catches during 1978-82 from four of the North American regions also suggest that cod abundance peaks in the eastern Bering Sea, with the Aleutians and Gulf of Alaska providing much larger catches than in earlier years:

Pacific cod catch (t)---1978-1982*

Year	Aleutians	E. Bering Sea	Gulf of Alaska	Canada
1978	3,295	42,543	12,160	6,750
1979	5,593	33,761	14,869	9,554
1980	5,788	45,861	35,439	8,703
1981	10,462	51,996	36,018	6,708
1982	11,526	55,040	33,563	4,808

*Sources: Aleutians and eastern Bering Sea data - Bakkala and Wespestad (1984); Gulf of Alaska data - Zenger (1983); Canada data - Smith (1979, 1980 and 1981) and Leaman (1982 and In press).

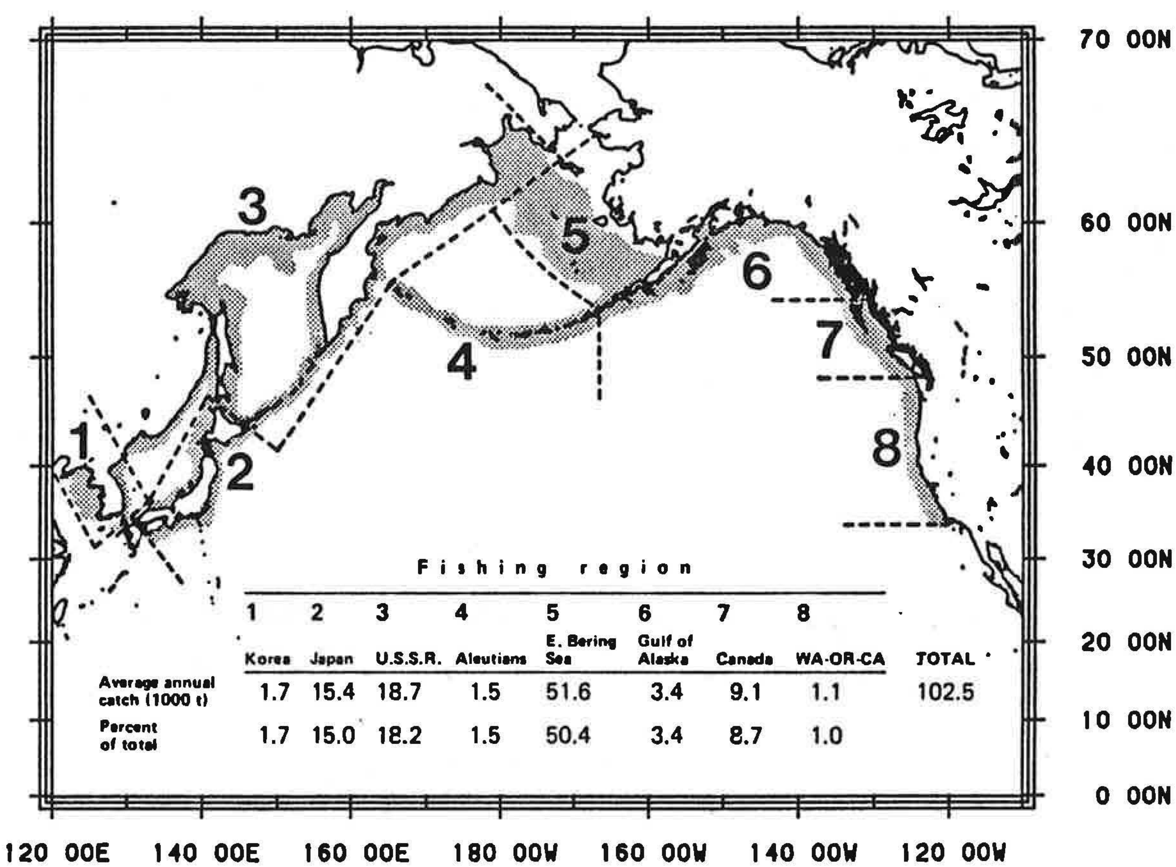


Figure 2.--Average annual catches of Pacific cod, in thousands of tons, by region of the North Pacific Ocean, 1968-77. (From Bakkala et al., 1984.)

b. Overall Distribution in Eastern Bering Sea.

The overall distribution of Pacific cod in the region delineated in Figure 2 as the eastern Bering Sea is probably best illustrated by the results of a comprehensive demersal trawl survey of groundfish resources carried out by the Northwest and Alaska Fisheries Center, National Marine Fisheries Service, during May-August of 1979. That survey provided the most extensive single-year coverage of the region to date and showed Pacific cod to be distributed over most of the continental shelf and slope from the Alaska Peninsula northward to St. Lawrence Island (Figure 3). Cod were generally absent in waters off the Alaska mainland out to the 30 m or 40 m depth contour from St. Lawrence Island south. As for nearshore waters north of St. Lawrence Island, trawl surveys during September-October 1976 and July-August 1979 in Norton Sound and adjacent waters indicated that cod occur in only negligible quantities (Wolotira et al, 1977, and Sample et al, unpubl. manusc.).

To the west and northwest of St. Lawrence Island a cooperative U.S.-Japan-U.S.S.R. demersal trawl survey in 1982 showed cod to be distributed from the continental slope well into the Gulf of Anadyr and along the Asian coast between Cape Navarin and Cape Olyutorski, much as indicated in Figure 1. Extent of intermixing of cod populations of the eastern and northwestern Bering Sea is not known, but tagging studies presently in progress are expected to provide detailed information on the matter and also on movements of cod between eastern Bering Sea, the Aleutians, and the western Gulf of Alaska.

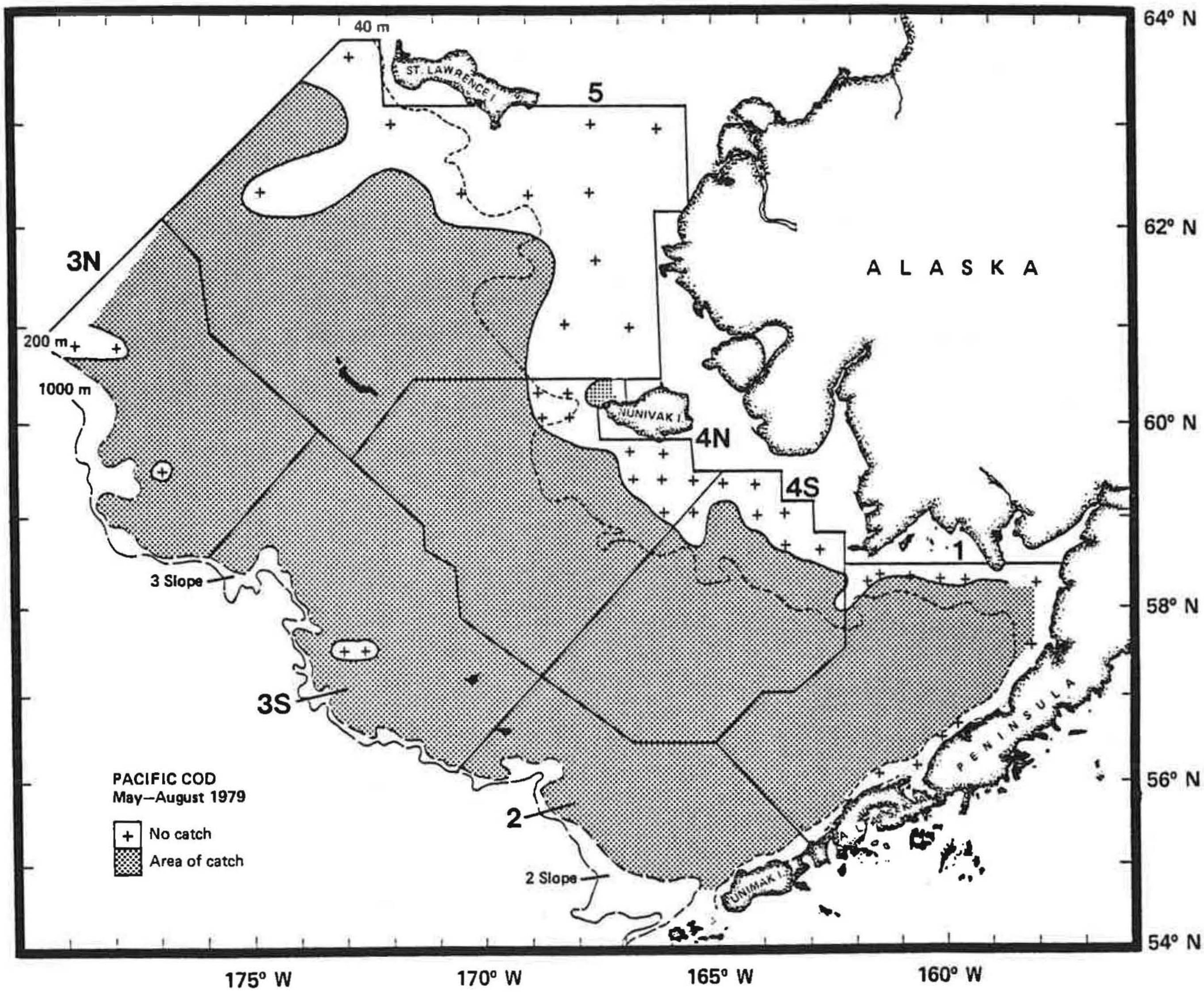


Figure 3.--Distribution of Pacific cod in eastern Bering Sea during May-August 1979. (From Bakkala et al., 1982.)

c. Distribution by Subarea Within the NWAFC Survey Area.

Estimates of abundance of Pacific cod obtained from NWAFC trawl surveys in May-August 1978-82 and June-August 1983 indicate that approximately 60 to 90 percent of the total number of cod in the survey area during a given summer are found in Subareas 1, 4N, 4S and 5, the remaining 10 to 40 percent in Subareas 2, 3N and 3S (Figure 4). Unweighted averages of annual percentages by subarea provide the following rankings with respect to cod abundance:

Subarea	Percent of total population in trawl survey area
1	30
4N	22
4S	18
3S	12
3N	7
2	6
5	3

The estimates of abundance likely would have been somewhat different in some subareas and years had there not been gaps in areal coverage (such as there were in Subareas 4S and 4N in 1978 and 1981 or in other subareas in one or more years), but the overall ranking of the subareas in regard to cod abundance probably would not be changed much. More serious errors may stem from one or more of the assumptions carried in making trawl survey (swept area) estimates of abundance, such as the assumption that the cod population is static (i.e., doesn't move from one sampling station or subarea to another) during the 3-4 months that the surveys are carried out and the assumption that the trawl sampling gear has a 100% capture efficiency (Pereyra et al, 1976 and Smith and Bakkala, 1982). Magnitude of errors in population estimates revolving around the assumptions is not known.

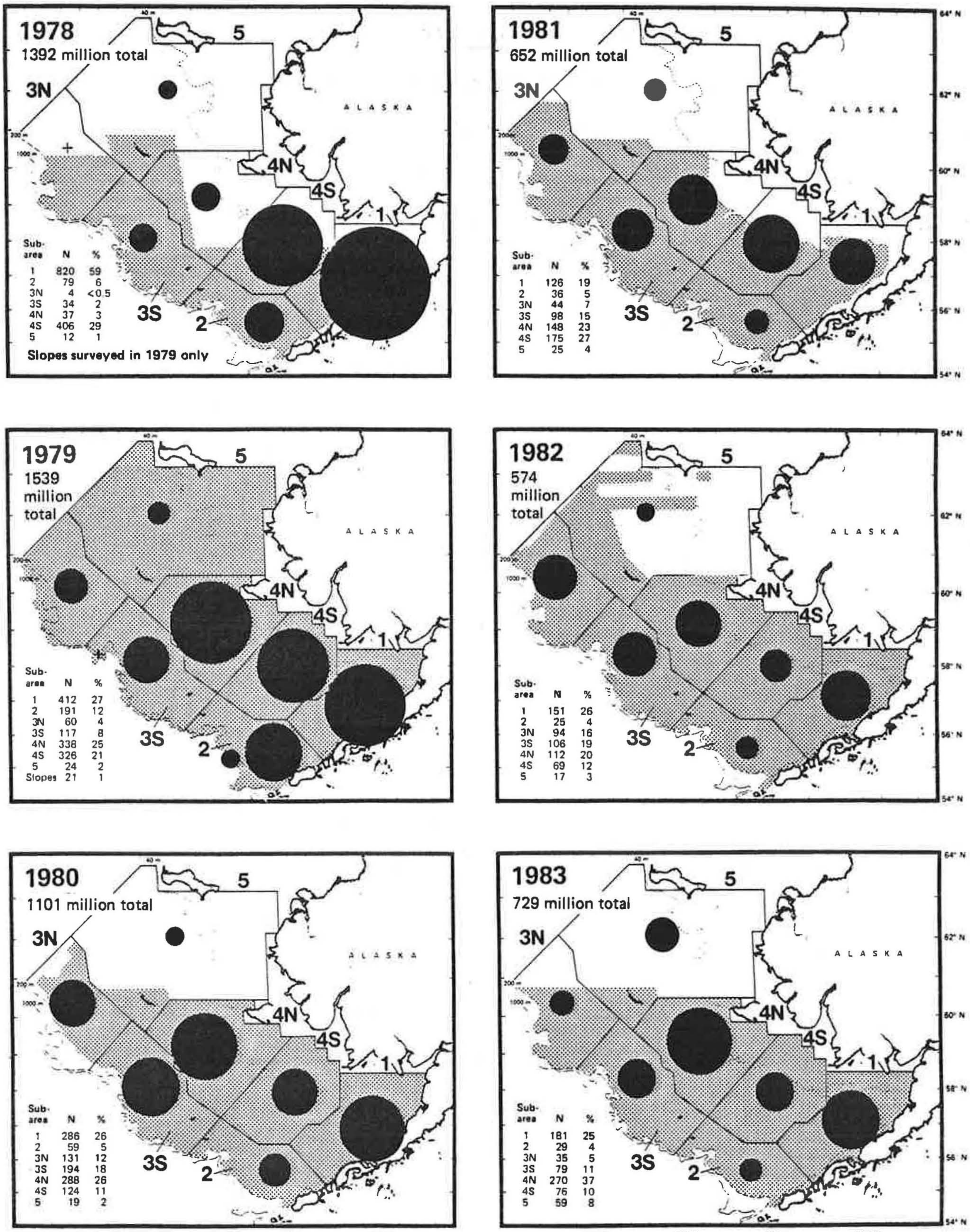


Figure 4.--Summer distribution of Pacific cod in the NWAFC trawl survey area in the eastern Bering Sea, 1978-1983, in millions of fish by subarea. (From NWAFC data files.)

d. Variability in Distribution.

The distribution of Pacific cod in the eastern Bering Sea varies between years and between seasons within years. The driving environmental variable behind the changes in distribution appears to be water temperature, with such biological factors as year-class abundance and age (size) composition, and probably spawning and feeding migrations, also playing important roles.

Between-year differences in distribution associated with water temperature are portrayed by Pereyra, Reeves, and Bakkala (1976), who compared distribution and relative abundance of Pacific cod in eastern Bering Sea during July-August of 1965-70 and 1971-75, sets of warm and cold years, respectively (Figure 5). In July-August of warm years cod occupied inner shelf waters from the Alaska Peninsula well to the north of Nunivak Island, but in cold years the population remained largely on the outer shelf and continental slope. In the relatively cold year of 1982, however, cod were found throughout eastern Bering Sea (Figure 6), indicating that distribution is influenced not only by water temperature but also by abundance. (As will be shown later, cod were much more abundant in 1982 than in the early 1970's.)

Seasonal changes in the distribution of cod are indicated by differences in the areas where they were found during a trawl survey in April-June 1976 (Figure 7) as compared to summer surveys (Figure 4). Catches during April, when ice cover was at its peak in 1976 and spring warming had yet to begin, are considered to depict winter distribution and May-June catches the spring distribution. Cod were concentrated on the outer continental shelf and along the shelf edge in April, whereas the May-June catches indicated a movement back to shallower waters. In appears from Figures 4 and 7 that cod move off the inner and central shelf regions as summer ends and winter approaches, concentrate

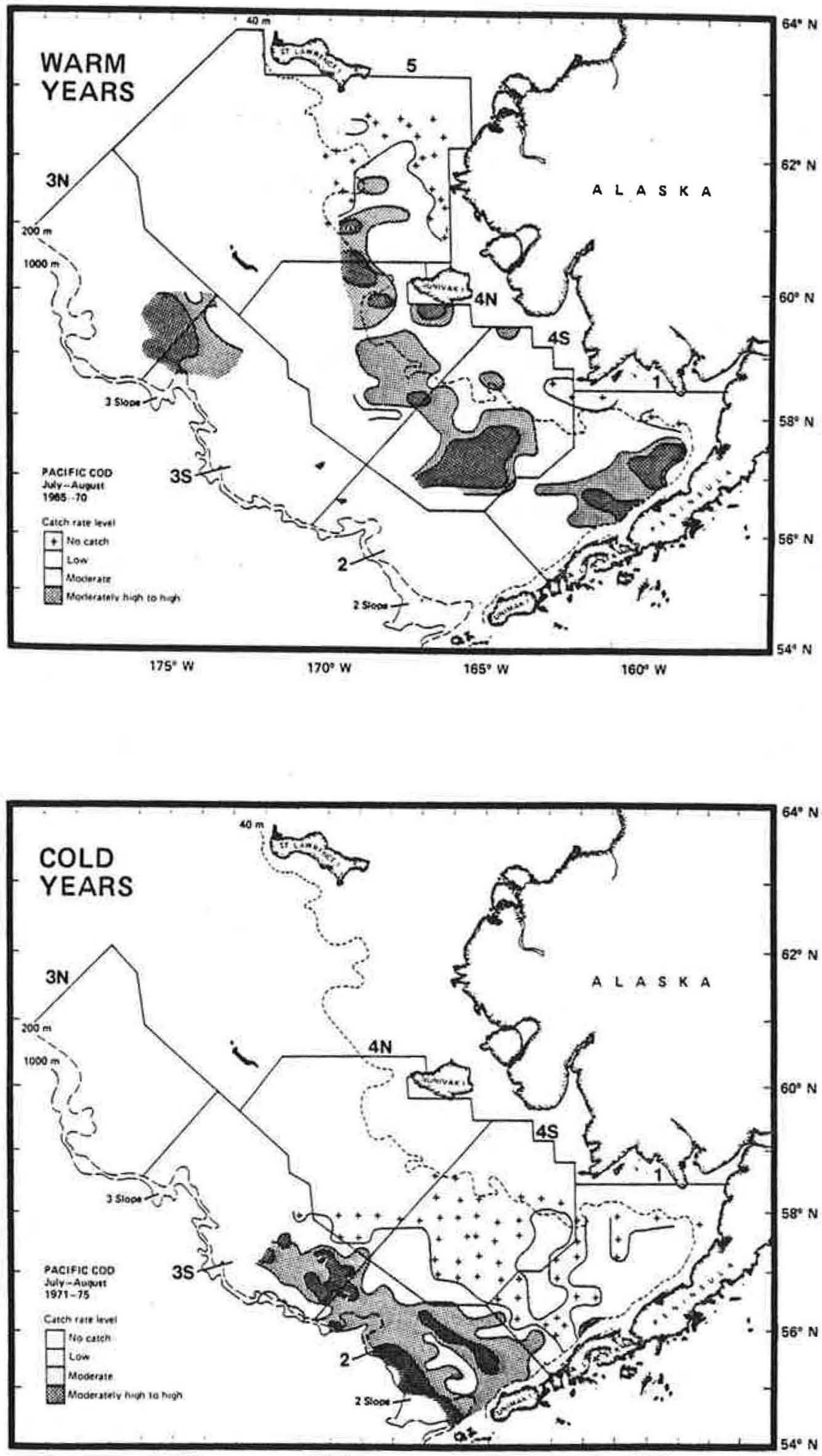


Figure 5.--Distribution and relative abundance of Pacific cod in July-August 1965-70 and 1971-75 as shown by a composite of catch rates from demersal trawl surveys. (From Pereyra, Reeves, and Bakkala, 1976. Warm and cold years refer to relative climatic conditions in eastern Bering Sea during 1965-70 and 1971-75 as described by McLain and Favorite, 1976.)

