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Center

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Discussion Summaries from the International Workshop on Bering Sea Pollock Stock Assessment, February 4-8, 1991

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INTRODUCTION

International Workshop on Bering Sea Pollock Stock Assessment

February 4-8, 1991

Alaska Fisheries Science Center
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Seattle, Washington USA

PARTICIPATING COUNTRIES

Canada
Japan
People's Republic of China
Poland
Republic of Korea
Union of Soviet Socialist's Republics
United States of America

CHAIRMAN: Vidar Wespestad
COORDINATOR: Loh-Lee Low

WORKSHOP THEME

This workshop was recommended at the International Pollock Symposium held in April 1990 at Khabarovsk, USSR. It was agreed that the United States would hold the stock assessment workshop in Seattle to address the wide differences in estimates of biomass and potential yield of the pollock resources in the Bering Sea.

The theme of the workshop was to gather scientists from all countries having pollock fisheries in the Bering Sea and bring together all available data for analyses at a single forum. The scientists reviewed all pertinent data on pollock biology and population dynamics in order to construct working models of the dynamics of Bering Sea pollock.

The results from the modelling exercise contributed important new information on the status of pollock stocks and impacts of exploitation by commercial fisheries.

Data was found sufficient to perform a Bering Sea catch-at-age analysis and to develop a working model of the dynamics of Bering Sea pollock. The working model will be used to estimate the abundance trend of pollock throughout the Bering Sea and to evaluate the sensitivity of the results to input parameters and to identify critical data needs.

The workshop consisted of a series of modules which examined the available data and identified the data appropriate for the entire Bering Sea population or sub-components. In cases where data did not support a single solution, a range of alternative parameters was developed for evaluation. Scientists from the Alaska Fisheries Science Center were asked to prepare material for each module and facilitate discussions. The body of this report consists of the material presented in each module and resulting discussions where appropriate.

AGENDA

Monday, February 4

Opening Remarks -- William Aron

Module A -- Reproduction and Recruitment
(Facilitator: Bernard Megrey)

Tuesday, February 5

Module B -- Fishery Statistics
(Facilitator: Dick Bakkala)
Catch data--estimation, discards, completeness, reliability
Effort Data--estimation, reliability
CPUE
Seasonality
Gear factors/selectivity

Module C -- Mortality Rates
(Facilitator: Anne Hollowed)
Area and Sex differences
Age-specific vs. constant

Wednesday, February 6

Module D -- Age and Growth
(Facilitator: Dan Kimura)
Area Differences
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Module E -- Distribution, Migration and Stock Structure
(Facilitator: Pierre Dawson)
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Thursday, February 7

Module F -- Survey Abundance Estimates

(Facilitator: Jim Traynor)
Hydroacoustic
Bottom trawl
Relative vs. absolute abundance

Friday, February 8

Synthesis and Model Formulation
(Facilitator: Vidar Wespestad)
Synthesis and Model Formulation
Summary and Recommendations

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MODULE A

Module A: Recruitment and Reproduction

Facilitator: Bernard A. Megrey

INTRODUCTION

The purpose of this paper is to present a summary of available information on aspects of reproduction and recruitment for walleye pollock (*Theragra chalcogramma*) stocks in the Bering Sea. Since the focus of this workshop is the entire Bering Sea ecosystem, information availability is classified into western Bering Sea, Aleutian Basin (the international zone), and the eastern Bering Sea. Data availability and the present state of knowledge is summarized in the information matrix (Fig. 1) should help guide future research and field work efforts[1]. Much of the information herein builds upon an earlier synopsis (Megrey 1989c).

1.0 REPRODUCTION

1.1 Spawning

1.1.1 Location and Timing

Based on U.S. Foreign Fisheries Observer coverage of the eastern Bering Sea commercial fishing fleet in 1984, Hinckley (1987) presents information which indicates that spawning pollock can be found in just about every month (Fig. 2). Time of peak spawning depends on specific locations, but generally spawning occurs from February to May at depths of between 100 and 200 m and at temperatures ranging between 1.8 and 6.0°C.

In the eastern Bering Sea, two distinct spawning locations seem to be evident. In the Aleutian Basin spawning peaks during February. Spawning groups then seem to move onto the shelf where spawning peaks in March or April. Based on the evidence from the U.S. Foreign Fisheries Observers, Hinckley (1987) suggested that there may be three distinct spawning groups in the Bering Sea: One in the Aleutian Basin, one on the northwest slope and southeast shelf, and one on the southeastern slope and northwest shelf.

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[1] Delegates from the Soviet Union were not present at the workshop on the day this module was discussed. Therefore blank cells in Figure 1 for the Western Bering Sea do not necessarily indicate a lack of information.

U.S. Foreign Fisheries Observer data from the Bering Sea in 1985 shows a similar spawning pattern when compared to 1984 with respect to intra-annual variation. Of interest in 1985 was the observed spawning in the Donut Hole area during Jan-Mar (Fig. 3) (Mulligan et al. 1989).

A generalized map of spawning locations in the Bering Sea (Fig. 4), including the western Bering Sea, is provided by Bulatov (1989). Spawning distributions in the eastern Bering Sea from Figure 4 are consistent with the earlier two figures. It appears that winter and spring spawning occurs in the eastern Bering Sea and only spring spawning occurs in the western Bering Sea. Zver'kova (1969) also shows spawning locations along the west coast of Kamchatka (Fig. 5). and indicated that spawning occurred during the winter-spring period, peaking in March.

Several points were made by workshop participants during the discussion. The southeast Bering Sea basin is an important spawning location since at least 1983. Time of peak spawning is Jan-Mar. The U.S. has little data prior to 1988. There were Soviet reports of spawning in this area as inferred from egg distributions as far back as summer of 1965 (Serobaba 1968) (Fig. 6). Spawning in the Bogoslof area occurs during Feb-April and the period of peak spawning is rather narrow, being about one week in duration. Spawning on the eastern Bering Sea shelf and slope occurs about one month later, peaking in about March and April and is much more protracted in duration. Based on egg and larval surveys, approximately 90% of the spawning in the Bering Sea occurs in the Bogoslof area and the remaining 10% occurs in the western Bering Sea. Poland observed spawning pollock in the SE corner of the doughnut hole during Feb of 1988-90, but only 3-5% of the catch were spawning. Mostly males were mature. There was an observation that it appeared that the spawning distribution was contracting. No spawning has been observed along the Aleutian chain west of Bowers ridge.

1.1.2 Timing Relative to Environmental Conditions

Not much is known regarding timing of spawning relative to environmental conditions; however, we do know that water temperature plays an important role in determining the geographic extent of adult distributions. Data from Bakkala and Alton (1986) show that in cold years, the distribution of adult pollock in the eastern Bering Sea is quite restricted compared to adult distributions in warm years. Zver'kova (1969) also suggested that water temperature played an important role in cuing the onset of spawning.

1.1.3 Vertical Distribution

During spawning, pollock appear to separate into distinct layers (Takakura 1954; Saito 1957). Females are found in the deeper layers, while males prefer the midlayers of the water column. Maeda (1986) hypothesized that the two-layered distribution of the sexes was a characteristic spawning behavior. Presumably eggs spawned by females at the bottom layer would be fertilized as they floated to the surface and passed through the layer of spermatophore released by the males at midlayers. Similar two-layered sex-stratified distributions have been observed in the Gulf of Alaska Shelikof Strait spawning aggregations (Nelson and Nunnallee 1985, 1986).