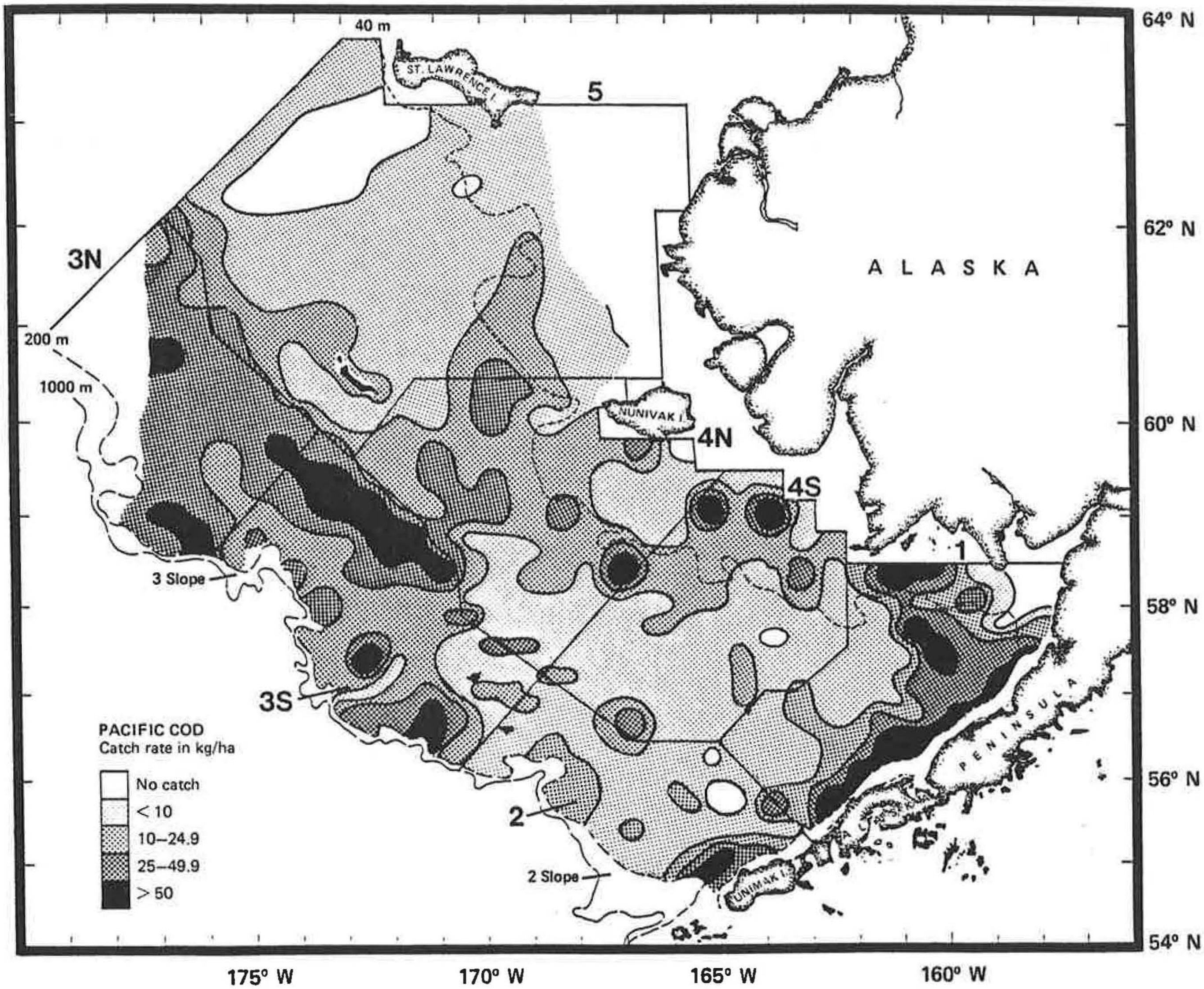


Figure 6.--Distribution of Pacific cod in the NWAFC trawl survey area in eastern Bering Sea during May-August 1982. (From NWAFC data files.)

in deeper water on the outer shelf and along the shelf edge during winter, migrate back toward the inner shelf as the ice pack recedes northward in the spring, and are broadly dispersed over much of the inner and central shelf, as well as the outer shelf and along the continental slope, during the summer.

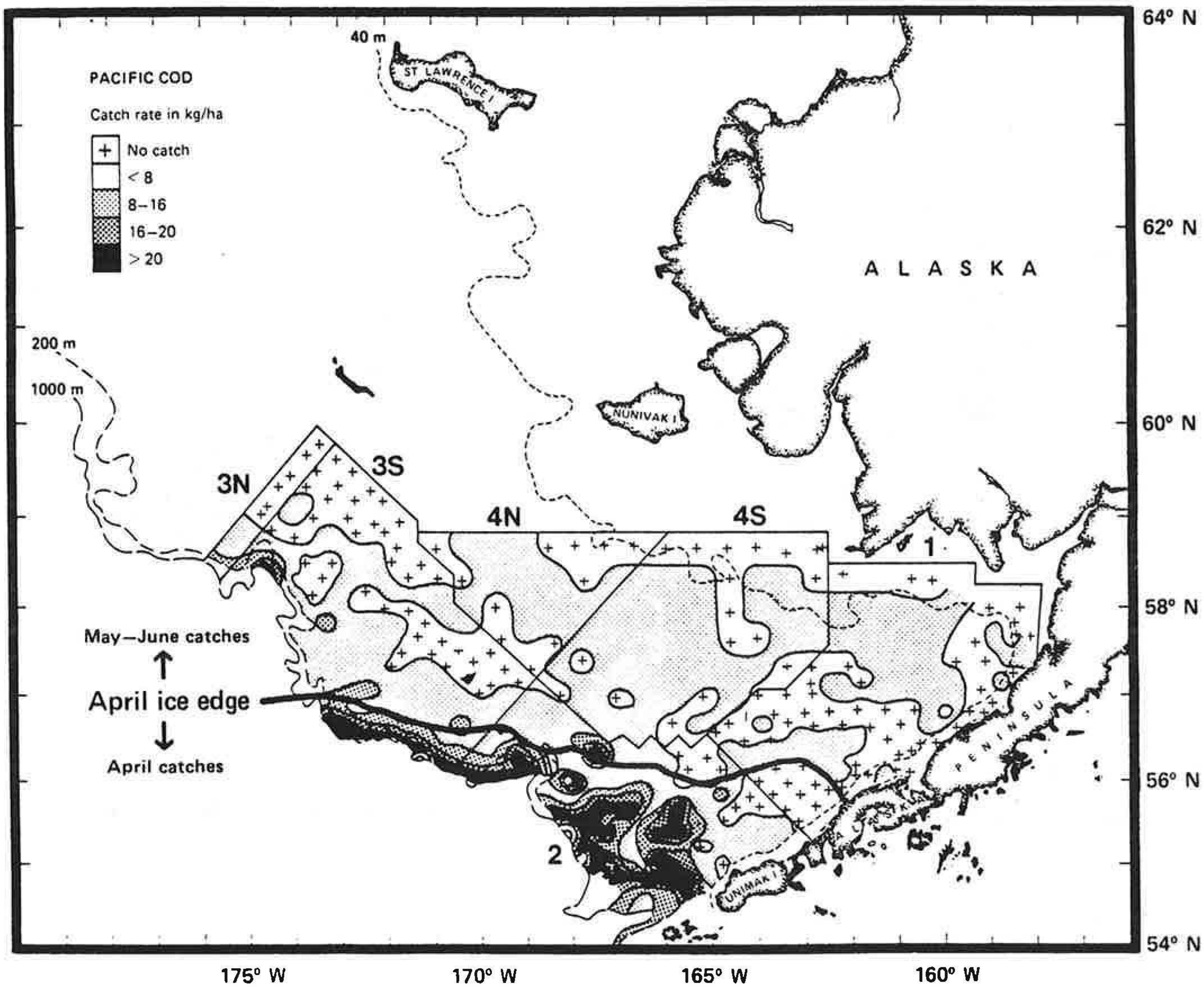


Figure 7.--Distribution of Pacific cod in eastern Bering Sea during April-June 1976 as indicated by NWAFC demersal trawl survey. (From Smith and Bakkala, 1982, and Bakkala, 1984.)

e. Distribution of Life History Groups.

(i) Spawning population. Musienko (1970) reported that cod populations around the Commander Islands and along the coast of Siberia from the general latitude of the Commanders northeasterly to the Gulf of Anadyr spawn during the period from January to May. On the basis of such evidence for cod populations in the western and northwestern Bering Sea, Bakkala (1984) concluded that spawning in the eastern Bering Sea can be expected to take place within the period of January to April. As to where Pacific cod spawn in eastern Bering Sea, normal development of fertilized eggs requires a water temperature greater than 0°C Mukhacheva and Zvyagina, 1960), with the optimum temperature for hatching and survival considered to be about 5°C (Teshima, 1983) and the optimum incubation temperature at 3-5°C (Musienko, 1970 and Yamamoto and Nishioka, 1952). Such temperature requirements preclude the inner continental shelf as an area for successful reproduction of Pacific cod, the bottom temperatures under ice cover there during winter being less than -1.5°C (Dodimead et al, 1962), and indicate that spawning takes place in the warmer waters on the outer continental shelf and slope or in protected bays and adjacent ice-free waters along the Alaska Peninsula and westward. Japanese longline vessels have taken spawning cod along the continental slope south of the Pribilofs from late January through March (Allen Shimada, pers. comm.), and U.S. fishermen have observed spawning from late December to April in bays and shallow near-shore waters in the eastern Aleutians and along the north side of Unimak Island to False Pass (Konrad Uri, pers. comm.).

(ii) Eggs and larvae. Pacific cod eggs are demersal, and none have been reported from the numerous ichthyoplankton surveys that have been carried out in eastern Bering Sea since 1955. Only five larvae, all taken in the central shelf region south of Nunivak Island, were reported (Waldron, 1981). Large numbers of larvae averaging 4-5 mm in April and 7-10 mm in May-June were collected during research vessel cruises in the Gulf of Alaska from Kodiak Island westward to Unimak Island during 1972-82 (Kendall, pers. comm.). Prevailing ocean currents could carry such larvae "downstream" through passes into the eastern Bering Sea.

(iii) Age 0 fish. During an August-October trawl survey in 1975, concentrations of small cod averaging 11-14 cm in length and considered to have been age 0 fish (young of the year) were encountered inside or near the 40 m depth contour from south of Nunivak Island into the outer reaches of Bristol Bay and along the north sides of the Alaska Peninsula and Unimak Island (Figure 8). It appears that cod are distributed in coastal waters from Unimak Island to the vicinity of Nunivak Island during the summer and early fall of their first year of life.

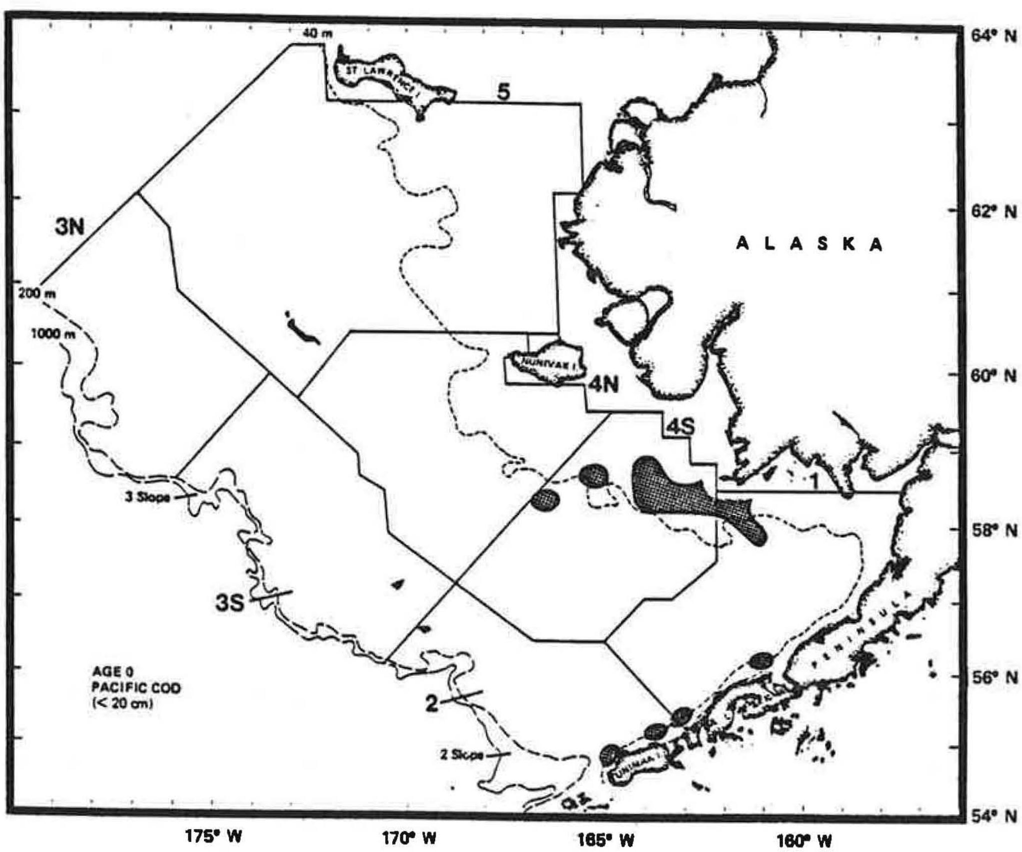


Figure 8.--Distribution of age 0 Pacific cod in the eastern Bering Sea as observed during NWAFC demersal trawl survey, August-October 1975. (From Bakkala, 1984.)

(iv) Age 1 and older fish. After the manner of Bakkala (1984), the distributions of age 1 and older cod in eastern Bering Sea during 1978-83 are based on length classes expected to represent specific ages, as follows: Age 1 - <28 cm, Age 2 - 28 to 38 cm, Age 3 - 39 to 50 cm, and Age 4 and older - >50 cm.

Bakkala (1984) shows some marked differences in the distribution of the age groups in 1979. Concentrations of age 1 fish were located in a continuous band along the north side of the Alaska Peninsula and northward near the 40 m depth contour to north of Nunivak Island. Age 2 cod were similarly distributed but tended to be in somewhat deeper waters in the central shelf region, extending to the north of St. Matthew Island. The distribution of age 3 cod was practically identical to that of age 2 fish except some concentrations of age 3 cod were found on the outer shelf and slope whereas age 2 fish were observed there only at low levels of abundance. The distribution of age 4 and older fish was distinctly different in that they were found almost exclusively on the outer shelf and slope. Thus there appeared to be an inshore to offshore progression in the distribution of age groups in 1979, with age 1 fish in inner shelf waters, ages 2 and 3 fish in central shelf waters, and age 4 and older fish in outer shelf and slope waters.

Distributions of the various age groups in 1983 (Figures 9a and 9b) suggest very little in the way of an inshore-offshore progression for ages 1 and 2 cod. The distribution of age 3 fish extended well onto the outer shelf but numerous concentrations were found near the 40 m depth contour on the inner shelf, where concentrations of younger fish were also found. Age 4 and older cod were observed throughout the survey area, and not almost exclusively on the outer shelf and slope, as was the case in 1979. Most of the larger concentrations of age 4 and older fish were observed near or inside the 40 m depth contour. Thus, and as Bakkala has pointed out (pers. comm.), there was not the marked inshore-offshore progression

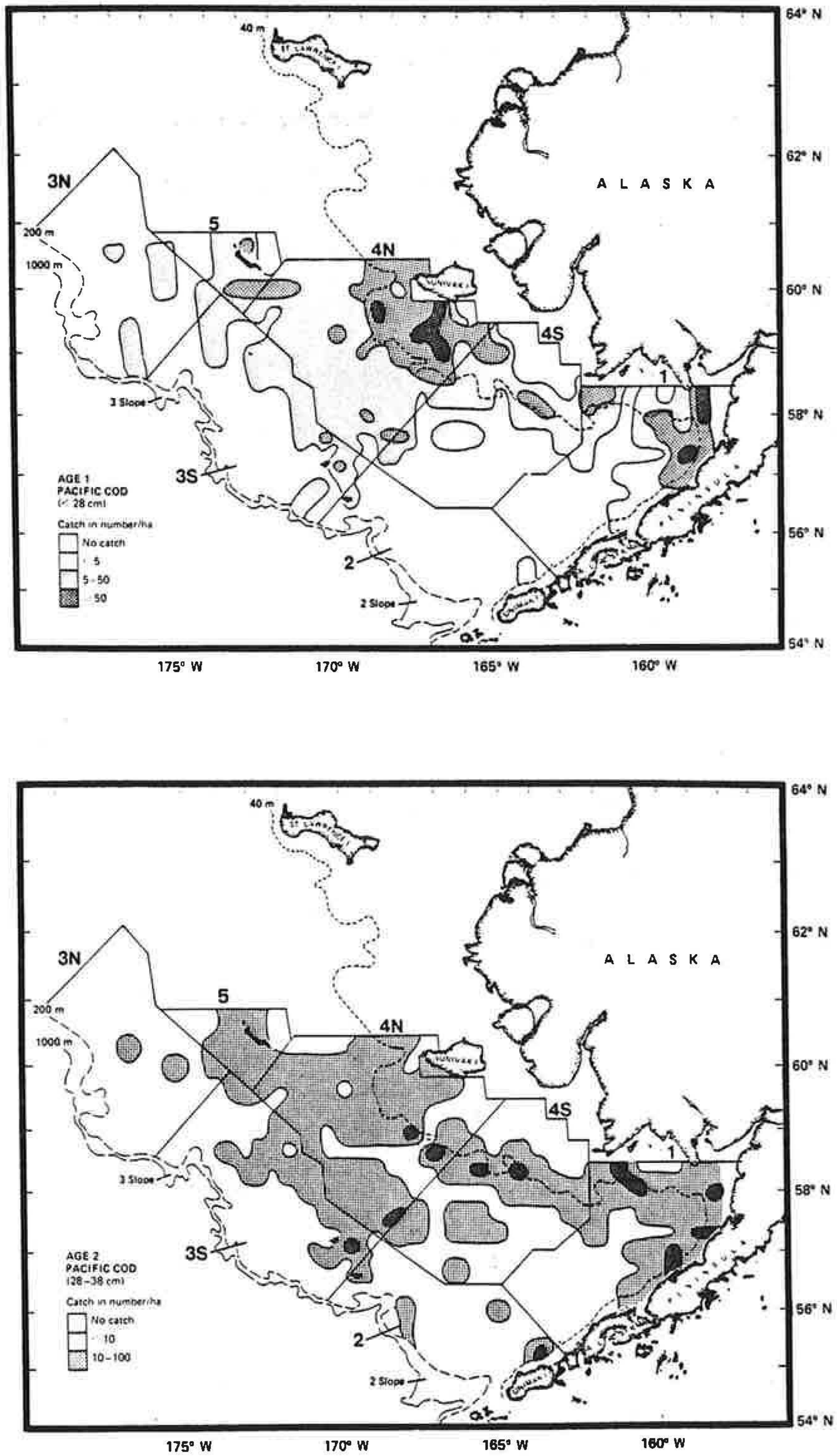
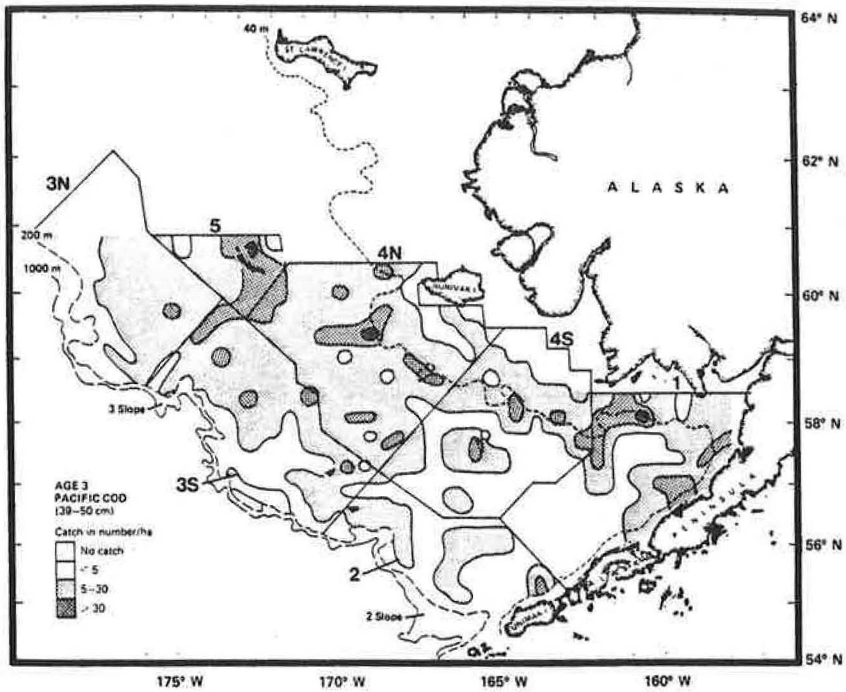


Figure 9a.--Distributions of Age 1 and Age 2 Pacific cod in the NWAFC trawl survey area in eastern Bering Sea in 1983. (From NWAFC data files.)



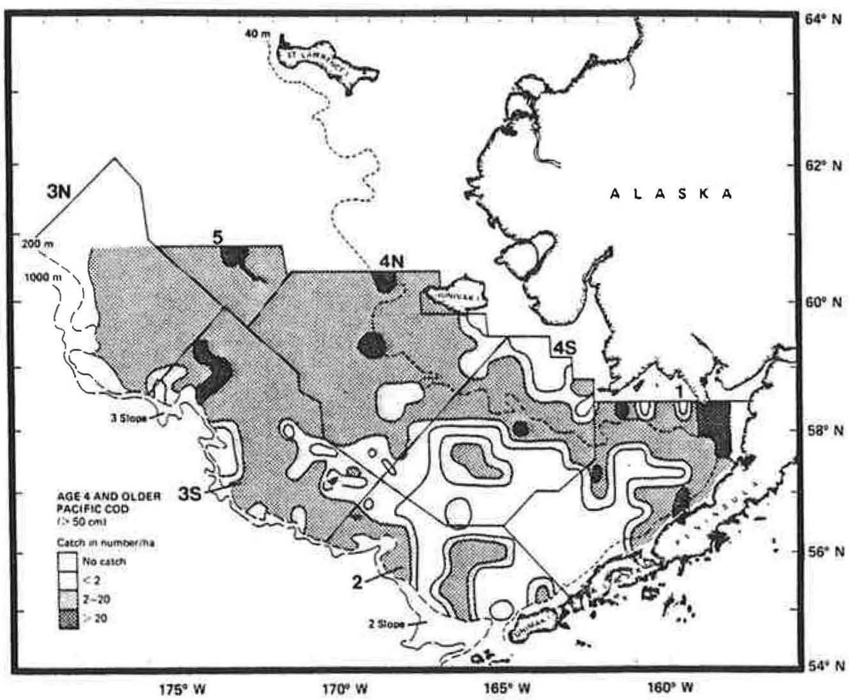


Figure 9b.--Distributions of Age 3 and Age 4 Pacific cod in the NWAFC trawl survey area in eastern Bering Sea in 1982. (From NWAFC data files.)

in the distribution of cod with age in 1983 that there was in 1979. Although some of the ages 3 and 4 and older fish were found farther out on the shelf than the younger fish in 1983, most of them were mixed in with ages 1 and 2 fish on the inner shelf.

Annual distributions of the different age groups of cod by subarea in the NWAFC trawl survey area in eastern Bering Sea during the summers of 1978-83 are shown in Figures 10a-10d. Practically all of the age 1 cod and about 80% of the age 2 fish were found on the inner shelf, with Subareas 1, 4S and 4N being the key areas. The same subareas accounted for 50 to 80% of the age 3 fish, depending on the year. Percentage of the estimated total population of age 4 and older cod occurring in Subareas 1, 4S, and 4N varied from a low of 6% in 1978 to a high of 68% in 1983 and appears to have been fairly closely related to abundance.

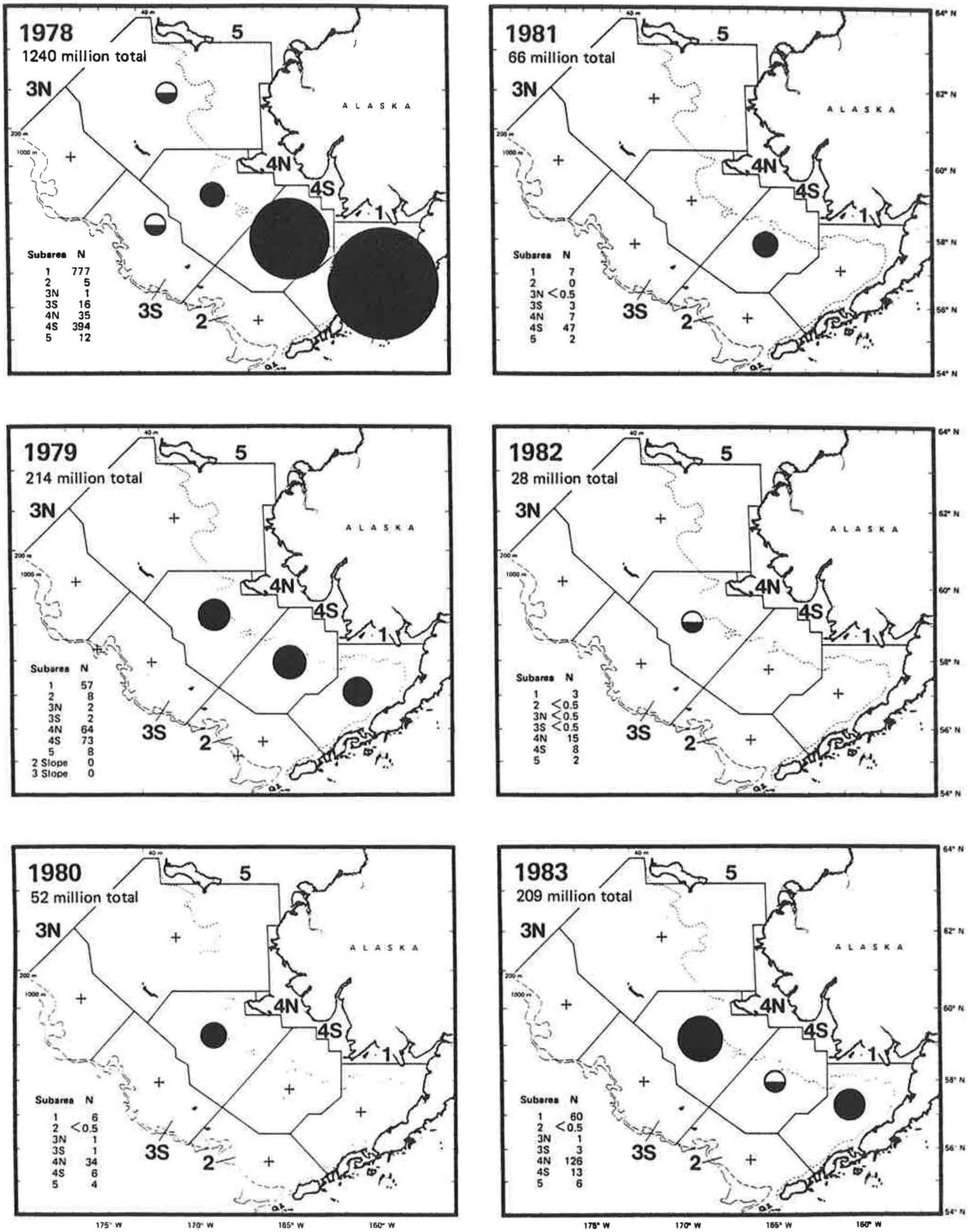


Figure 10a.--Abundance of Pacific cod <28 cm (Age 1) in the NWAFC trawl survey area in eastern Bering Sea during summers of 1978-83, in millions of fish by subarea. (From NWAFC data files.)

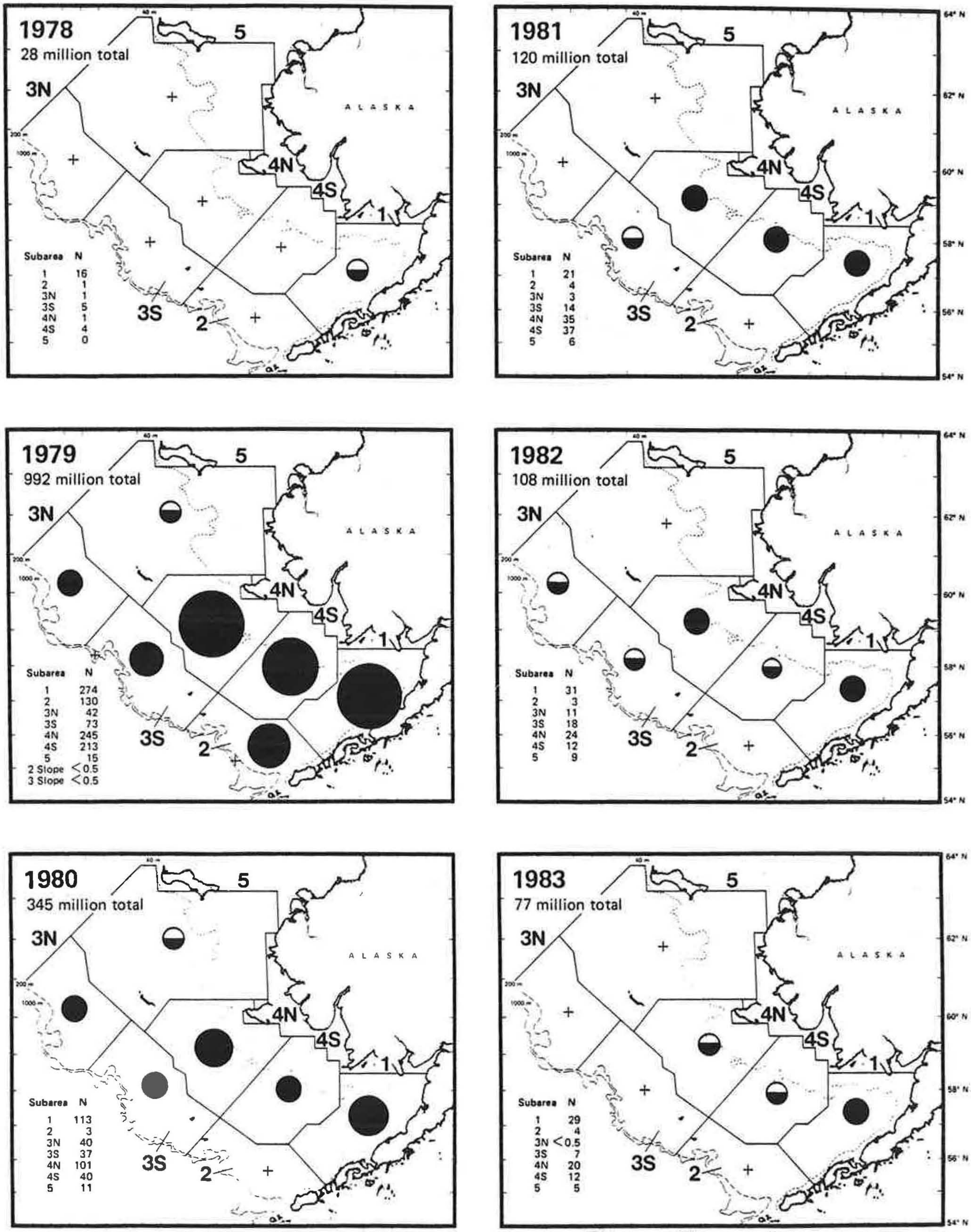


Figure 10b.--Abundance of Pacific cod 28-38 cm (Age 2) in the NWAFC trawl survey area in eastern Bering Sea during summers of 1978-83, in millions of fish by subarea. (From NWAFC data files.)

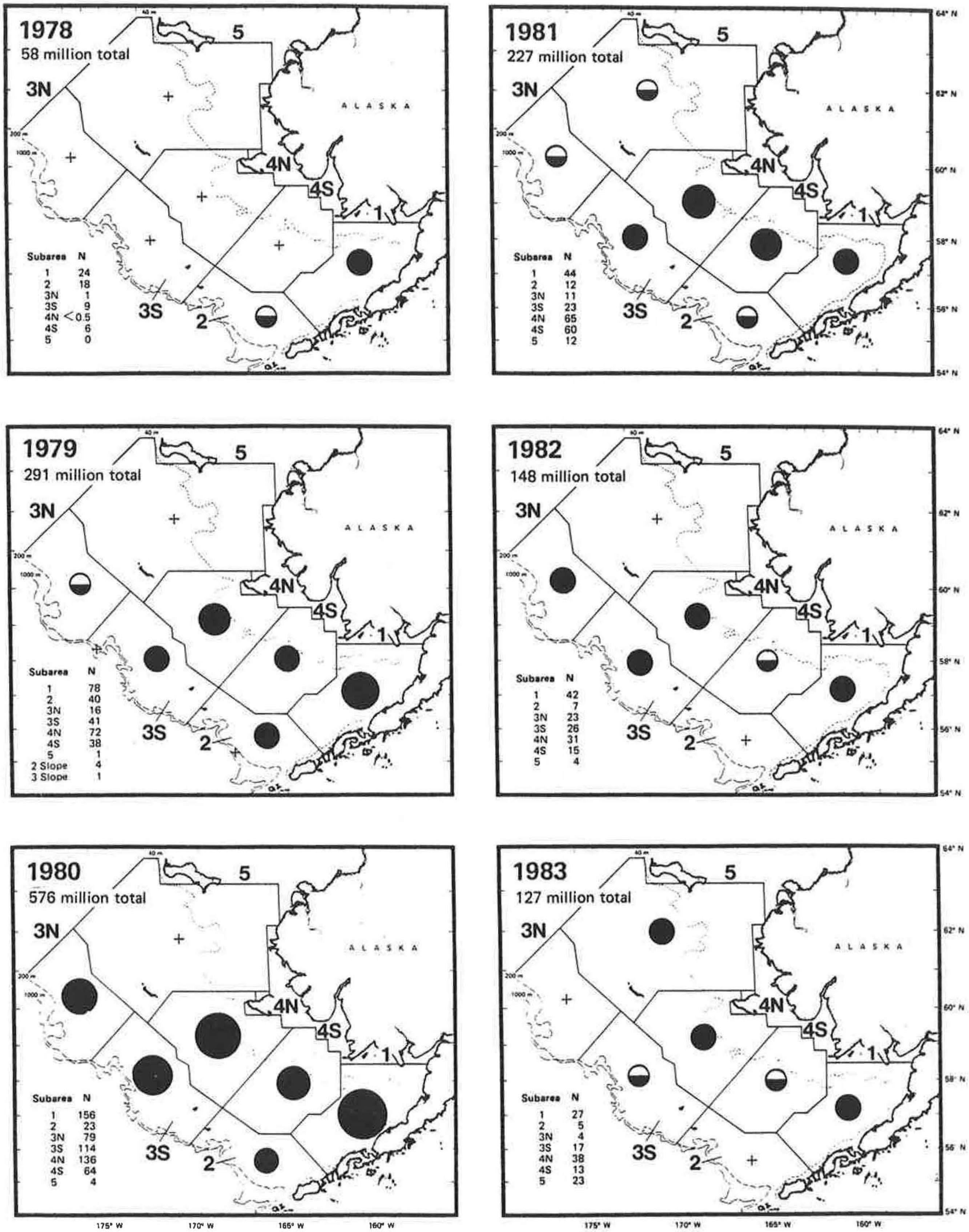


Figure 10c.--Abundance of Pacific cod 38-50 cm (Age 3) in the NWAFC trawl survey area in eastern Bering Sea during summers of 1978-83, in millions of fish by subarea. (From NWAFC data files.)