1.1.4 Spawning Biomass

Estimates of spawning biomass/abundance (Fig. 7) are available from eastern Kamchatka (Zolotov and Antonov 1989), the western Bering Sea (Balykin, 1989), and the eastern Bering Sea (Wespestad et al. 1990). Spawning biomass estimates from the Kamchatka area are calculated from application of VPA techniques to catch data as well as application of egg production methods to egg surveys. Inter-area comparisons are difficult because spawning is reported in units of biomass and numbers. Despite this differences, Figure 7 does show that trends between the western Bering Sea and eastern Bering Sea area agree while the trends between the eastern Kamchatka area and the western Bering Sea/eastern Bering Sea areas do not agree.

No spawning biomass estimate was available from the Aleutian Basin. It was also noted that spawning biomass estimates from the eastern Bering Sea may depend on more than one stock of pollock.

1.2 Maturity

1.2.1 Maturity-at-length Relationships

Few maturity studies have been carried out. Smith (1981) presented information on eastern Bering Sea pollock maturity-length relationships (Fig. 8) based on the National Marine Fisheries Service (NMFS) five point maturity scale. Maturity was recorded by direct visual inspection of gonads by either U.S. Foreign Fisheries Observers or NMFS Research Fisheries Biologists. These data indicate that females mature at a larger size than males do. In the Bering Sea, lengths at 50% maturity for males and females are 31.0 and 34.2 cm, respectively. Maturity-length data are also available from the eastern Bering Sea from 1989 (Fadeev 1989) which shows length at 50% maturity was 34.8 and 37.2 cm for males and females respectively (Fig. 9). This is in agreement with data from Megrey (1989b) on Gulf of Alaska pollock.

Parameter estimates from different empirical maturity-length relationships and estimates of the length at 50% maturity are presented in Table 1.

1.2.2 Spatial/Temporal Difference

Okada (1983) presented data from the eastern Bering Sea and Aleutian Basin during the time of pollock spawning (18 January to 20 March 1983) which shows substantial temporal and geographic variation in male and female pollock maturity (Fig. 10). Traynor (1990) also presented data on pollock maturity from the eastern Bering Sea which showed both temporal and spatial differences. Presented were maturity distributions from aggregations near Bogoslof Island in 1988 and 1989 and the southern eastern Bering Sea shelf north of Unimak Island (Fig. 11). Data from the Aleutian Basin during 1988 (Teshima and Sasaki 1990) also show spatial variation in pollock maturity for both males and females (Fig. 12).

Maturity condition is not constant from year-to-year. Maturity, measured as gonadal somatic index (GSI), show well defined seasonal variation for both males and females in the eastern Bering Sea (Maeda 1986) and eastern Bering Sea and Aleutian Basin (Teshima and Sasaki 1990) (Figs. 13 and 14). The Korean delegation presented GSI data from the international waters of the Aleutian Basin (Fig. 15) which also show seasonal variation. Data from pollock in the Gulf of Alaska (Megrey 1989a) show that the length at 50% maturity varies substantially over the 1983-88 period (Fig. 16) for both males and females. The range for female pollock is almost 8 cm. This type of analysis has not been carried out for the eastern Bering Sea however the data have been collected by U.S. surveys. When this new data become available, a closer look at interannual variation in eastern Bering Sea pollock maturity-length relationships will be possible.

1.2.3 Vertical Distribution

Data presented by Sasaki (1990) for the international zone in the Aleutian Basin shows that mature females pollock are typically found in the deeper layers, while less mature females prefer the midlayers of the water column (Fig. 17). This pattern is consistent with observations on vertical distribution of spawning pollock.

1.2.4 Factors Influencing Maturation Rates

Not much is known regarding factors that influence maturity rates. Maturity may be related to environmental conditions or, alternatively, it could be solely a function of body weight or growth rate characteristics.

1.3 Fecundity

1.3.1 Fecundity-at-length Relationships

Teshima et al (1989) show fecundity-length relationship for pollock from the international zone of the Aleutian Basin (Fig. 18). Comparison of pollock fecundity from different systems (Miller et al. 1986) shows that the fecundity-length relationship can be quite variable (Fig. 19). Fecundity of pollock from the Aleutian Basin differed from shelf and slope pollock in 1986, with Aleutian Basin pollock being less fecund, especially for pollock greater than 50 cm. Reduced food supply may produce slower growth and lower fecundity of the Aleutian Basin pollock. Interannual variability does not seem to be significant as demonstrated by a comparison of shelf and slope pollock fecundity in 1978 versus 1986. Pollock from the Bering Sea were less fecund over all length ranges compared to pollock from other systems. These intersystem differences are probably due to different underlying system productivity characteristics.

Parameter estimates of pollock empirical fecundity-length relationships from different areas are presented in Table 2.

1.3.2 Spatial/Temporal Differences

There is little evidence for spatial or temporal differences in fecundity.

1.3.3 Factors Influencing Egg Production Rates

Not much is known regarding factors that influence egg productivity rate, although nutritional status should be an important factor.

1.3.4 Egg Size, Energy Content, and Viability

In the eastern Bering Sea, egg size ranges from 1.3 to 1.9 mm with a mean of 1.5 mm (Incze et al. 1984). These compare well with the Gulf of Alaska where egg size has been estimated to be 1.2 to 1.85 mm with a mean of 1.4 mm (Kendall and Kim 1989). Development time of eggs from spawning to hatching ranges from about 14 days at 5°C to about 25 days at 2°C (Hamai et al. 1971). Kendall and Kim (1989) also estimate incubation times for Shelikof Strait pollock eggs to be about 14 days at 5°C. Based on an average temperature for the southeastern Bering Sea of 3.0-3.5°C, time to hatching should be about 22 days (Incze et al. 1984).

1.4 Sex Ratios

In discussions at the workshop it was mentioned that estimation of sex ratios during the spawning period are highly variable due to the fact that pollock aggregate by size and sex. At other times of the year the sex ratio is often observed to be 1:1. It was suggested by several delegates that using a 1:1 ratio would be the best way to deal with the problem.

1.4.1 Spatial/Temporal Differences

Maeda (1986) presented evidence from the eastern Bering Sea in 1973 demonstrating that pollock sex ratios exhibit intra-annual variations (Fig. 20). Throughout the wintering and feeding periods of the year, the sex ratio for mature and immature pollock is approximately 1:1. During the spawning period (1 April to 30

May), the female ratio for both mature and immature pollock drops. Data presented by Okada (1983) from the eastern Bering Sea during the time of pollock spawning (18 January to 20 March 1983) shows that sex ratios exhibit substantial temporal and geographic variation (Fig. 21). Data presented from the Korean (Fig. 22) and Polish delegation (Fig. 23) shows seasonal variation in sex ratio in the international zone of the Aleutian Basin.

2.0 RECRUITMENT

2.1 Observed Trends in Year Class Strength

Trends in pollock year class strength are available from all areas of the Bering Sea. Strong year classes are indirectly demonstrated from annual age composition estimates (Fig. 24) from eastern Kamchatka (Zolotov and Antonov 1989). These data show the strong 1978 year class showing up in the fishery as 3-year-olds in 1981 and this year class contributed to the catch until 1985. Also the 1982 year class appeared above average, showing up in 1984 as 2-year-olds. Application of age-structured stock assessment models to commercial catch-at-age data provide estimates of year class strength (Fig. 25) from both the western Bering Sea (Balykin 1989) and the eastern Bering Sea (Wespestad et al. 1990). These data both show the 1978 and 1982 year classes as strong and the 1981 and 1983 year classes as weak. Data provided by the Polish delegates (Fig. 26) from 1990 catches in the international zone also shows the strong 1978 and 1982 year classes. A quarterly breakdown of the Polish data (Fig. 27) shows the 1977 year class strong in the first quarter and the 1979 year class strong in the last quarter. In all quarters the 1978 and 1982 year class appeared strong. Age composition data from Polish catches in the international zone from 1985-1989 (Kowalewska-Pahlke 1990) shows a consistent showing of the 1977-78 and the 1972-73 year classes in the catch (Fig. 28).