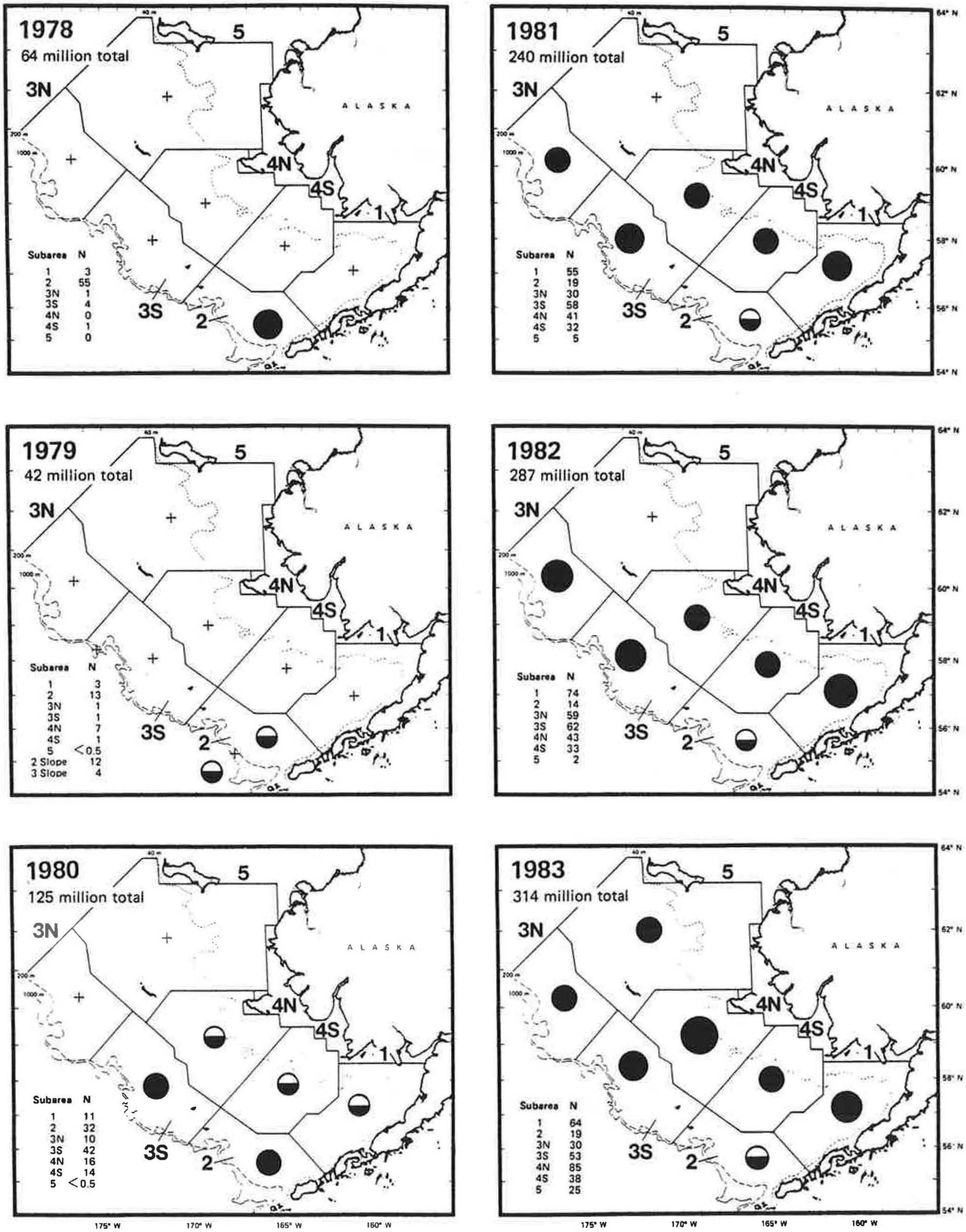


Figure 10d.--Abundance of Pacific cod >50 cm (Age 4 and older) in the NWAFC trawl survey area in eastern Bering Sea during summers of 1978-83, in millions of fish by subarea. (From NWAFC data files.)

3. BIOLOGICAL CHARACTERISTICS

a. Sex Ratios.

Bakkala (1984) reports that for eastern Bering Sea as a whole and for all age groups combined, females accounted for 51% of the total population of Pacific cod in 1976 and 48% in 1979. Samples collected during the 1980 trawl survey indicate that females accounted for 50.5% of the population in that year (Umeda and Bakkala 1983).

Population estimates by sex and size group in 1979 (Bakkala et al, 1982) and 1980(Umeda and Bakkala, 1983) show that the proportion of females generally increases with size class, as follows:

	Percent females by size class (cm)					
Year	10-19	20-29	30-39	40-49	50-59	≥60
1979	43.3	44.6	49.1	54.5	54.3	45.6
1980	44.0	44.4	47.7	51.0	58.0	61.6

The overall sex ratio and size-specific differences for cod in eastern Bering Sea are similar to findings reported by Vershinin (unpubl. MS) for cod in the Anadyr-Navarin region in the northwestern Bering Sea, where the sex ratio is nearly 1:1 and males dominate in the younger age groups, females in the older age groups. Vershinin ascribes the age-specific differences in sex ratio to the earlier maturity of males and their entry into the fishery at a younger age than females.

b. Fecundity.

Fecundity of Pacific cod in eastern Bering Sea has yet to be determined, but Figure 11, taken from Thomson (1962), provides a clue as to what it might be for different sizes of fish, assuming that the fecundity-length relationship for the species is constant. If that is the case, cod of slightly over 50 cm in length in eastern Bering Sea would be expected to produce approximately 0.5 million eggs, 60 cm cod 1.2 million eggs, 80 cm fish 3.25 million eggs, and 90 cm cod a little over 5 million eggs. The eggs are 1 mm in diameter.

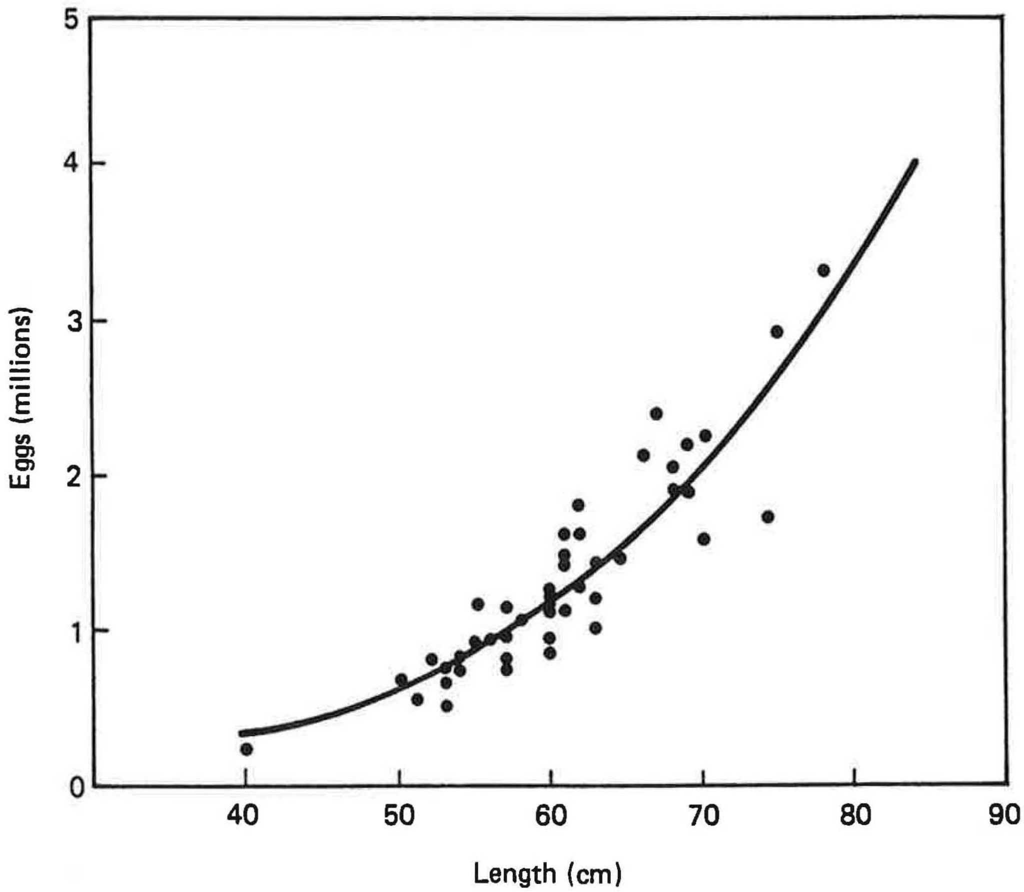


Figure 11.--Fecundity of Pacific cod from Hecate Strait. The solid line is the calculated regression: $\log_{10}$ fecundity (in thousands) = 3.64658 $\log_{10}$ fish length (in cm) - 3.41209. (From Thomson, 1962.)

c. Egg development.

The eggs of Pacific cod are demersal and, during early development, slightly adhesive (Hart, 1973 and Zhang, 1981). Time of development is highly temperature dependent as illustrated in Figure 12. Temperatures resulting in maximum hatching success have been variously reported as 3-5°C (Musienko, 1970), 3-6°C (Yamamoto and Nishioka, 1953), 1-8°C (Mukhacheva and Zvyagina, 1960) and 5°C (Teshima, 1983).

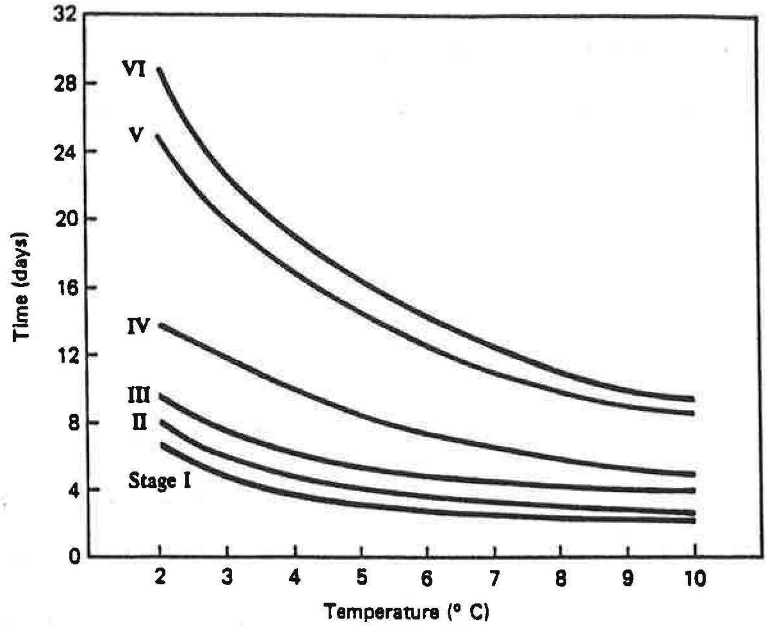


Figure 12.--Number of days required for Pacific cod eggs to reach six developmental stages when held at constant temperatures of 2 to 10°C. (From Forrester and Alderdice, 1966.)

d. <u>Larval Development and Early Growth of Juveniles.</u>

Hart (1973) reported the length of newly hatched larvae as 4.5 mm, which is practically identical to the 4 and 5 mm lengths reported by Musienko (1970) and Zhang (1981), respectively, for larvae after yolk sac absorption. Zhang also gave lengths of larval and juvenile cod in a natural environment in Korea over a 6-month period:

Time after hatching	Total length in mm
At hatching	3.6
30 days	10-13
2 mos	15-25
3 mos	23-40
4 mos	40-70
5 mos	60-90
6 mos	80-110

Zhang's data suggest that the abundant small cod on the inner continental shelf of eastern Bering Sea during the August-October 1975 trawl survey, which averaged about 11 cm in length in Subarea 4S and 14 cm in Subarea 1 (Pereyra et al, 1976), were approximately 6 to 8 months old.

e. Growth.

Growth of Pacific cod in eastern Bering Sea has not been well defined because of problems in aging the fish in the region. Counts of annual rings on scales appear to give unreliable results (Bakkala, 1984) and modal analyses of length frequency data using the method of MacDonald and Pitcher (1979) may not accurately separate certain age groups due to overlapping of lengths of fish of adjacent ages. In spite of its shortcomings, and because a more satisfactory alternative aging procedure has yet to be developed, NWAFC scientists presently use the latter method for aging cod in eastern Bering Sea.

Length-at-age data automatically generated for each year's length frequency by the modal analysis method of aging provide a composite age-length relationship for cod sampled during the 1978-83 trawl surveys in eastern Bering Sea. Means and ranges of estimated modal lengths at age for the six years of sampling are shown in Figure 13.

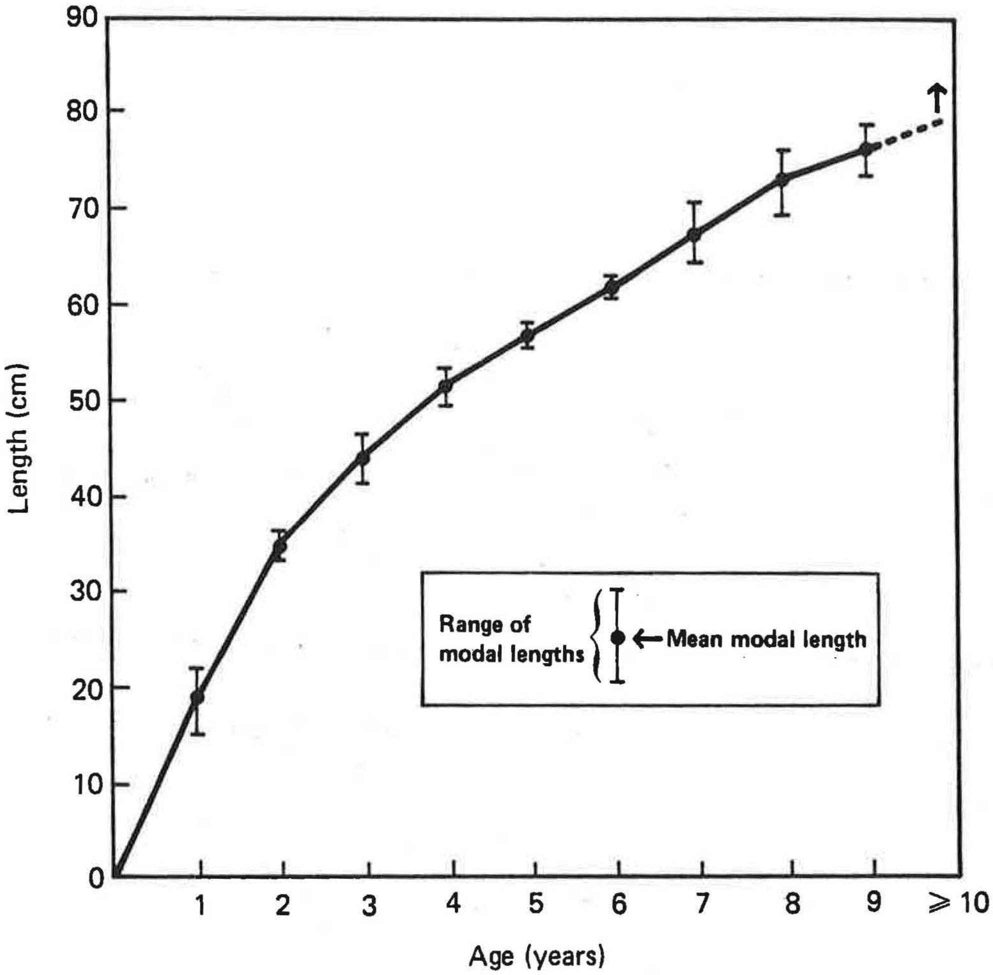


Figure 13.--Age-length relationship for Pacific cod in eastern Bering Sea as aged by modal analyses of length frequencies, 1978-83. (From Shimada, pers. comm.)

f. <u>Size at maturity</u>.

An analysis by Teshima (unpublished manuscript) indicates that sexual maturity of Pacific cod in eastern Bering Sea is first reached by both sexes when their body length is slightly over 50 cm; that the length at which 50 percent of the fish are mature is 60 cm for males, 62 cm for females; and that both sexes mature at a larger size than cod from Hecate Strait, but at a smaller size than those off the west coast of Kamchatka (Figure 14).

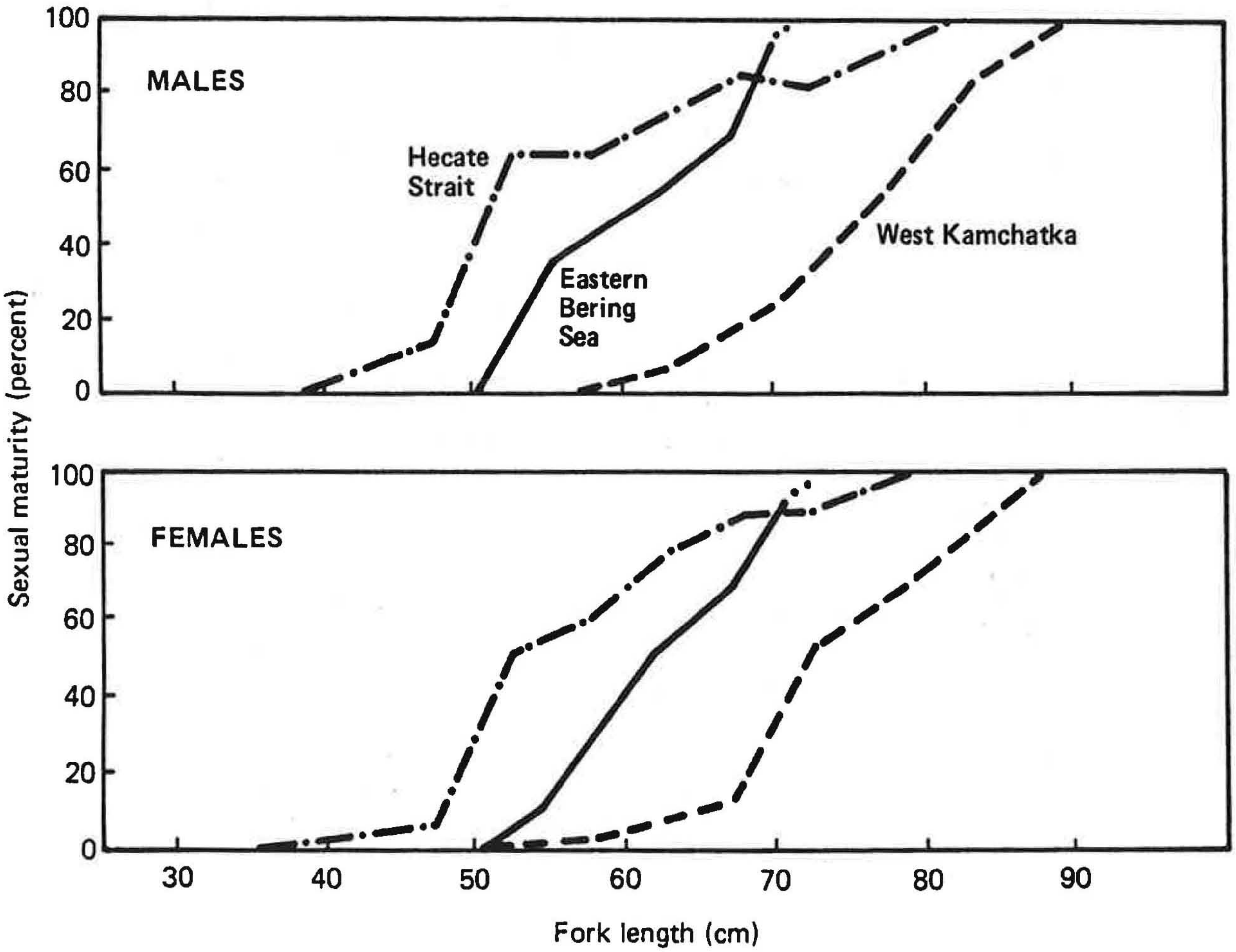


Figure 14.--Relationship between sexual maturity and body length for Pacific cod in eastern Bering Sea and Hecate Strait and off the west coast of Kamchatica. (From Teshima, unpublished manuscript.)

g. Size and age at entry into fisheries.

Length compositions of Pacific cod taken in the Japanese trawl and longline fisheries in eastern Bering Sea during 1978-83 indicate that cod enter the trawl fishery when they are about 30 cm in length and the longline fishery at approximately 40 cm (Figure 15). In most years cod taken in the longline fishery are 5 to 10 cm longer than those caught in the trawl fishery. The difference in size composition can be attributed primarily to differences in area of fishing, with gear selectivity probably also playing a role.

Comparison of the length frequency distributions of cod taken in NWAFC trawl surveys with the distributions for the Japanese fisheries during 1978-81, years when the 1977 year class predominated in the survey catches as 1, 2, 3, and 4-year-old fish successively, indicates that cod enter the Japanese trawl fishery at 3 years of age and the longline fishery mainly as 4-year-olds (Figure 15). (Assignation of cod to the 1977 year class is based on information on larval development and growth of young of the year linked to a backcalculation from modal lengths of fish sampled during the 1978 and 1979 trawl surveys.)

h. Natural Mortality.

The instantaneous rate of natural mortality (M) of Pacific cod in eastern Bering Sea is not known, nor has the rate been directly estimated for any cod population in the North Pacific Ocean except the stock in Hecate Strait in Canadian waters. For that population, Ketchen (1964) indicates that M lies in the range of 0.83 to 0.99, the midpoint of which is 0.9. If cod in Canadian waters have a much shorter lifespan than elsewhere, as Ketchen (1961) suggests, it can be assumed that M for the eastern Bering Sea population is substantially less than 0.9.

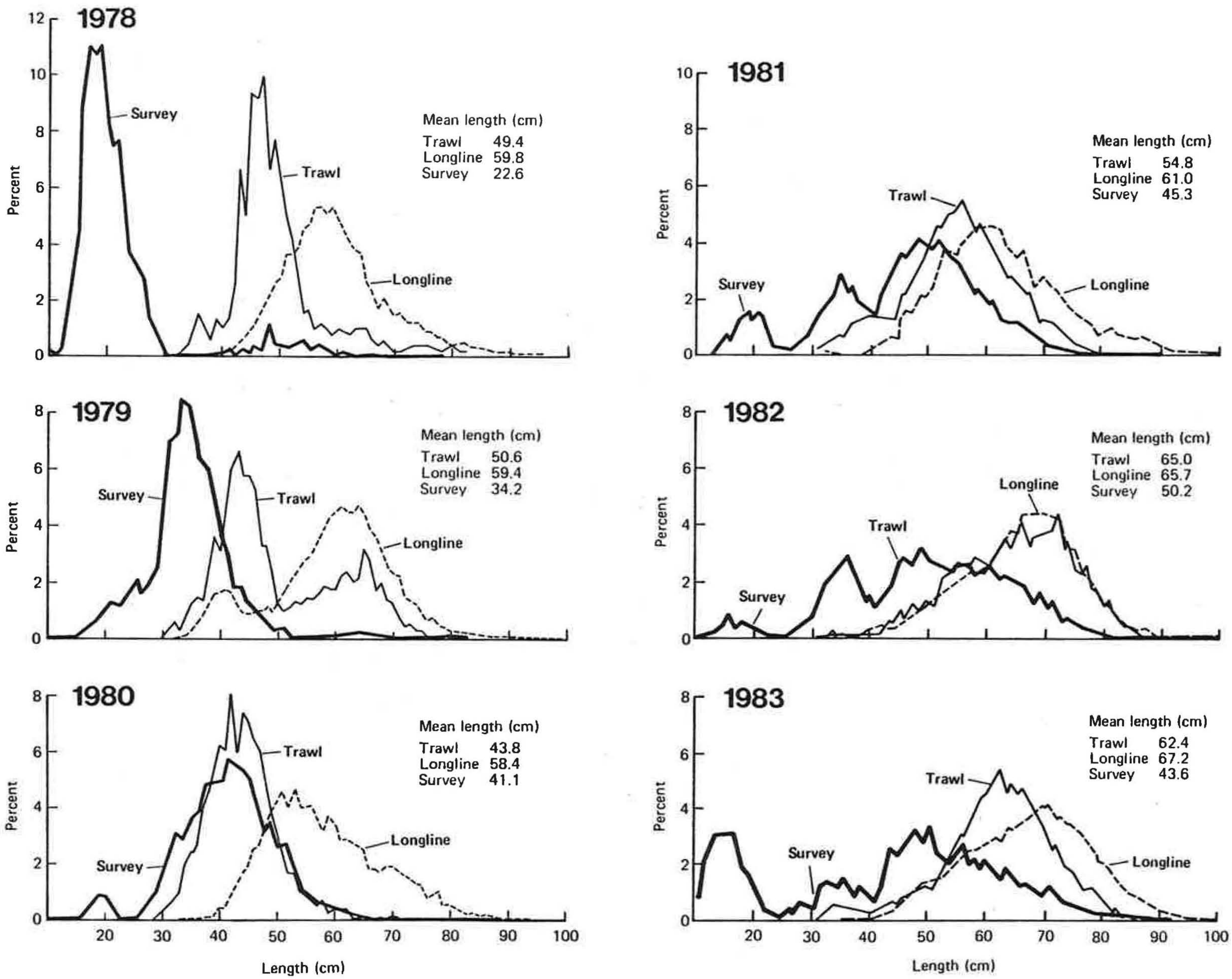


Figure 15.--Length composition of Pacific cod in NWAFC trawl surveys and Japanese trawl and longline fisheries in the eastern Bering Sea, 1978-1983. (From Bakkala, 1984, and NWAFC data files.)

i. Length-weight relationship

From samples of approximately 3,500 fish measured and weighed in the course of trawl surveys during 1975-1981, June and Shimada (pers. comm.) have determined the length-weight relationship for Pacific cod in eastern Bering Sea to be as shown in Figure 16. Their estimates of weights for fish of different lengths are 30 to 60% greater than those reported by Niggol (1982).

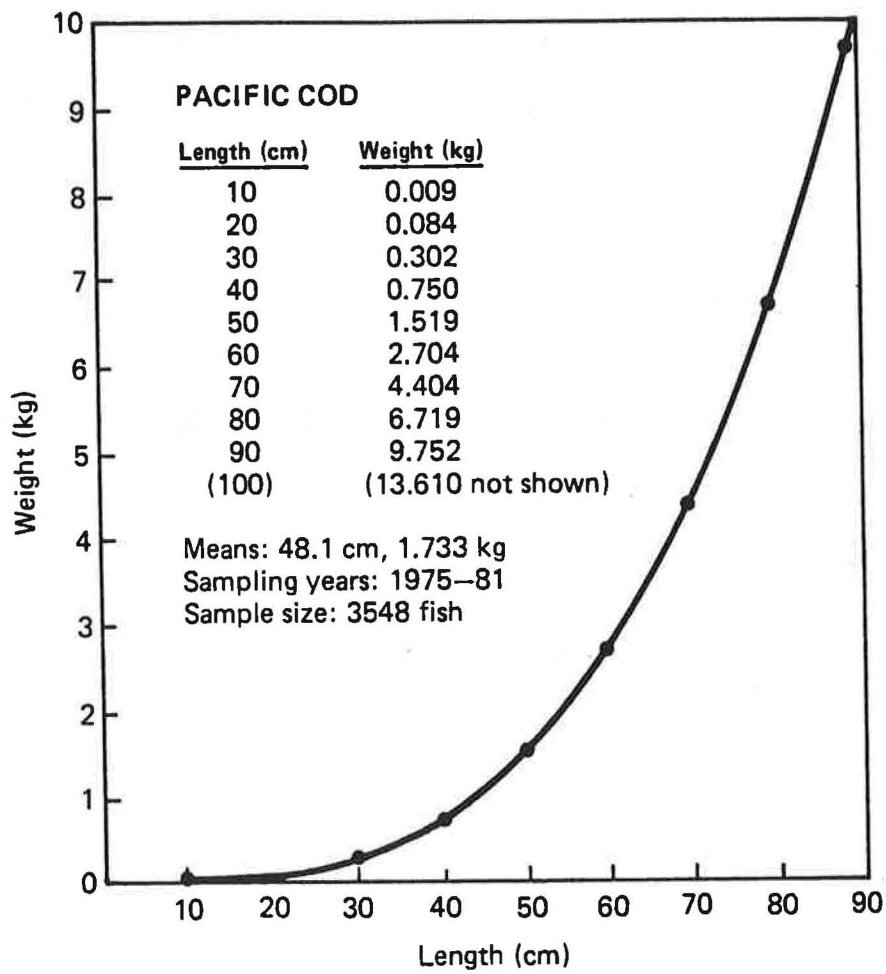


Figure 16.--Length-weight relationship for Pacific cod in eastern Bering Sea, sexes combined, (From June and Shimada, pers. comm.)

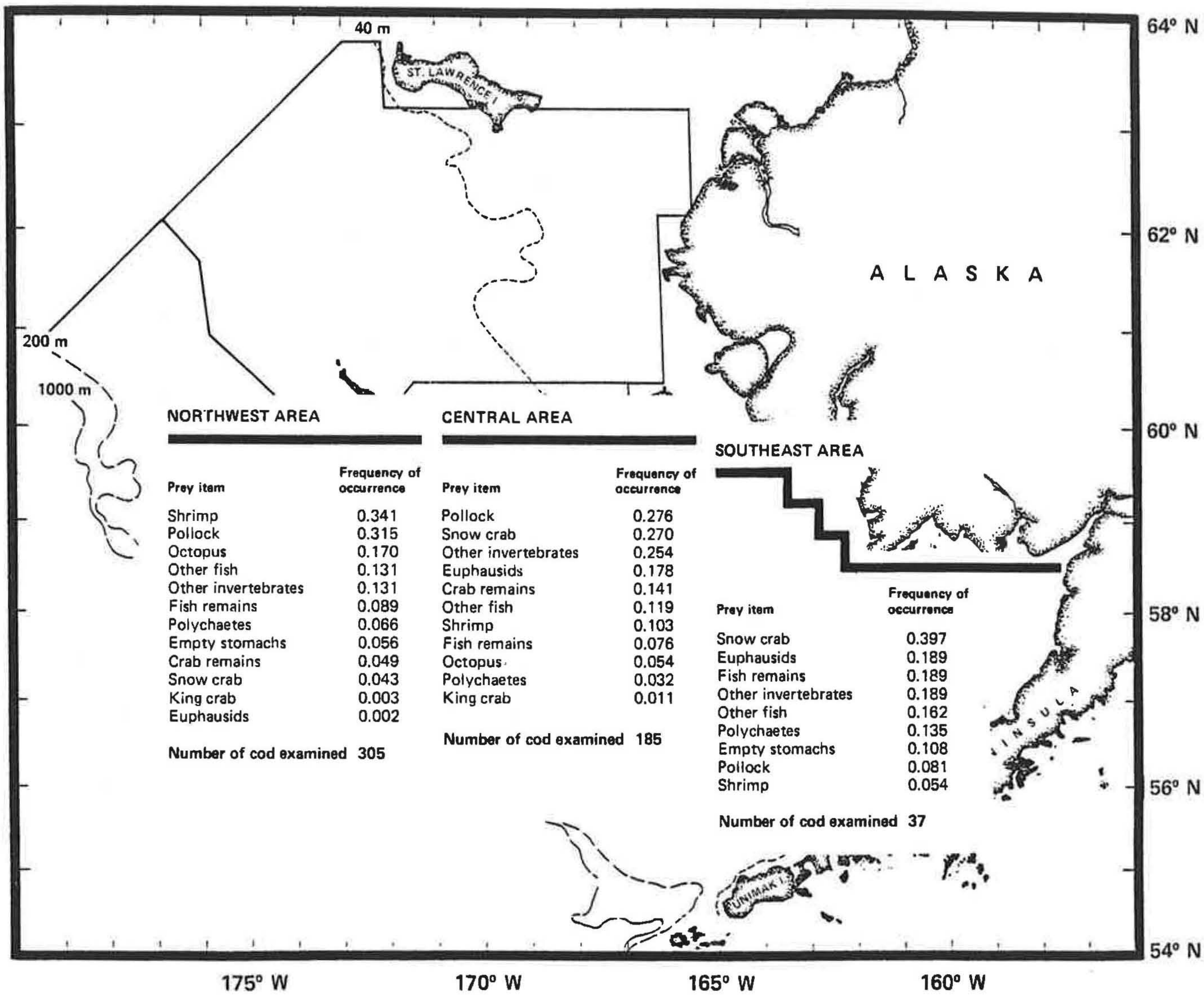
j. Feeding habits.

Krivobok and Tarkovskaya (1964) reported that cod from the southeastern Bering Sea contained large numbers of pollock (*Theragra chalcogramma*), Pacific herring (*Clupea harengus pallasi*), smelt (Osmeridae), capelin (*Mallotus villosus*), flatfish (Pleuronectidae), eel pouts (Zoarcidae), crab, shrimp, octopus, mollusk, and other fish, but they gave no specific quantities. Similar prey species were found in stomachs of cod sampled during NWAFC's trawl survey in eastern Bering Sea in June-July of 1980, with the principal species varying between sectors of the survey area (Figure 17). Snow crab predominated among food items in the southeast sector; pollock, snow crab, and miscellaneous invertebrates (including clams, hermit crab, and snails) in the central sector; and shrimp and pollock in the northwest sector. For the overall area sampled, unweighted averages of frequency of occurrence indicate that the four most important prey items were snow crab (23.7%), pollock (22.4%), miscellaneous invertebrates (19.1%), and shrimp (16.6%).

June (pers. comm.) has estimated the minimum and maximum daily consumption of five species of crab prey by Pacific cod in eastern Bering Sea during the summer (June-August) of 1981. His estimates of minimum daily consumption are as follows:

Species of crab	Number consumed per day (1000's)	Weight consumed per day (m.t.)
Red king	100	122.9
Blue king	39	11.8
Tanner - opilio	4,093	106.8
Tanner - bairdi	10,069	32.1
Korean horsehair	2,265	4.9

Estimates of maximum daily consumption are approximately ten times the minimum estimates.



NORTHWEST AREA

Prey item	Frequency of occurrence
Shrimp	0.341
Pollock	0.315
Octopus	0.170
Other fish	0.131
Other invertebrates	0.131
Fish remains	0.089
Polychaetes	0.066
Empty stomachs	0.056
Crab remains	0.049
Snow crab	0.043
King crab	0.003
Euphausids	0.002

Number of cod examined 305

CENTRAL AREA

Prey item	Frequency of occurrence
Pollock	0.276
Snow crab	0.270
Other invertebrates	0.254
Euphausids	0.178
Crab remains	0.141
Other fish	0.119
Shrimp	0.103
Fish remains	0.076
Octopus	0.054
Polychaetes	0.032
King crab	0.011

Number of cod examined 185

SOUTHEAST AREA

Prey item	Frequency of occurrence
Snow crab	0.397
Euphausids	0.189
Fish remains	0.189
Other invertebrates	0.189
Other fish	0.162
Polychaetes	0.135
Empty stomachs	0.108
Pollock	0.081
Shrimp	0.054

Number of cod examined 37

Figure 17.--Frequency of occurrence of prey items taken by Pacific cod in three sectors of the eastern Bering Sea, June-July, 1980. (From Bakkala, 1984.)