The available data on year class strength show remarkable consistency in the strong 1978 year class and the weak 1981 and 1983 year classes despite the fact that the data come form wide geographic areas of the Bering Sea. The apparent coherence in strong and weak year classes implies that possibly something on the climate scale might be playing a role in determining year class strength.

3.0 Spawner-Recruit Data

Plotting the paired data points for recruitment and spawner abundance after accounting for the recruitment time lag is one method of revealing the existence of any relationship between spawners and recruits. The relationship between spawners and recruits was quantified for the western Bering Sea and eastern Bering Sea using a Ricker spawner-recruit model. The curves fit to the data are presented in Figure 29 and they show the typical wide scatter of data points. For the western Bering Sea, the curve appears to describe the data well except for the two weak 1981 and 1983 year classes. Data from the eastern Bering Sea are not described well by the spawner-recruit model. Of interest is the fact that three strong year classes (1965, 1972, and 1978) which were very similar in magnitude were produced from spawning populations that differed significantly in their abundance. This indicates that pre-recruit mortality during these 3 years was highly variable. If the 1978 year class was removed from the analysis, it appears that a straight line (i.e. an average) would describe the data fairly well. Mito (1990) also constructed similar cures for the eastern Bering Sea which again showed the strong 1978 and 1982 year classes (Fig. 30).

The lack of range in recruitment values in the eastern Bering Sea case might be due to the fact that the spawning area is very broad and the spawning period is rather protracted.

The use of spawner-recruit models ignores the fact that recruitment and spawner data are highly time-structured. Nonetheless, these types of analyses might prove useful in a modeling exercise as they would provide a means of allowing a model to predict future recruitment.

3.1 Density-dependent/Density-independent effects

Currently there is insufficient data to determine the role that density-dependent and density-independent factors play in determining year class strength.

3.2 Environmental correlates

The relation of year class strength to environmental conditions has not received much attention. An analysis carried out by Wespestad (unpublished) (Fig. 31) does suggest a relationship between year class strength and water temperature for the eastern Bering Sea. His data indicate that above average year classes occur when water temperature is warm and below average year classes appear when water temperature is average or cold.

3.3 Biological correlates

The relationship of biological correlates to year class strength has not been looked at in great detail. There are no studies relating recruitment to food density or quality. The role of cannibalism in the Bering Sea has been demonstrated, yet it is difficult to quantify the role of predation mortality in determining year class strength. A point of interest is the fact that one of the underlying biological mechanisms of the Ricker spawner recruit curve is cannibalism of young by adults (Ricker 1975) and in fact high levels of pollock cannibalism have been demonstrated in the Bering Sea (Dwyer et al. 1987; Livingston et al. 1986)

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Table 1. Parameter estimates from empirical maturity-length relationships on walleye pollock from different areas in the Gulf of Alaska and Bering Sea. P is proportion mature and L is fork length (cm).

Area	Model	Sex	Parameter Estimates a	b	Source	L50
EBS	P=exp(-a*exp(-bL))	M	-725.947	-0.224	Smith 1981	31.0
EBS	P=exp(-a*exp(-bL))	F	-867.088	-0.209	Smith 1981	34.2
EBS	P=exp(a+bL)/(1+exp(a+bL))	M	-17.23	0.50	Fadeev 1989*	34.8
EBS	P=exp(a+bL)/(1+exp(a+bL))	F	-18.02	0.48	Fadeev 1989*	37.2
GOA	P=exp(a+bL)/(1+exp(a+bL))	M	-18.29	0.52	Megrey 1989b	34.9
GOA	P=exp(a+bL)/(1+exp(a+bL))	F	-16.01	0.44	Megrey 1989b	36.6

* - curve fit to Fadeev's data by author with nonlinear regression

Table 2. Parameter estimates from empirical fecundity-length and fecundity-weight relationships on walleye pollock from different areas in the Gulf of Alaska and Bering Sea. F is fecundity, L is fork length (cm), and W is weight (gm).

Area	Model	Parameter Estimates a	b	Source
EBS	F=aL**b	0.29	3.462	Shew (1978), Smith (1981)
EBS	F=aL**b	10.1719	3.6046	Fadeev 1989
EBS-Southeast shelf	F=aL**b	0.1926	3.5439	Hinckley 1987*
	F=aW**b	91.7096	1.1423	Hinckley 1987*
EBS-Southeast slope	F=aL**b	4.6528	2.8066	Hinckley 1987*
	F=aW**b	906.4315	0.8534	Hinckley 1987*
EBS-Northwest slope	F=aL**b	0.0872	3.7869	Hinckley 1987*
	F=aW**b	118.6879	1.1439	Hinckley 1987*
AB	F=aL**b	469.2282	1.5575	Hinckley 1987*
	F=aW**b	9119.3100	0.4570	Hinckley 1987*
GOA-Shelikof Strait	F=aL**b	1.2604	3.2169	Megrey 1989b
	F=aW**b	387.4551	1.0160	Megrey 1989b
WBS-Sea of Okhotsk	F=aL**b10e-6	8.05	4.45	Sergeeva 1981
WBS-Sea of Okhotsk	F=AL**b	0.0875	2.3082	Fadeev and Smirnov 1987
AB-Donut Hole	F=aL**b	1.08849	3.21203	Teshima et al. 1989

* - Fecundity in 1000s of oocytes

RECRUITMENT AND REPRODUCTION INFORMATION MATRIX

Information Available: Y - Yes N - No ? - unknown		Western Bering Sea	Aleutian Basin	Eastern Bering Sea
REPRODUCTION	*Spawning*			
	Location	Y	Y	Y
	Timing	Y	Y	Y
	Biomass	Y	N	Y
	Maturity			
	Size-age Fxns		Y	Y
	Spatial Differences		Y	Y
	Temporal Differences		Y	Y
	Vertical Distribution		Y	Y
	Fecundity			
	Size-age Fxns	Y	Y	Y
	Spatial Differences		N	N
	Temporal Differences		N	N
	Egg size/energy		N	Y
	Sex Ratio			
	Spatial Differences		Y	Y
	Temporal Differences		Y	Y
RECRUITMENT	*Trends in YCS*	Y	Y	Y
SPAWNER RECRUIT DATA	*Density-dep effects*	?	?	?
	Density-indep effects	?	?	?
	S-R Model	Y	N	Y
	Env Correlates	N	N	Y
	Biological Correlates	N	N	Y

Figure 1. -- Recruitment and reproduction information matrix.

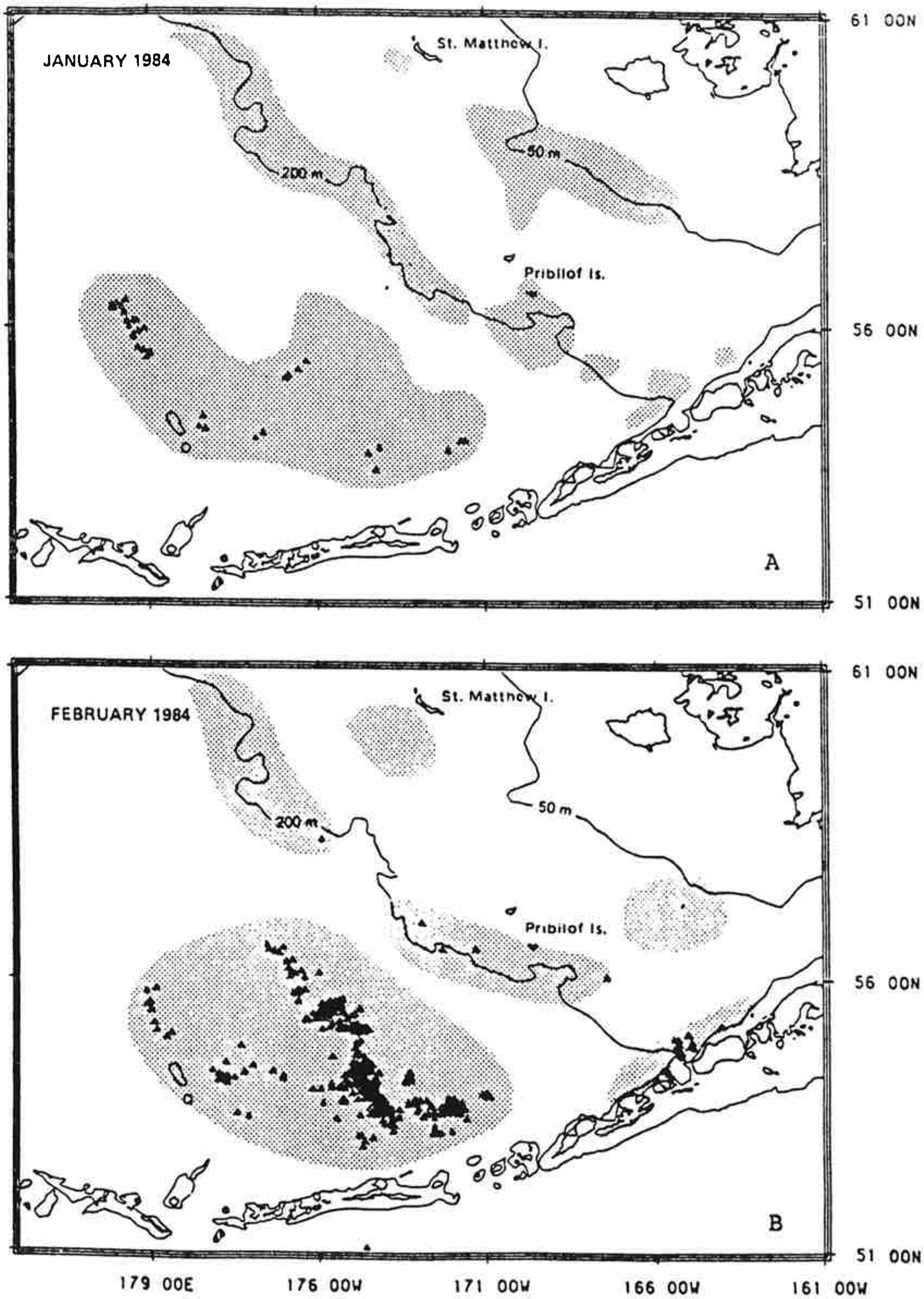


Figure 2.-- Observed distribution of spawning pollock in the Bering Sea by month, 1984. Shaded areas indicate effort distribution of the commercial fleet. Triangles indicate observed spawning locations (from Hinckley 1987).

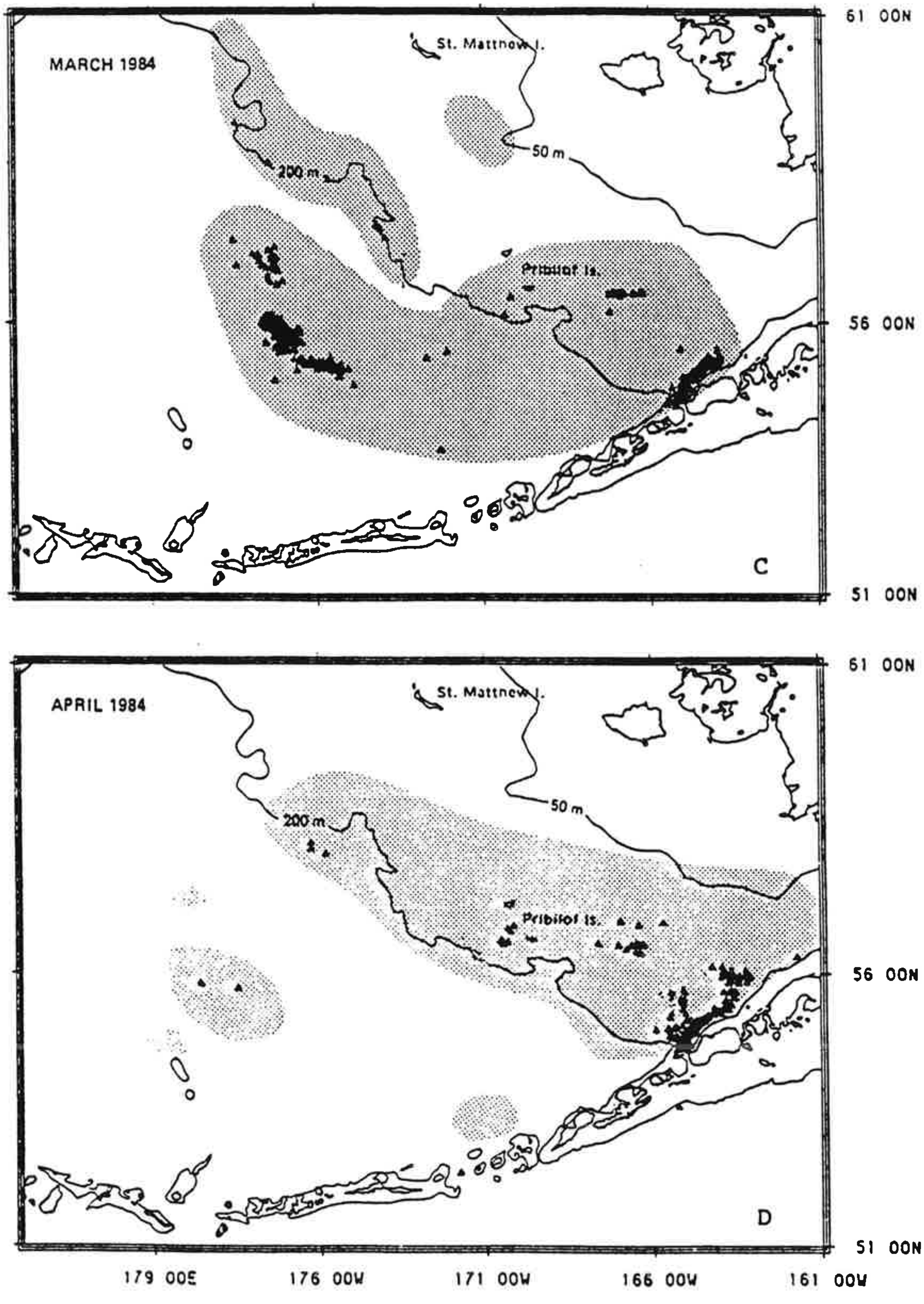


Figure 2.-- (continued).