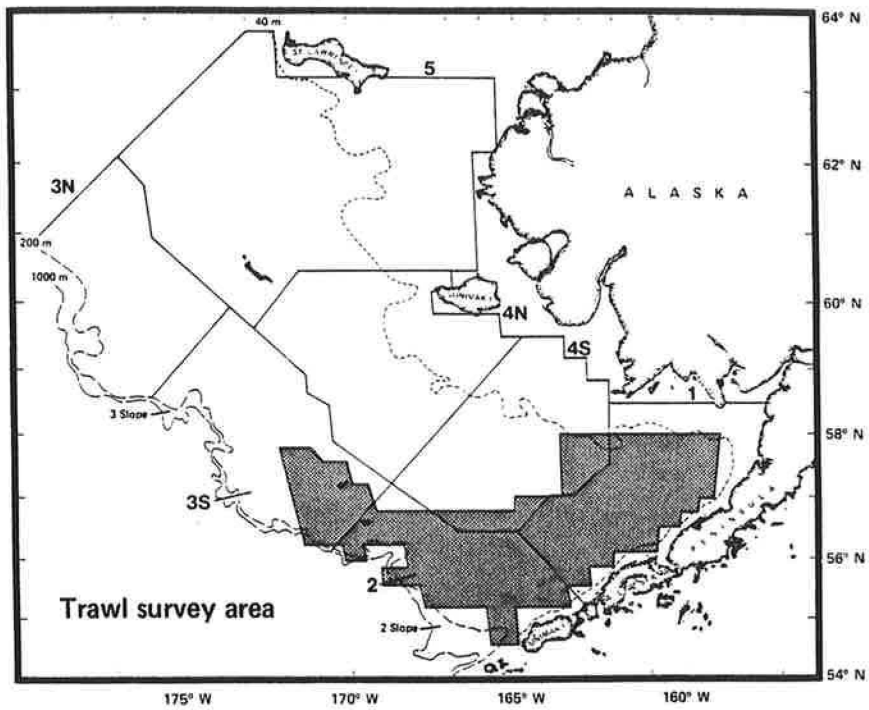
In regard to predation on red king crab by cod, all of the crabs in cod stomachs for which sex could be determined were females. Connecting such evidence with June's estimates of daily consumption and, as will be shown subsequently, indications of a major increase in cod abundance beginning in the late 1970's, it appears that predation by Pacific cod may be the principal cause of the sharp decline in abundance of red king crab in eastern Bering Sea in recent years.

Cannibalism does not seem to be a significant aspect of feeding by Pacific cod in eastern Bering Sea. By way of contrast, Daan (1983) estimates that cannibalism by Atlantic cod in the North Sea exercised a mortality of 5% on 2-year-old cod in 1981, and he indicates that the numbers of cannibalized young-of-the-year and 1-year-old cod exceeded the number of 2-year-olds meeting a similar fate by factors of nearly 150 and 10, respectively.

4. ABUNDANCE

Catch per unit effort (CPUE) data for Pacific cod in an area in southeast Bering Sea where NWAFC has conducted annual demersal trawl surveys of groundfish populations since 1973 indicate that after several years at a relatively stable and low level of abundance the size of the cod population began to increase in 1978 and by 1983 was 4-5 times the 1973-77 level of abundance (Figure 18). Recruitment of the exceptionally strong 1977 year class into the population undoubtedly contributed greatly to the increase, but it is possible that some of the difference between the 1973-77 and 1979-83 levels of abundance is due to improvements in survey methods over the years, including those accruing from experience.

CPUE's from the Japanese longline fishery also point to a major increase in the cod population in recent years, a doubling to tripling of abundance between 1977-79 and 1980-82 (Figure 19). The increase, however, lags by a couple of years



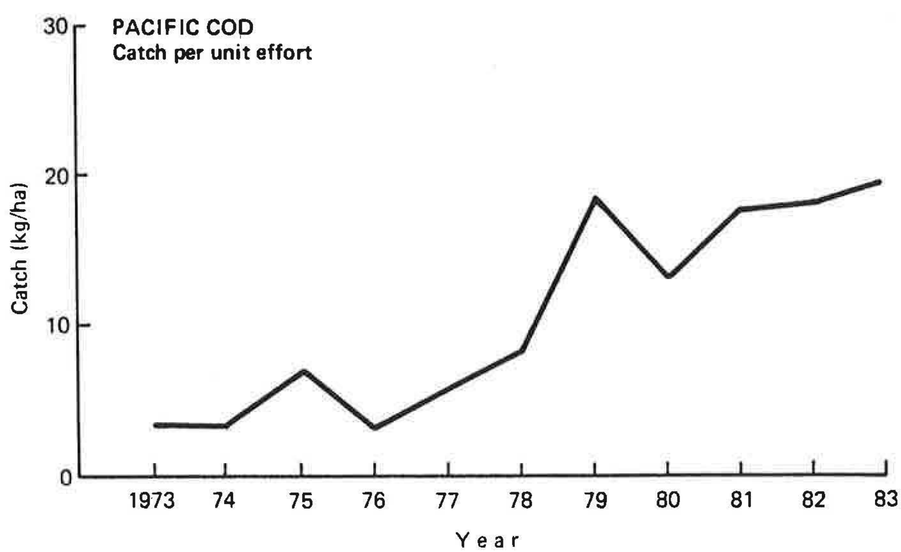
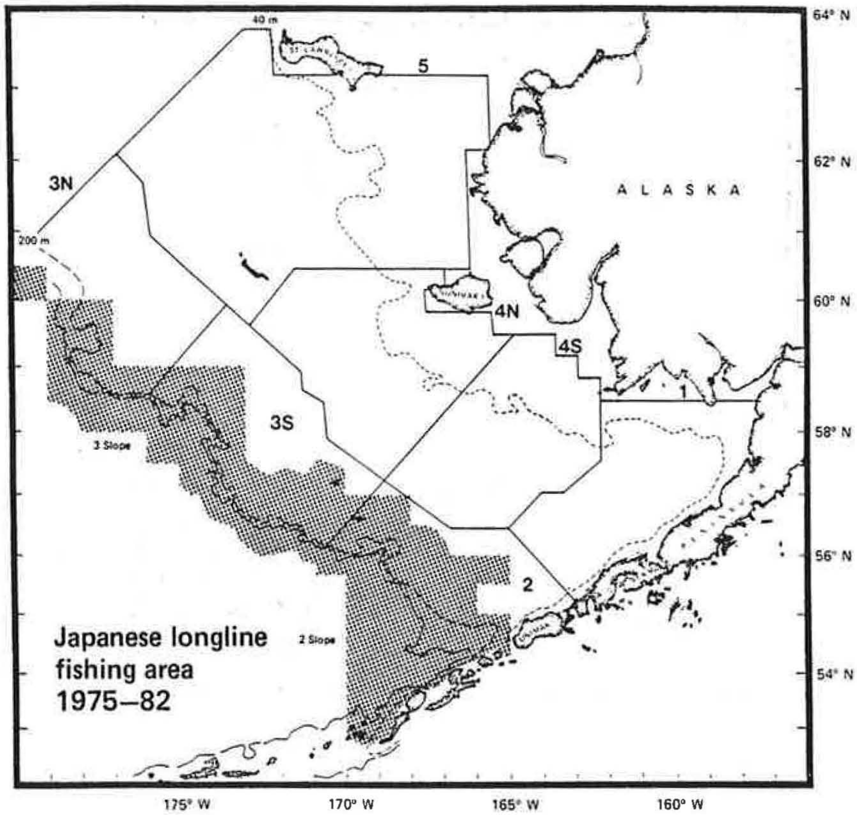


Figure 18.--Relative abundance of Pacific cod in southeast Bering Sea as indicated by catch per unit effort data from NWAFC demersal trawl surveys, 1973-1983. (From Bakkala and Wespestad, 1984.)



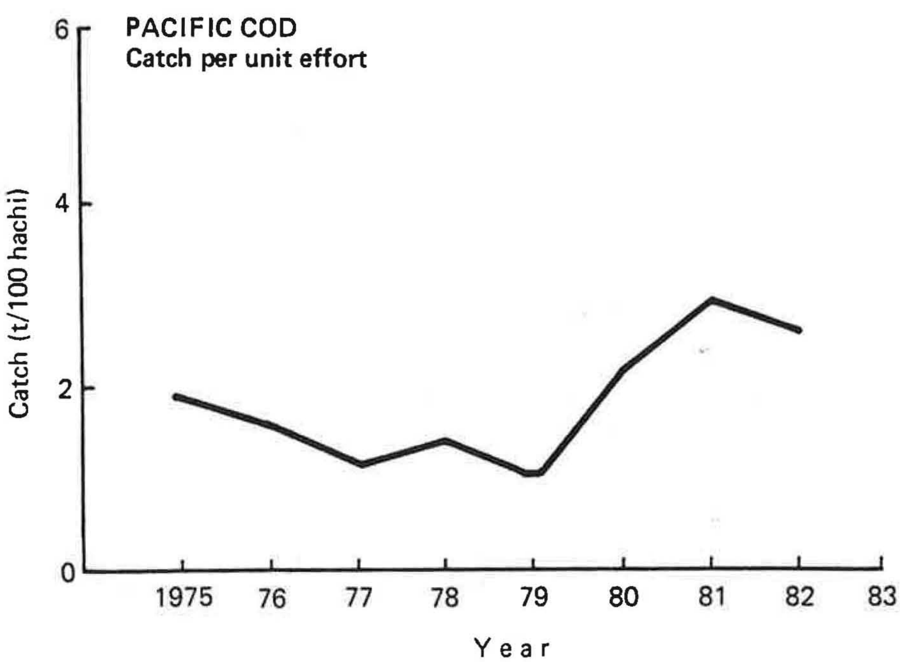


Figure 19.--Relative abundance of Pacific cod in the Japanese longline fishing area in eastern Bering Sea as indicated by catch per unit effort data from the fishery, 1975-1982. (Area of fishing from NWAFC data file. CPUE data are from Bakkala and Wespestad, 1984.)

the increase shown by the trawl survey data in Figure 18 because cod recruit to the longline fishery at a later age in life than they first appear in the surveys.

Based on estimates derived from large-scale trawl surveys, the biomass of Pacific cod in eastern Bering Sea increased from approximately 300 thousand tons in 1978 to more than 1.1 million tons in 1983 (Figure 20). Since the 1978 survey did not include sampling in large portions of subareas 3N, 4N and 4S, the biomass estimate for that year probably is on the low side relative to 1983. Nevertheless, there is little doubt that cod biomass increased markedly between 1978 and 1983.

Bakkala and Wespestad (1984) have projected the biomass of Pacific cod in eastern Bering Sea in 1984-86 to be as follows:

	Thousands of t	
Year	Age 2 and above	Age 3 and above
1984	688	581
1985	462	356
1986	385	278

Assumptions carried in the projections include a natural mortality coefficient of 0.5, recruitment at age 2 of 190 million fish in each of the three years, and annual catches ranging from 111 to 232 thousand tons. It remains to be seen how accurate the projections might be, but the following comparison of projections (age 2 and over) and survey estimates (all ages) of biomass for 1979-83 suggests that there may be considerable differences between projected values and survey estimates of biomass for 1984-86:

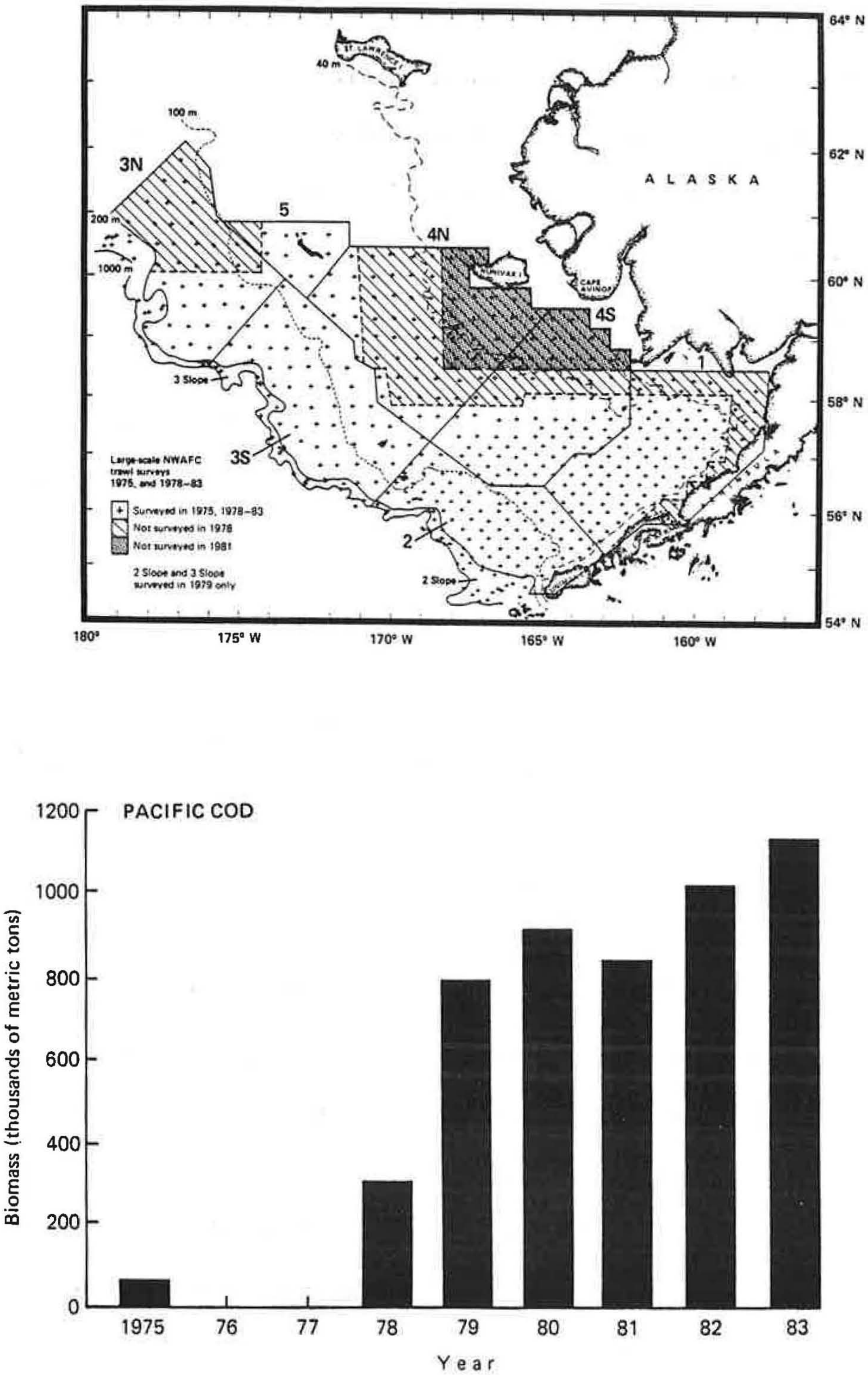


Figure 20.--Estimates of biomass of Pacific cod in eastern Bering Sea as derived from large-scale trawl surveys by NWAFC in 1975 and 1978-83. (From Bakkala and Wespestad, 1984.)

Year	Projected biomass, age 2 and above	Survey estimates of biomass, all ages	Projection/survey estimate, %
	Thousands of t		
1979	966	792	121
1980	1,271	913	139
1981	1,267	840	151
1982	1,100	1,013	109
1983	882	1,126	78

Notwithstanding differences between projections and survey estimates of biomass, which of course could be a consequence of errors in either or both, it appears that the abundance of cod in eastern Bering Sea will diminish significantly from the current level as the lifespan of the 1977 year class, which accounted for about one-third of the estimated total biomass in 1983, comes to an end.

5. COMMERCIAL CATCH

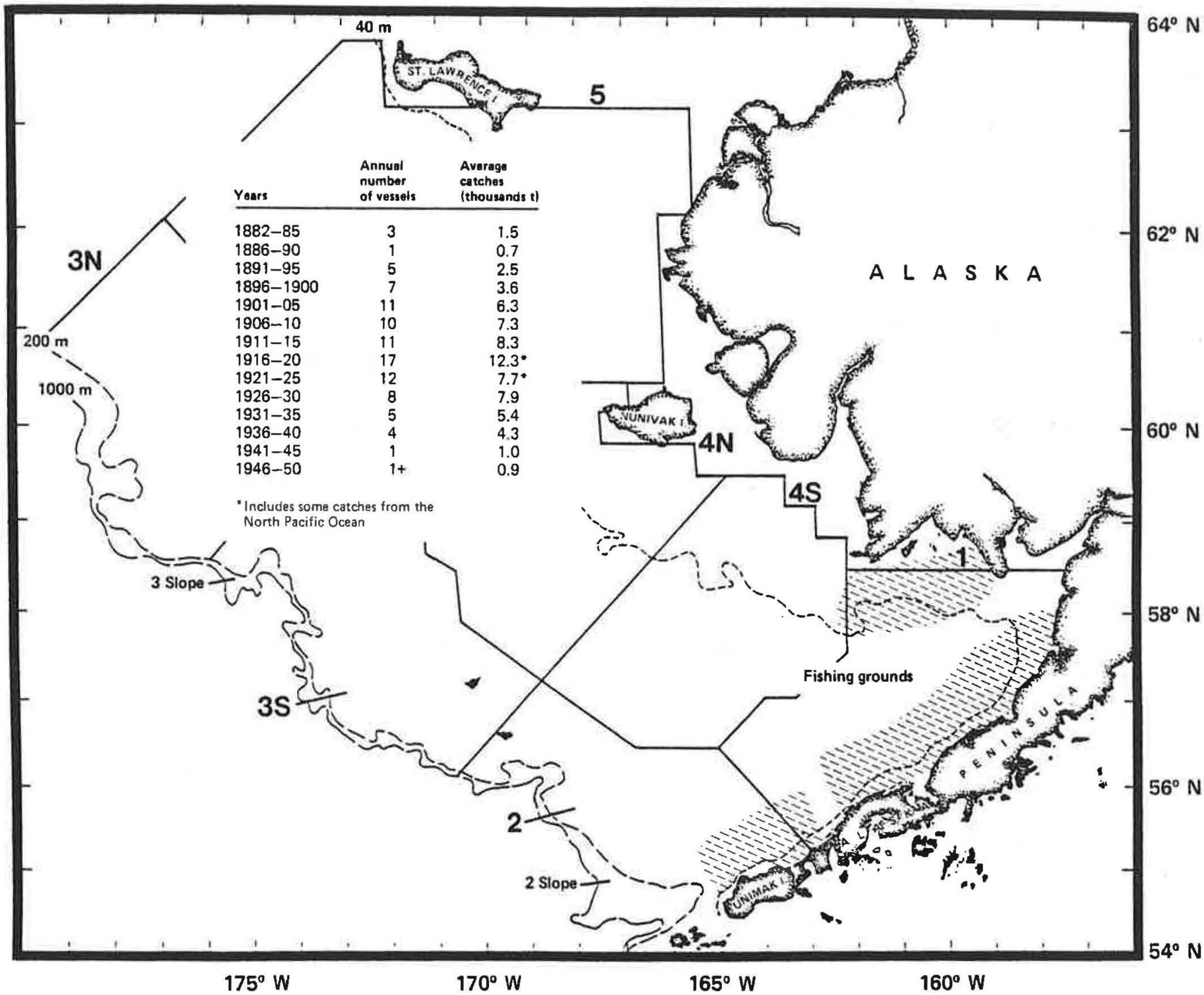
a. North American Fishery - 1882 to 1950

After beginning on a regular annual basis in the early 1880's, the North American schooner - dory catcher boat fishery for Pacific cod in eastern Bering Sea developed slowly over a 20-year period, reached its peak around the time of World War I, and then gradually declined until the fishery terminated in 1950 (Figure 21). Fishing took place during May-August at depths of 25 to 100 m on cod banks along the north side of Unimak Island and the Alaska Peninsula and between Capes Constantin and Newenham. Maximum annual catch was 14,000 t.

b. Foreign Fisheries

A Japanese mothership fleet operated in the eastern Bering Sea between 1933 and 1941, targeting first on pollock and then on yellowfin sole, with cod probably being taken as a by-catch and included in the 1,100 to 2,800 t of species other than pollock and flatfish caught annually (Forrester et al, 1978; and Bakkala, 1984).