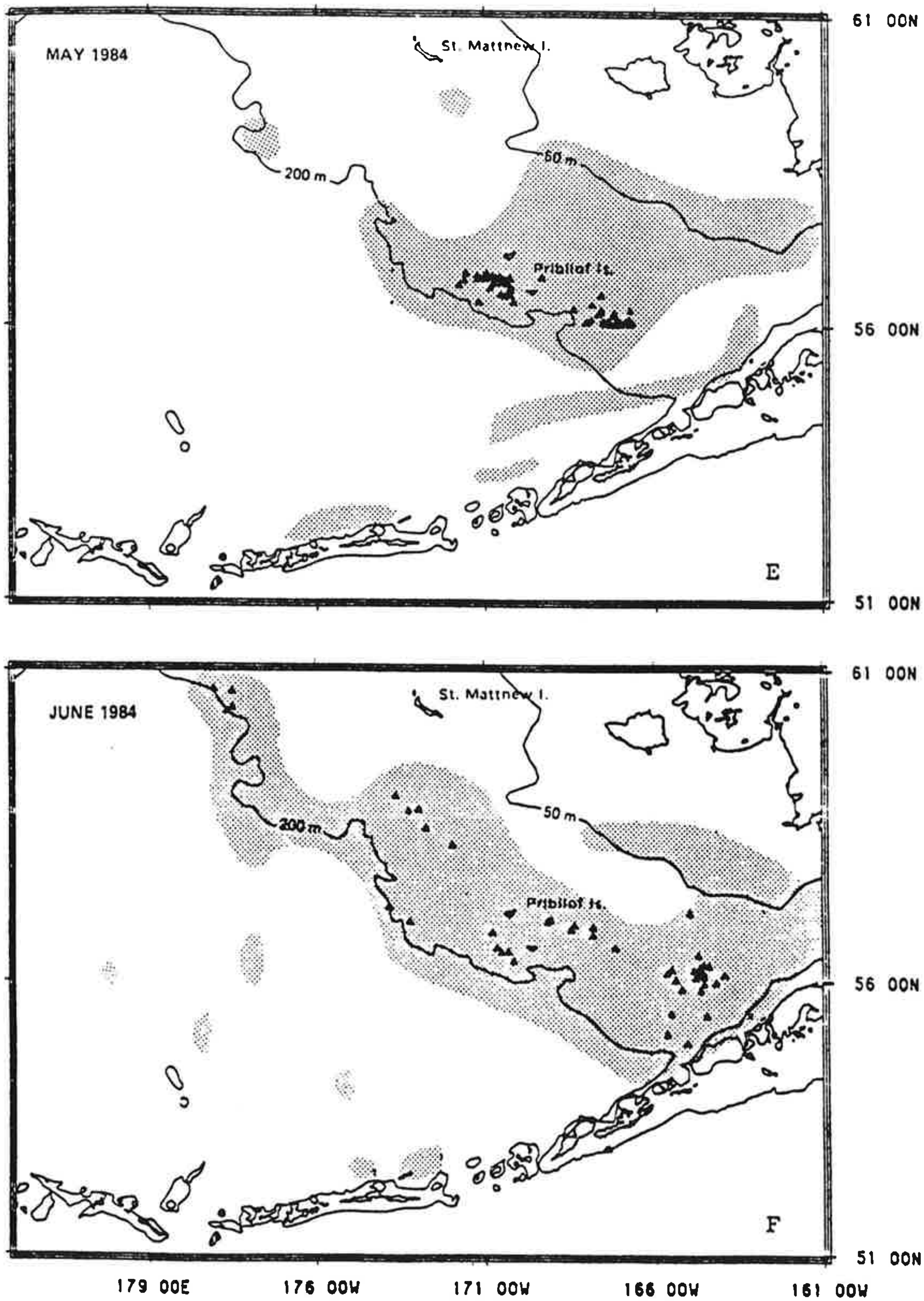


Figure 2.-- (continued).

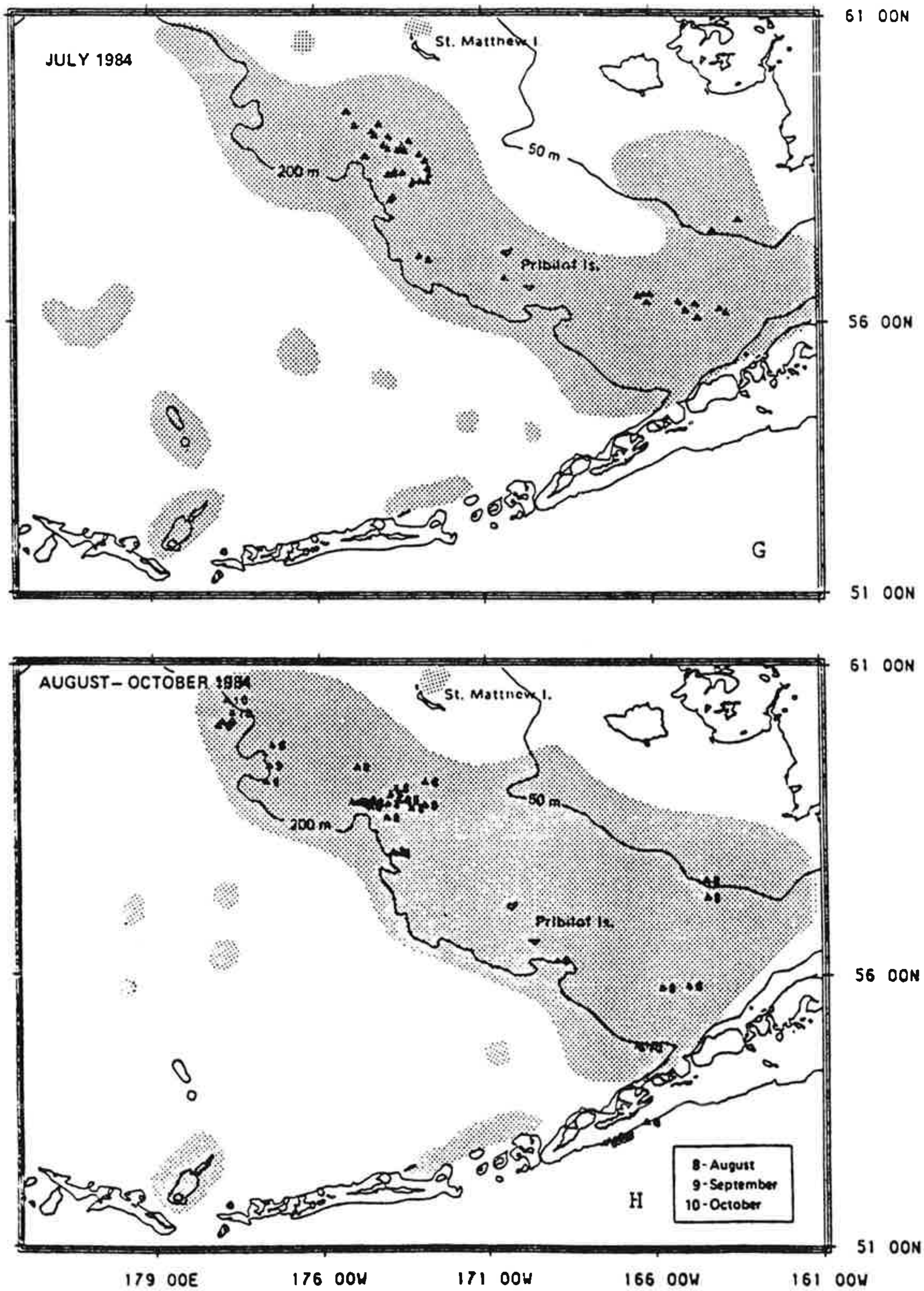


Figure 2.-- (continued).

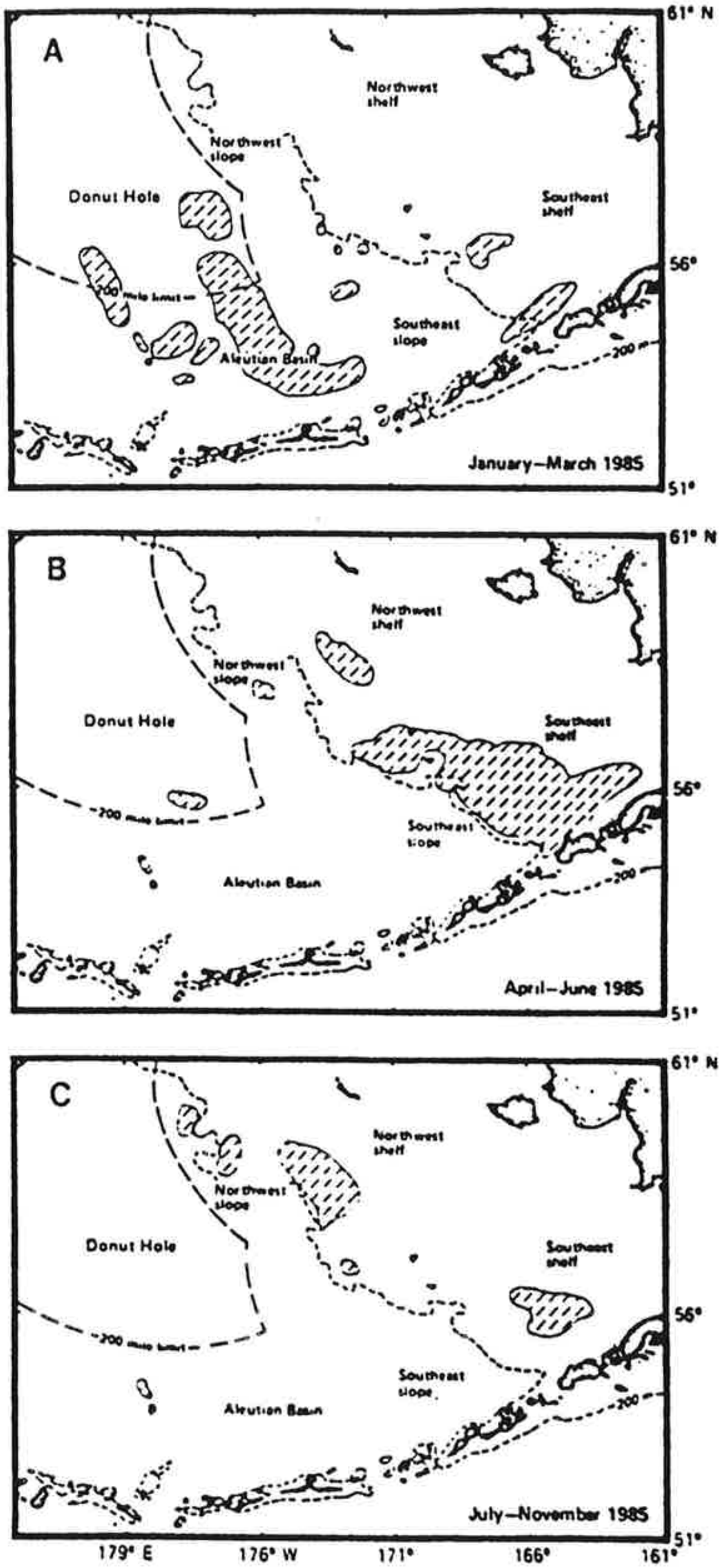
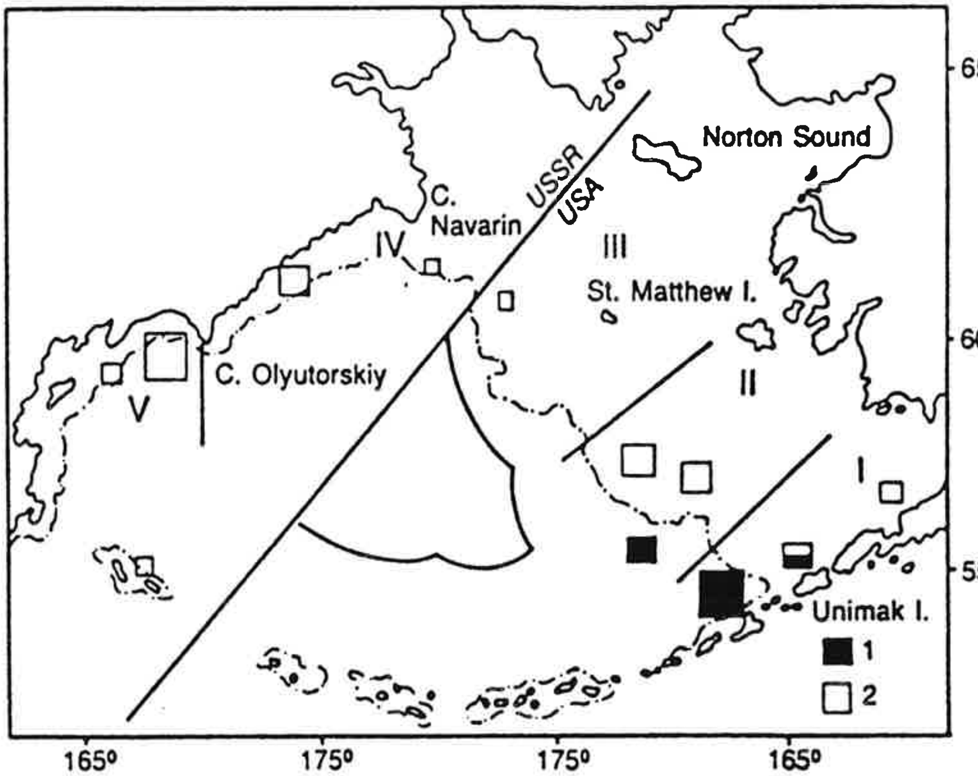


Figure 3.-- Spawning distributions of walleye pollock in the eastern Bering Sea, 1985 (from Mulligan et al. 1989).



Legend: 1 = Unimak grounds, II = Pribilof grounds, III= St. Matthew grounds, IV = Olyutorskiy-Navarin grounds, V = Korfa-Karagin grounds. 1 = winter spawning, 2 = spring spawning.

Figure 4.-- The main spawning grounds of walleye pollock in the Bering Sea (generalized) (from Bulatov 1989).