After a hiatus of a dozen years during and following World War II, Japanese vessels resumed fishing for groundfish in eastern Bering Sea in 1954. They were joined by trawling vessels of the U.S.S.R. in 1958, Republic of Korea in 1967, Taiwan in 1974, Poland in 1979, and the Federal Republic of Germany in 1980. Yellowfin sole was the target species of the Japanese fishery through the early 1960's and of the Soviet fishery through 1970. In 1963 and 1971, respectively, pollock became the target species for the two fisheries, and it has been the main species sought by vessels of the other nations. Pacific cod have not been a target species of the trawl fisheries except when concentrations are found during the course of fishing for other species, but they have been a target of the Japanese longline fishery at times (Bakkala, 1984).



Years	Annual number of vessels	Average catches (thousands t)
1882–85	3	1.5
1886–90	1	0.7
1891–95	5	2.5
1896–1900	7	3.6
1901–05	11	6.3
1906–10	10	7.3
1911–15	11	8.3
1916–20	17	12.3*
1921–25	12	7.7*
1926–30	8	7.9
1931–35	5	5.4
1936–40	4	4.3
1941–45	1	1.0
1946–50	1+	0.9

*Includes some catches from the North Pacific Ocean

Figure 21.--Area fished by the North American schooner-dory catcherboat fishery for Pacific cod in eastern Bering Sea and average annual catches and number of vessels, 1882-1950. (From Cobb, 1927, and Pereyra et al., 1976.)

Annual catch of cod increased from slightly over 200 t in 1958 (the first year that any foreign nation reported cod catches separately from other species) to nearly 14,000 t in 1963 and then to 70,000 t in 1970. From that peak it fell to an average annual catch of 50,000 t during 1971-76 and 35,000 t during 1977-82 (Table 1). Most of the cod have been taken on the outer continental shelf each year (Bakkala, 1984 and Low, 1974). Distribution of trawl catches is much more widespread than longline catches, as shown by average annual catches during 1978-82 (Figure 22).

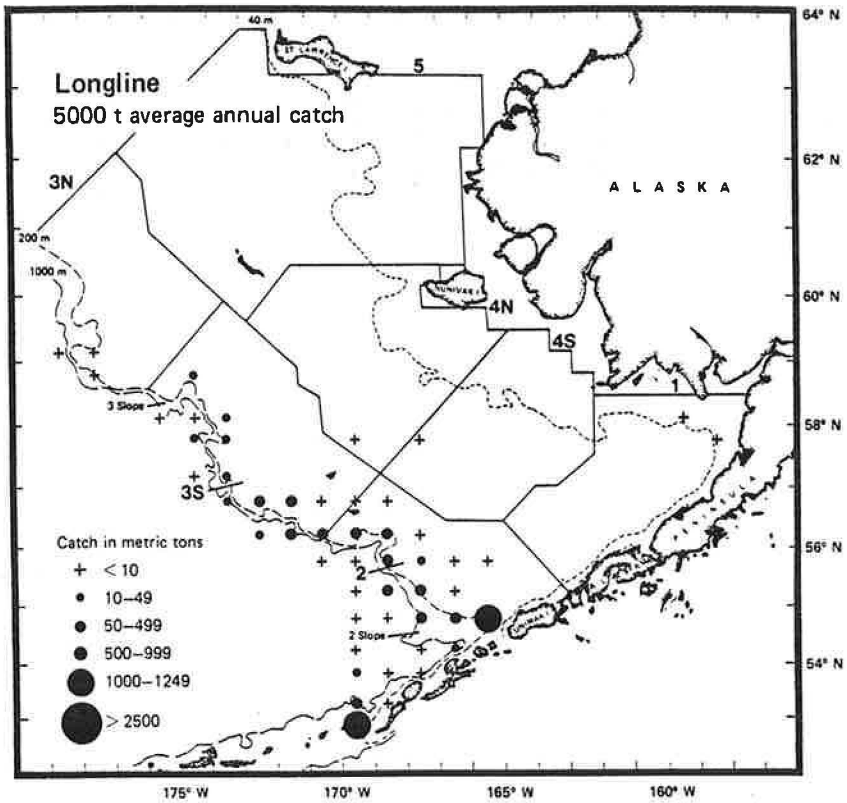
c. U.S. Fisheries --Recent Years.

A U.S. domestic trawl fishery and joint venture fisheries, the latter involving U.S. catcher boats delivering catches to processing vessels of other nations, recently began operations in eastern Bering Sea. Areas fished are shown in Figure 23. Combined catches of Pacific cod by these fisheries increased from less than 1,000 t in 1979 to nearly 49,000 t in 1983, accounting for more than one-half of the all-nation catch in the latter year (Table 1).

Table 1.--Commercial catches (t) of Pacific cod in eastern Bering Sea, 1958-82, by nations. (From Bakkala, 1984; Bakkala and Wespestad, 1984; and NWAFC data files.)

Year	Foreign fisheries					U.S. fisheries			All-nation catch
	Japan	USSR	ROK2/	Other nations3/	Total	Joint ventures4/	Domestic5/	Total	
1958	223	-1/			223				223
1959	3,632	-			3,632				3,632
1960	5,679	-			5,679				5,679
1961	6,883	-			6,883				6,883
1962	10,347	-			10,347				10,347
1963	13,641	-			13,641				13,641
1964	13,408	-			13,408				13,408
1965	14,719	-			14,719				14,719
1966	18,200	-			18,200				18,200
1967	32,064	-	-		32,064				32,064
1968	57,902	-	-		57,902				57,902
1969	50,351	-	-		50,351				50,351
1970	70,094	-	-		70,094				70,094
1971	40,568	2,486	-		43,054				43,054
1972	35,877	7,028	-		42,905				42,905
1973	40,817	12,259	-		53,386				53,386
1974	45,915	16,547	-	-	62,462				62,462
1975	33,322	18,229	-	-	51,551				51,551
1976	32,009	17,756	716	-	50,481				50,481
1977	33,141	177	-	2	33,320		15	15	33,335
1978	41,234	419	859	-	42,512		31	31	42,543
1979	28,532	1,956	2,446	47	32,981		780	780	33,761
1980	27,334	7	6,346	1,371	35,058	8,370	2,433	10,803	45,861
1981	27,570		6,147	2,481	36,198	7,410	8,388	15,798	51,996
1982	17,380		8,151	647	26,178	9,312	19,550	28,862	55,040
1983	31,256		10,185	65	41,506	14,362	34,315	48,677	90,183

1/ Dash indicates fishing but catches of cod not reported.
2/ Republic of Korea.
3/ Taiwan, Poland, and West Germany.
4/ Joint ventures between U.S.-ROK and U.S.-USSR.
5/ U.S. vessels delivering to domestic processors.



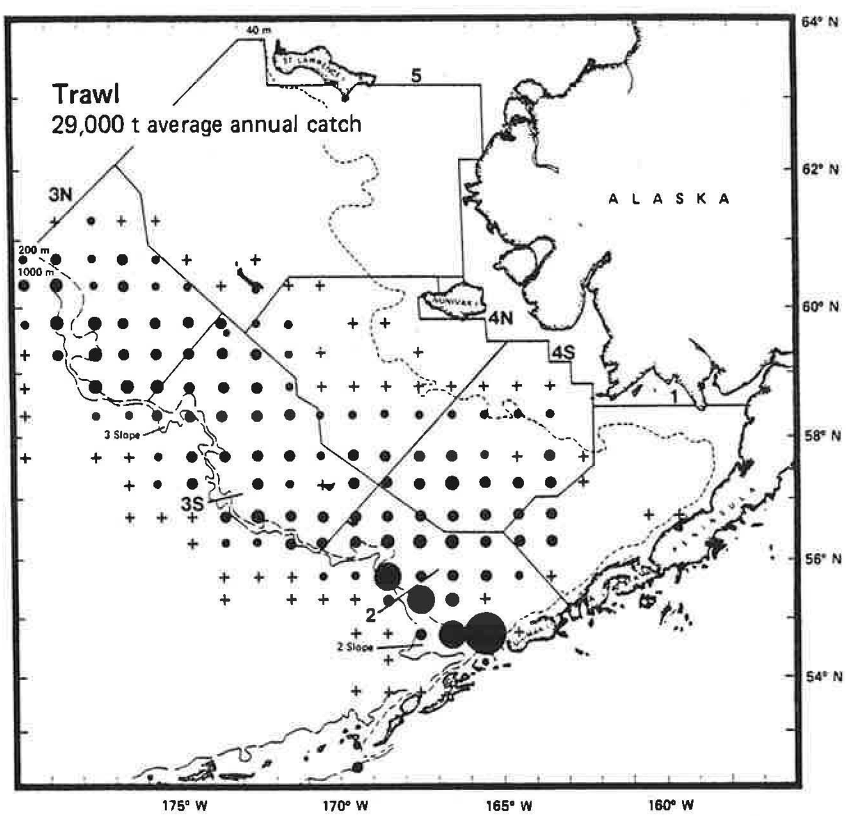
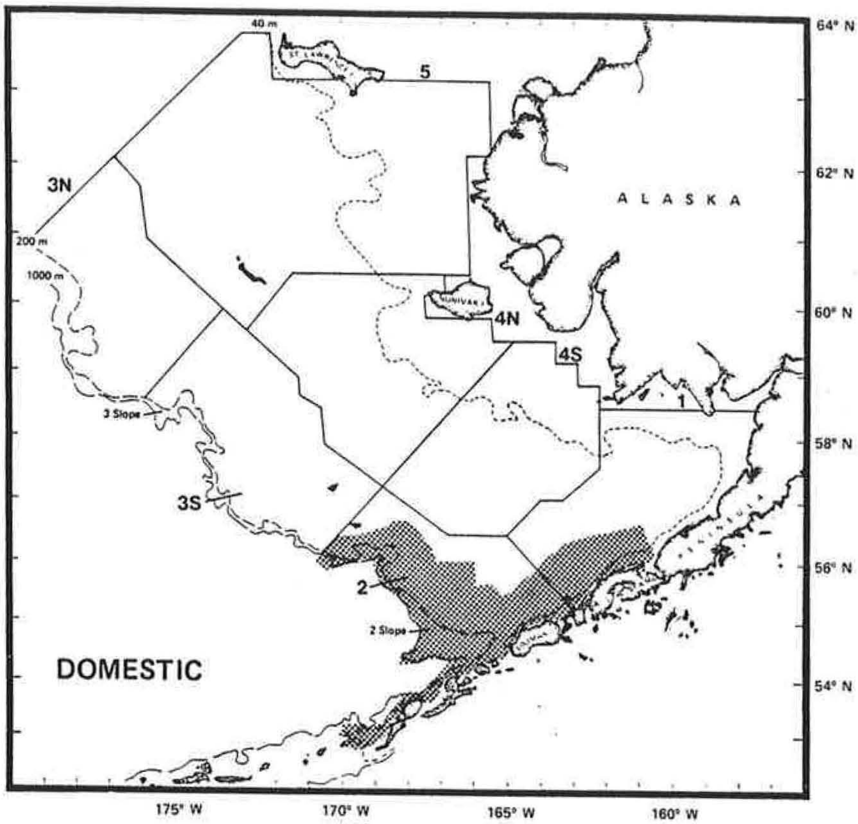


Figure 22.--Distribution of average annual catches of Pacific cod by foreign trawl and longline fisheries in eastern Bering Sea during 1978-82, as reported by fishing nations and U.S. observers. (From NWAFC data files.)



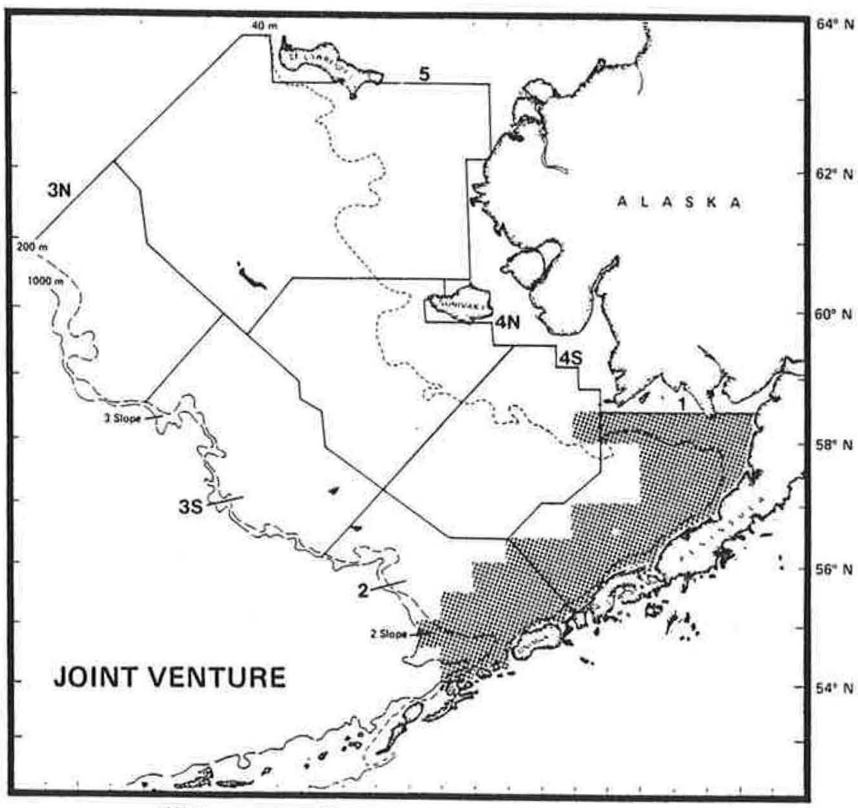


Figure 23.--Areas fished for Pacific cod in eastern Bering Sea by U.S. vessels connected with domestic and foreign (joint venture) processing operations. (R. Nelson and S. Hughes, pers. comm.)

6. MANAGEMENT

Measures employed in regulating domestic and foreign fisheries for groundfish in eastern Bering Sea prior to enactment of the U.S. Fishery Conservation and Management Act (FCMA) of 1976 included gear restrictions, licensing of vessels and fishing gear, time-area closures, requirements for reporting of catches or landings, and quotas for some species in some years. A detailed summary of the historical regulations is given in the Fishery Management Plan (FMP) for the Groundfish Fishery in the Bering Sea/Aleutian Islands Area (Figure 24) prepared by the North Pacific Fisheries Management Council in October 1983. The FMP also describes in full the current management regime for the domestic and foreign fisheries for groundfish (excluding Pacific halibut) under the provisions of the FCMA.

Four priority objectives dictate the philosophy of management for the groundfish fishery in the region:

(1) Provide for the rational and optimal use, in a biological and socio-economic sense, of the region's fisheries resources as a whole;

(2) Minimize the impact of groundfish fisheries on prohibited species (including halibut, herring, salmonids, shrimps, scallops, snails, king crab, Tanner crab, Dungeness crab, corals, surf clams, horsehair crab and lyre crab) and continue the rebuilding of the Pacific halibut resource;

(3) Provide for the opportunity and orderly development of domestic groundfish fisheries, consistent with (1) and (2) above; and

(4) Provide for foreign participation in the groundfish fishery, consistent with all three objectives above, to take the portion of the total allowable catch (TAC) not utilized by domestic fishermen.