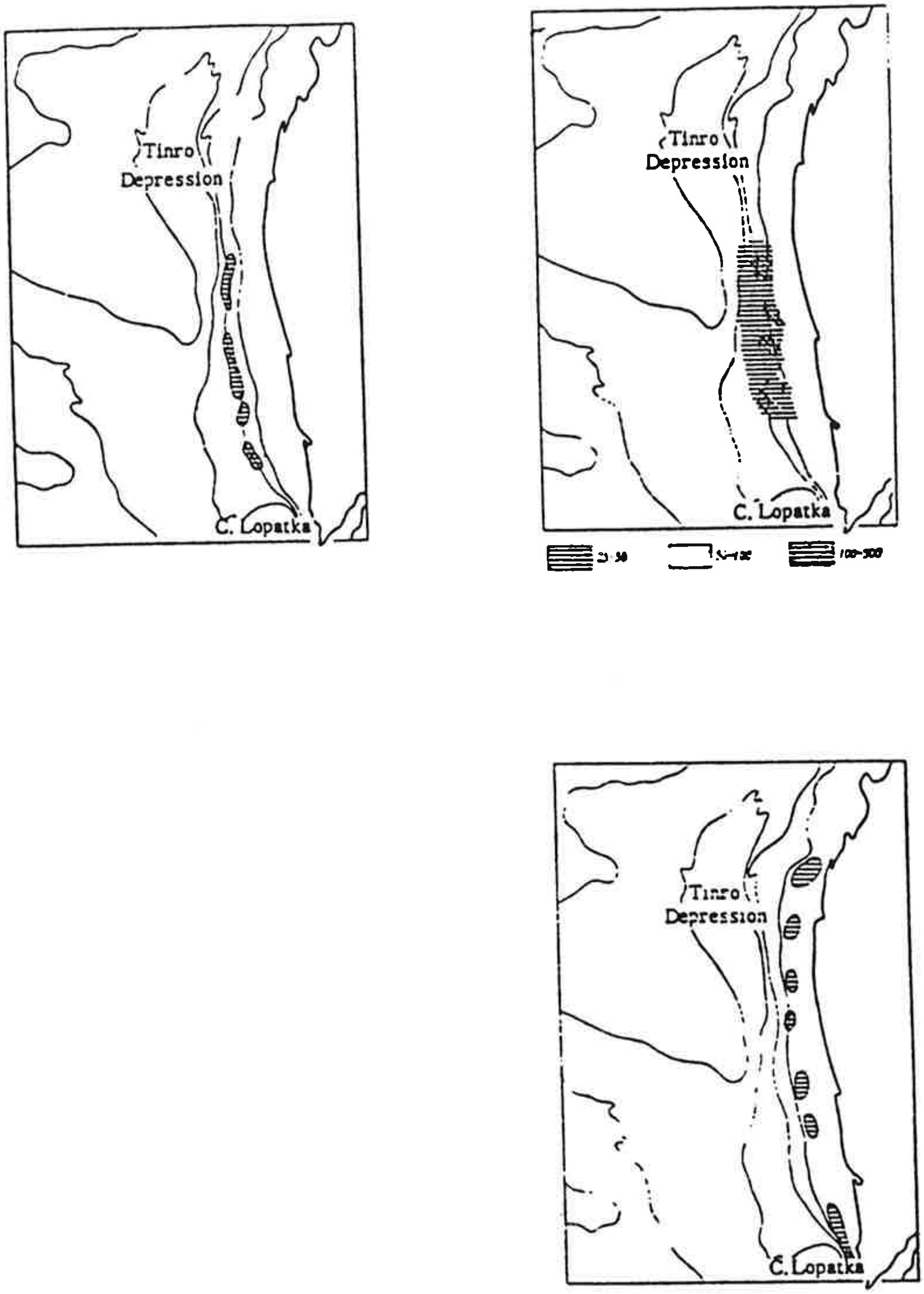


Figure 5.-- Distribution of spawning shoals of pollock in the western Bering Sea, March 1965 (upper left panel); distribution of pollock spawn in the western Bering Sea at the end of second 10 days of March 1965 (eggs per 1 m^2 of surface) (upper right panel); and distribution of pollock in the western Bering Sea in May (data for 1963- 1965) (lower right panel) (from Zver'kova 1969).

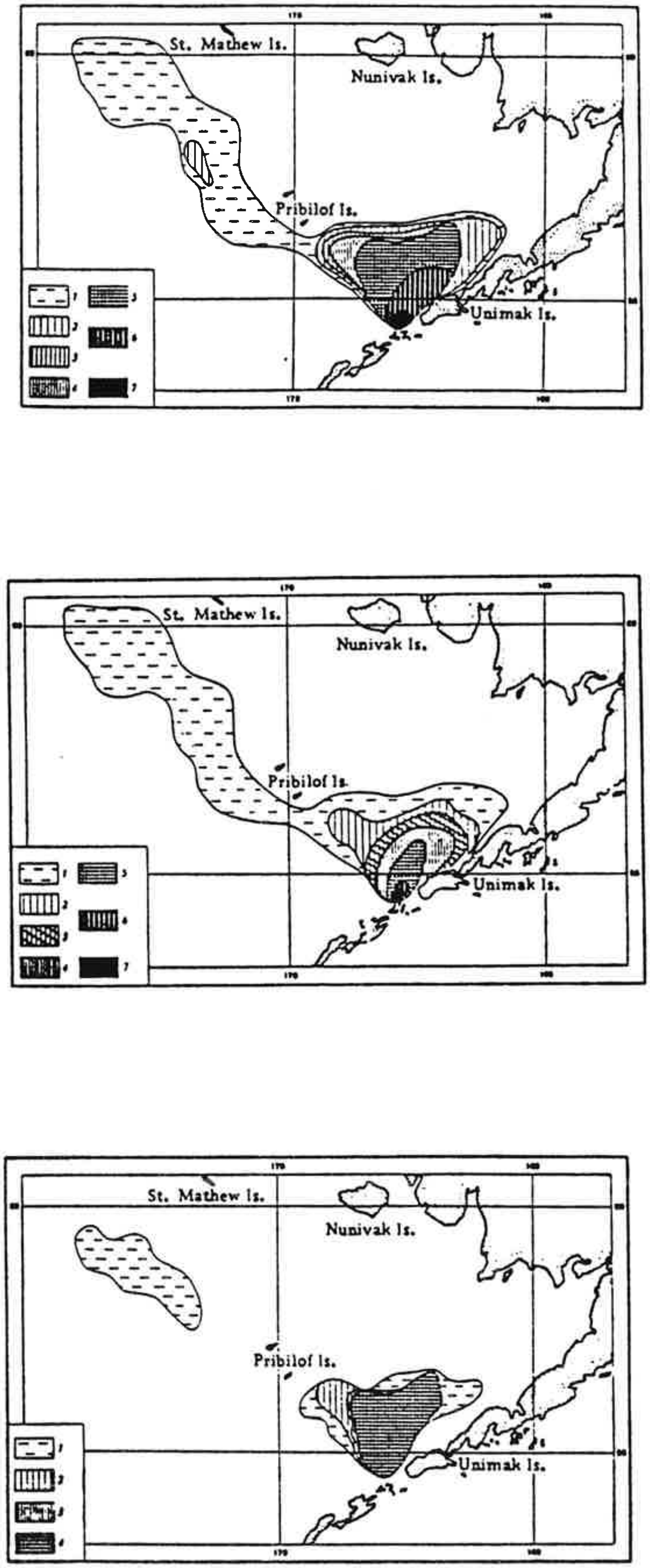
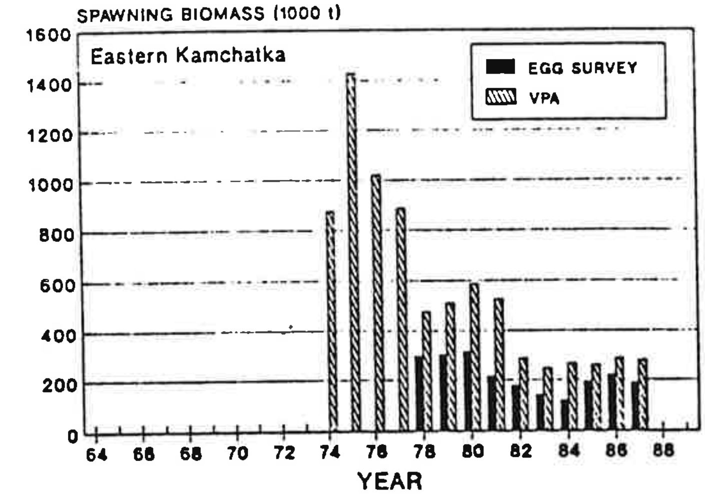
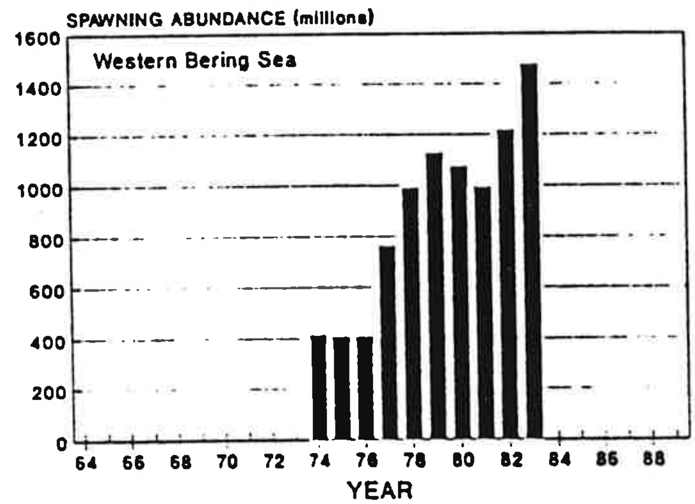