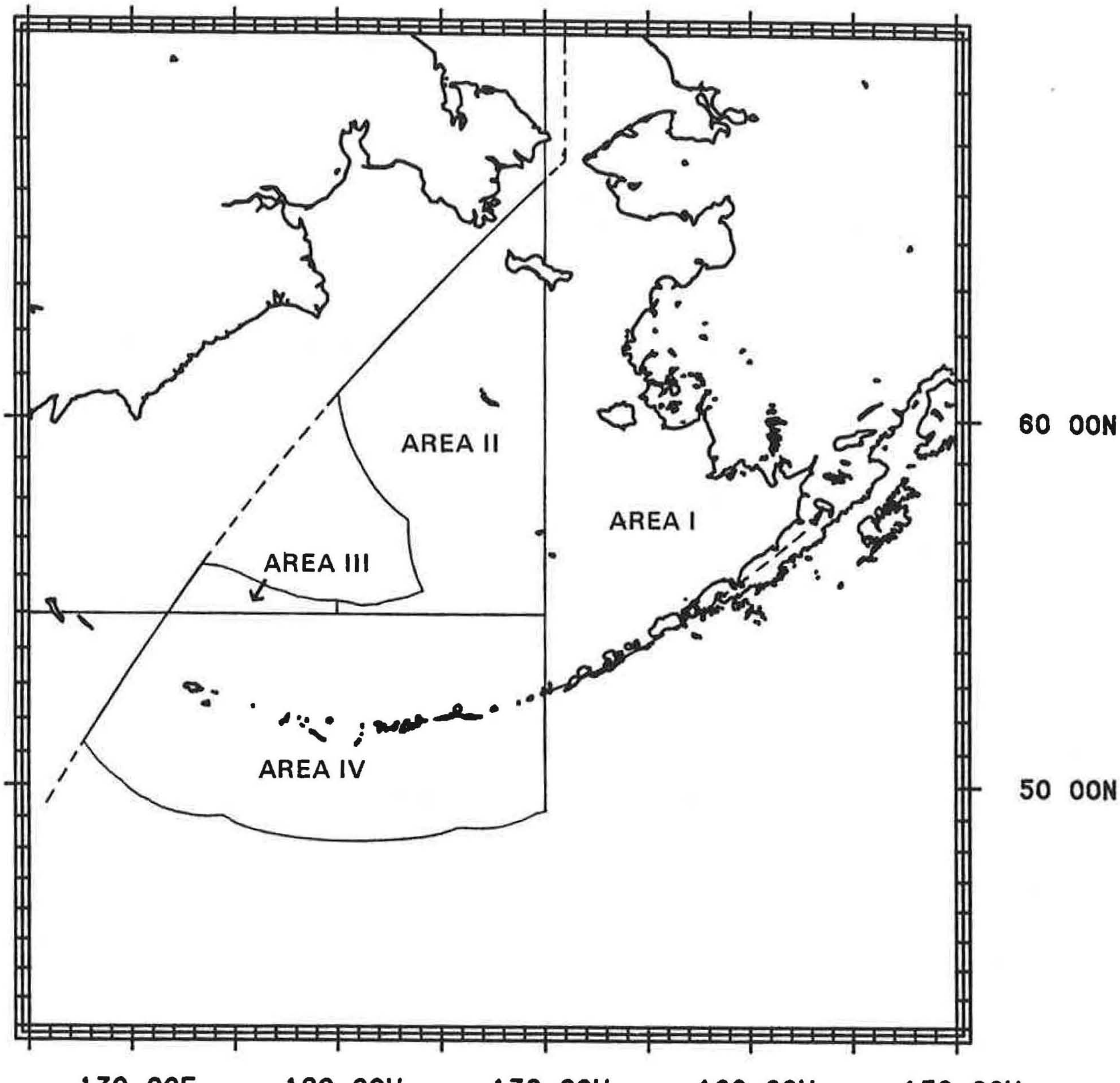


Figure 24.--Fishing areas in the Bering Sea and Aleutian Islands as established by the North Pacific Fisheries Management Council.

In connection with the last two objectives the proportion of the TAC of Pacific cod from the Bering Sea/Aleutian Islands area allocated to U.S. fisheries increased from zero in 1977 to 55% in 1982 (Table 2). The proportion of the TAC allocated to U.S. fisheries is expected to become much greater in the near future.

Table 2.--Allocation of total allowable catches (t) of Pacific cod in the Bering Sea/Aleutian Islands area, 1977-82 (from Fishery Operations Branch, NMFS, Alaska Region).

		Allocations			
Year	TAC	U.S. fisheries	Foreign fisheries	Reserves[a/]	% U.S.
1977	58,000	-	58,000	-	0
1978	70,500	-	58,070	12,430	0
1979	58,000	-	56,500	1,500	0
1980	70,700	22,265	48,435	-	31
1981	78,700	27,232	51,468	-	35
1982	78,700	43,265	35,435	-	55

a/ Set aside for unexpected expansion of U.S. fisheries, possible operational problems of domestic and foreign fleets, adjustment of TAC according to stock conditions during the fishing year, or subsequent apportionment.

7. THE RESOURCE IN RELATION TO OIL DEVELOPMENTS IN BRISTOL BAY

Simulation studies of the uptake and depuration of petroleum hydrocarbons in selected marine species resulting from exposure to oil-contaminated water and sediments and the consumption of oil-contaminated food following hypothetical oil spills off Port Heiden on the Alaska Peninsula (Gallagher and Pola, 1984) provide an indication of the possible consequences of oil developments in the Bristol Bay ecosystem as they relate to the Pacific cod resource and fishery in eastern Bering Sea. The studies involve two accident scenarios, one a well blowout lasting five days and releasing 20,000 barrels of Prudhoe Bay crude oil per day for a total spill of 100,000 bbl, the other a tanker accident resulting in a spill of 200,000 bbl of refined automotive diesel fuel within a 24-hour period. The distribution of oil in a 15 m surface layer and in a 10 cm bottom layer was estimated over a 10,000 km^2 area for the blowout scenario, and a 4,352 km^2 area in the case of the tanker accident scenario. Concentrations of oil in the water in the surface layer (water soluble fractions, or WSF) and in the bottom layer (on-bottom fractions, or TARS) were measured in parts per billion over a period of 30 days following the hypothetical blowout or accident.

Findings from Gallagher and Pola's simulation study of oil concentrations in water can be summarized as follows:

Scenario 1-a: Blowout, WSF. Maximum concentration was 0.1 to 1.0 ppm, lasting approximately 17 days after the blowout and contaminating less than 3% of the study area, that is, less than 300 km^2.

Scenario 1-b: Blowout, TARS. Maximum concentration also was 0.1 to 1.0 ppm, beginning about two weeks after the blowout and lasting 8 days, contaminating a maximum of 3% of the study area.

Scenario 2-a: Accident, WSF. Maximum concentration exceeded 5 ppm, but for only 4 days following the accident and contaminating less than 2% of the study area, that is, approximately 50 km^2. Concentrations of 1-5 ppm contaminated up to 10% of the study area (about 450 km^2) for about 12 days following the spill, and concentrations of 0.1 to 1.0 ppm contaminated up to 22% of the area (nearly 1,000 km^2) for 15 days immediately after the spill.

Scenario 2-b: Accident, TARS. Maximum concentration also exceeded 5 ppm, lasting nearly 2 weeks beginning 4 days after the spill and contaminating about 5% of the study area (about 225 km^2). Concentrations of 1-5 ppm, lasting for 4 weeks after the spill, contaminated up to 19% of the study area (about 825 km^2), and concentrations of 0.1-1.0 ppm lasted throughout the 30 days of the simulation study, contaminating 28% of the area (1,200 km^2).

A point of reference for relating the foregoing findings to the impact that a well blowout or tanker accident might have on the Pacific cod resource in eastern Bering Sea is given by Moore and Dwyer (1974) who estimated the concentrations of soluble aromatic derivatives causing mortalities of finfish in their larval and adult stages of life: 0.1-1.0 ppm for larvae and 5-50 ppm for adults. For purposes of this study, it is assumed that concentrations of 5-50 ppm are lethal for cod of 4 years of age and over, with concentrations of 1-5 ppm causing mortalities of cod of ages 1-3, which are referred to here as sub-adults.

Spawning populations. Relatively little is known about the distribution of spawning populations of Pacific cod in eastern Bering Sea, but evidence at hand indicates that spawning takes place in areas far removed from the three sites selected for simulation studies of oil spills: off Port Moller, Port Heiden, and Cape Newenham. It appears that an oil spill or well blowout at any one of the three offshore sites would have little, if any, effect on spawning adults.

Eggs and larvae. Not enough is known about the distribution of Pacific cod eggs and larvae in eastern Bering Sea to make a quantitative determination of the impact that a well blowout or tanker spill off Port Moller, Port Heiden, or Cape Newenham might have on their development or survival, or the abundance of the year class that they represent. The worst-case scenario indicated by Gallagher and Pola's simulation studies (Scenario 2-b) shows that an area of 1,200 km^2 would be contaminated with oil of sufficient concentration to be lethal to cod larvae. Such an area undoubtedly represents only a small fraction of the total area where cod larvae are to be found in eastern Bering Sea.

Sub-adults. Under Scenario 2-b, an oil spill from a tanker accident in Subarea 1, which encompasses 84,000 km^2, would contaminate about 825 km^2 of the subarea for a 4-week period with oil concentrations of 1-5 ppm. Assuming that sub-adult cod are evenly distributed throughout the subarea without moving in or out of the contaminated area during the 4-week period when the concentration of oil is assumed to be lethal, it is estimated that about 1% of the population of ages 1-3 cod in Subarea 1 would be killed as a result of a 200,000 bbl spill caused by a tanker accident. Based on the average annual abundance of ages 1-3 cod in the NWAFC trawl survey area in eastern Bering Sea during 1978-83 (Figure 10), a 1% mortality in Subarea 1 translates into about 0.3% mortality for the trawl survey area as a whole.

Adults. Under the same scenario as described for sub-adult cod and employing similar assumptions, it is estimated that slightly less than 0.3% of the total population of age 4 and older cod in Subarea 1 would be killed as a result of the oil spill. Such a loss would represent 0.05% of the total population of age 4^+ cod in the eastern Bering Sea, as indicated by trawl survey estimates of abundance during 1978-83.

Judging from trawl survey estimates of abundance of age 1 and older cod in the different subareas of eastern Bering Sea during 1978-83, the impact of an oil spill from a tanker accident (Scenario 2-b) off Cape Newenham in Subarea 4S on the total abundance of sub-adult and adult cod would be expected to be less (by 40%) than a corresponding spill in Subarea 1. In neither case would the kill of sub-adult and adult cod be detectable in trawl survey estimates of abundance. The estimated error of the point estimate of 727 million cod in the population in 1983 (Figure 10) was $\pm$22%, about fifty times greater than the estimated percentage kill of age 1 and older cod that would be attributable to a very large oil spill in Subarea 1.

Although not suffering a mortality due to a well blowout or tanker spill, a segment of the cod population would be tainted through the consumption of oil-contaminated food. Gallagher and Pola estimate that a well blowout would result in the tainting of up to 2% of the biomass in the spill area, a tanker accident up to 30%. As depuration proceeds, that is, the purging of hydrocarbons from contaminated fish over time, the percentage of tainted fish decreases. Extrapolation of data given by Gallagher and Pola on percent biomass tainted in relation to the number of days after the start of a spill suggests that it would take about 60 days for Pacific cod to be taint-free, which in turn suggests that the spill area would have to be closed to fishing for approximately two months to avoid the catching of tainted fish. The closed area would represent only a minor fraction of the total area where fishing for cod could be continued, unaffected by tainted fish.

REFERENCES

Bakkala, R. G.

1984. Pacific cod of the eastern Bering Sea. Int. North Pac. Fish. Comm., Bull. 42.

Bakkala, R. G., T. M. Sample, M. S. Bohle, J. A. June, A. M. Shimada and Y. Umeda.

1982. Data report: 1979 demersal trawl survey of the eastern Bering Sea continental shelf and slope. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC 30, 200 p.

Bakkala, R. G. and V. G. Wespestad.

1984. Pacific cod. _In_ R. G. Bakkala and L. L. Low (editors): Condition of groundfish resources of the eastern Bering Sea and Aleutian Islands region in 1983. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-53, 189 p.

Bakkala, R., S. Mishima, S. Westrheim, C. Zhang, and E. Brown.

1984. Distribution of Pacific cod (_Gadus macrocephalus_) in the North Pacific Ocean. Int. North Pac. Fish. Comm., Bull. 42.

Bohle, Michael S., and R. G. Bakkala.

1984. Data report: 1978 bottom trawl survey of eastern Bering Sea groundfish. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC 55, 164 p.

Cobb, J. N.

1927. Pacific cod fisheries. Rep. U.S. Comm. Fish., 1926, append. 7:305-499. (Doc. 1014.)

Daan, N.

1983. Analysis of the cod samples collected during the 1981 stomach sampling project. Unpubl. manusc. (Document submitted to ICES, Demersal Fish. Comm., 1983.)

Dodimead, A. J., F. Favorite, and T. Hirano.

1962. Salmon of the North Pacific Ocean. Part II. Review of oceanography of the subarctic Pacific region. Int. North Pac. Fish. Comm. Bull. 13:195 p.

Forrester, C. R. and D. F. Alderdice.

1966. Effects of salinity and temperature on embryonic development of Pacific cod (Gadus macrocephalus). J. Fish. Res. Board Can. 23:319-340.

Forrester, C. R., A. J. Beardsley, and Y. Takahashi.

1978. Groundfish, shrimp, and herring fisheries in the Bering Sea and Northeast Pacific -- historical catch statistics through 1970. Int. North Pac. Fish. Comm., Bull. 37, 147 p.

Gallagher, A. F. and Nancy B. Pola.

1984. The uptake and depuration of petroleum hydrocarbons in marine species: a simulation study of the uptake and depuration of petroleum hydrocarbons and its effect on selected marine species in the Bristol Bay ecosystem. Natl. Mar. Fish. Serv., Northwest and Alaska Fisheries Center, Seattle, WA. Processed Rpt. 84-16, 68 pp.

Hart, J. L.

1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. 180, 740 p.

Kennedy, W. A.

1970. Reading scales to age Pacific cod (Gadus macrocephalus) from Hecate Strait. J. Fish. Res. Board Can. 27:915-922.

Ketchen, K. S.

1961. Observations on the ecology of the Pacific cod (Gadus macrocephalus) in Canadian waters. J. Fish. Res. Board Can. 18:513-558.

1964. Preliminary results of studies on growth and mortality of Pacific cod (Gadus macrocephalus) in Hecate Strait, British Columbia. J. Fish. Res. Board Can. 21:1051-1067.

Krivobok, M. N. and O. I. Tarkovskaya.

1964. Chemical characteristics of yellowfin sole, cod, and Alaska pollock of the southeastern part of the Bering Sea. Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 49 (Izv. Tikhookean. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 51):257-271. (Transl. in Soviet Fisheries Investigations in the Northeast Pacific, Part II, p. 271-286, by Israel Program Sci. Transl., 1968, avail. Natl. Tech. Inf. Serv., Springfield, VA, as TT67-51204.)

Leaman, J. E.

1982. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1981. Can. Tech. Rep. Fish. Aquat. Sci. No. 1124. 90 p.

In press. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1982. Dept. Fish. and Oceans, Fish. Res. Branch, Pac. Biol. Sta., Nanaimo, B.C.,Canada V9R 5K6.

Low, L. L.

1974. A study of four major groundfish fisheries of the eastern Bering Sea. Ph.D. Thesis, Univ. Wash., Seattle, 240 p.

McLain, D. R. and F. Favorite.

1976. Anomalously cold winters in the southeastern Bering Sea, 1971-75. In Goulet, J. R., Jr. (ed). The environment of the United States living marine resources 1974. U.S. Dep. Commer., NOAA, NMFS, MARMAP Contr. No. 104. 38 p.

Moiseev, P. A.

1953. Cod and flounders of far eastern seas. Izv. Tikhookean. Nachno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 40:287 p. (Transl. Fish. Res. Board Can., Transl. Ser. 119, 596 p.)

Mukhacheva, V. A., and O. A. Zvyagina.

1960. Development of the Pacific cod Gadus morhua macrocephalus Til. Acad. Nauk. SSSR Tr. Inst. Okeanol. 31:145-165. (Transl., Fish. Res. Board Can., Nanaimo, B.C.)

Musienko, L. N.

1970. Reproduction and development of Bering Sea fishes. Tr. Vses. Nauchno-issled. Inst. Morsk. Rybn. Khoz. Okeanogr. 70 (Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr. 72):166-224. (Transl. in Soviet Fisheries Investigations in the Northeastern Pacific, Part V, p. 161-224, by Israel Program Sci. Transl., 1972, avail. Natl. Tech. Inf. Serv., Springfield, VA, as TT71-50127.)

Niggol, K.

1982. Data on fish species from Bering Sea and Gulf of Alaska. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/NWC-29. 125 p.

Pereyra, W. T., J. E. Reeves, and R. G. Bakkala.

1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Processed Rep., 619 p., Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd., Seattle, Wash. 98112.

Salveson, S. J. and J. R. Dunn.

1976. Pacific cod (Family Gadidae). In: Pereyra, Reeves, and Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Processed Rep., 619 p., Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd., Seattle, Wash. 98112.

Schultz, L. P. and A. D. Welander.

1935. A review of the cods of the northeastern Pacific with comparative notes on related species. Copeia 1935(3):127-139.

Smith, G. B. and R. G. Bakkala.

1982. Demersal fish resources of the eastern Bering Sea: Spring 1976. U.S. Dep. Commer., NOAA Tech. Rpt. NMFS SSRF-754, 129 p.

Smith, J. E.

1979. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1978. Fish. and Mar. Serv., Tech. Rep. No. 891. Dept. Fish and Ocean, Fish and Mar. Serv., Resource Serv. Br., Pac. Biol. Sta., Nanaimo, B.C., Can. 82 p.

1980. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1979. Can. Tech. Rep. Aquat. Sci. No. 961, 90 p.

1981. Catch and effort statistics of the Canadian groundfish fishery on the Pacific coast in 1980. Can. Tech. Rep. Aquat. Sci. No. 1032, 90 p.

Svetovidov, A. N.

1948. Gadiformes. In: Fauna of USSR. Izdatel'stvo Akad. Nauk., Moscow-Leningrad, 9(4), 222 p. (Transl. Israel Prog. Sci., Transl. 1962, 232 p. Avail. Natl. Tech. Inf. Serv., Springfield, VA, as OTS 63-11071.)

Teshima, K.

1983. Relationships between catch per hour trawled of Pacific cod and water temperature in the eastern Bering Sea. Unpubl. manusc.

Thomson, J. A.

1962. On the fecundity of Pacific cod (Gadus macrocephalus) from Hecate Strait, British Columbia. J. Fish. Res. Board Can. 19(3):497-500.

Umeda, Y. and R. Bakkala.

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

Vershinin, V. G.

1983. Cod biology and fishing in Anadyr-Navarin area of the Bering Sea. Abstract of unpubl. manusc.

Waldron, K. D.

1981. Ichthyoplankton. In: D. W. Hood and J. A. Calder (editors), The Eastern Bering Sea Shelf: oceanography and resources, Vol. 1, p. 471-493. Univ. Wash. Press., Seattle.

Wolotira, R. J., Jr., T. M. Sample, and M. Morin, Jr.

1977. Demersal fish and shellfish resources of Norton Sound, the southeastern Chukchi Sea and adjacent waters in the baseline year 1976. Processed Rep., 292 p. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

Yamamoto, G. and C. Nishioka.

1952. The development and rearing of hatched larvae of North Pacific cod (Gadus macrocephalus Tilesius). Japan Sea Reg. Fish. Res. Lab., Spec. Publ., 1952:301-308. (Transl. Fish. Res. Bd. Can., Transl. Ser. 402, 18 p.)

Zenger, H. H., Jr.

1983. Pacific cod. In: G. Stauffer (editor) et al: Condition of the groundfish resources of the Gulf of Alaska as assessed in 1983. Processed Rep., 190 p. Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd., Seattle, Wash. 98112.

Zhang, Chang Ik.

1981. Pacific cod of South Korean waters. (Document submitted to the annual meeting of the Int. North Pac. Fish. Comm., Vancouver, Can., Oct. 1981.) Northwest and Alaska Fisheries Center, Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.