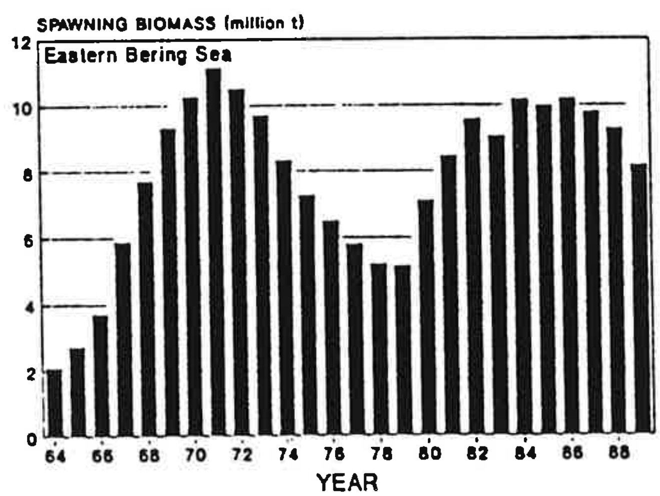
Figure 6.-- Distribution of walleye pollock eggs at development stages III and IV in March-May 1965 (number beneath 1 m^2). 1) 1-50; 2) 51-100; 3) 101-200; 4) 201-500. (from Serobaba 1968)



Source: Zolotov and Antonov 1989



Source: Balykin 1989



Source: Wespestad et al. 1990

Figure 7.-- Comparison of spawning biomass and abundance estimates from different regions of the Bering Sea.

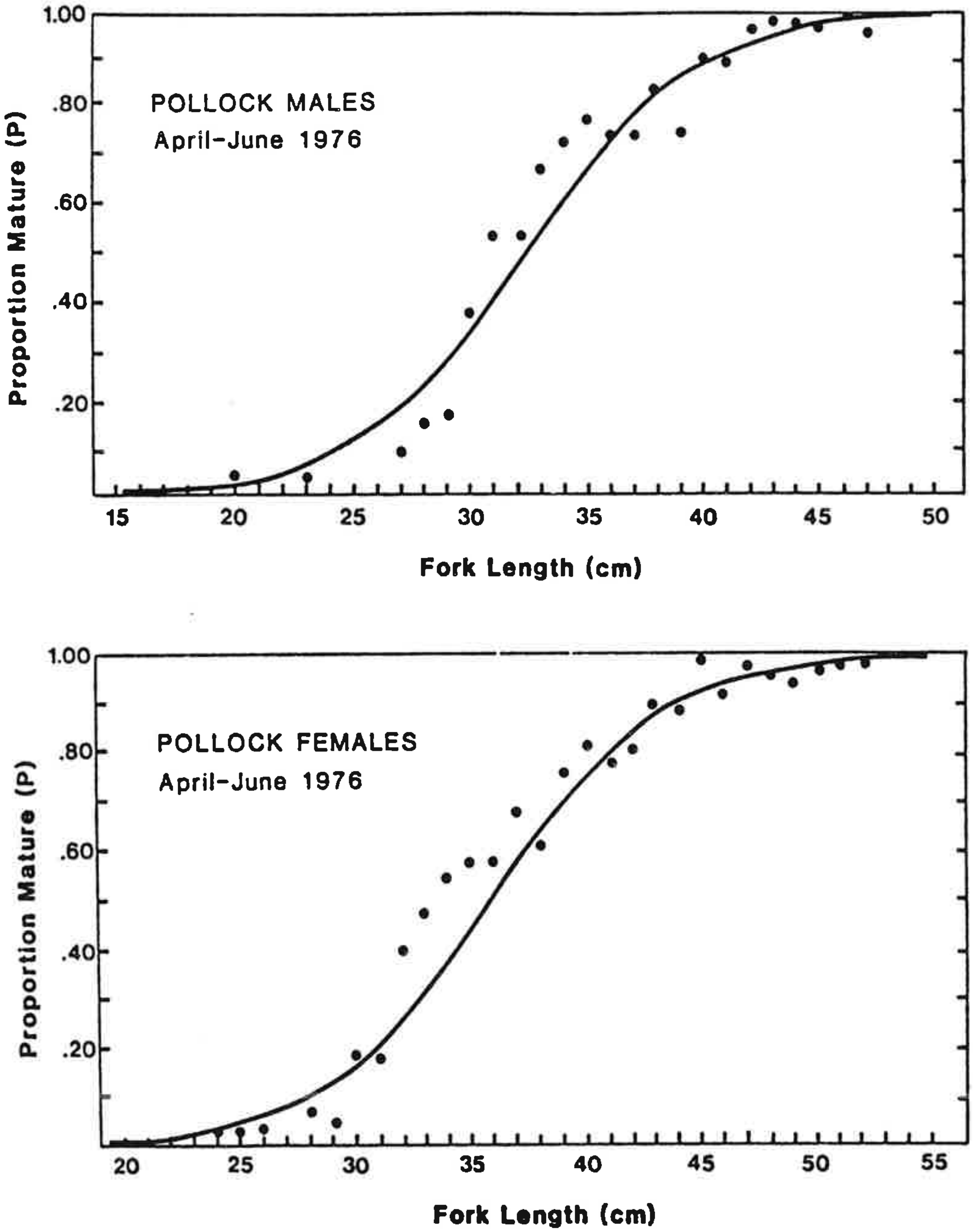


Figure 8.-- Length-maturity relationship for Bering Sea pollock taken during April-June, 1976 (from Smith 1981).

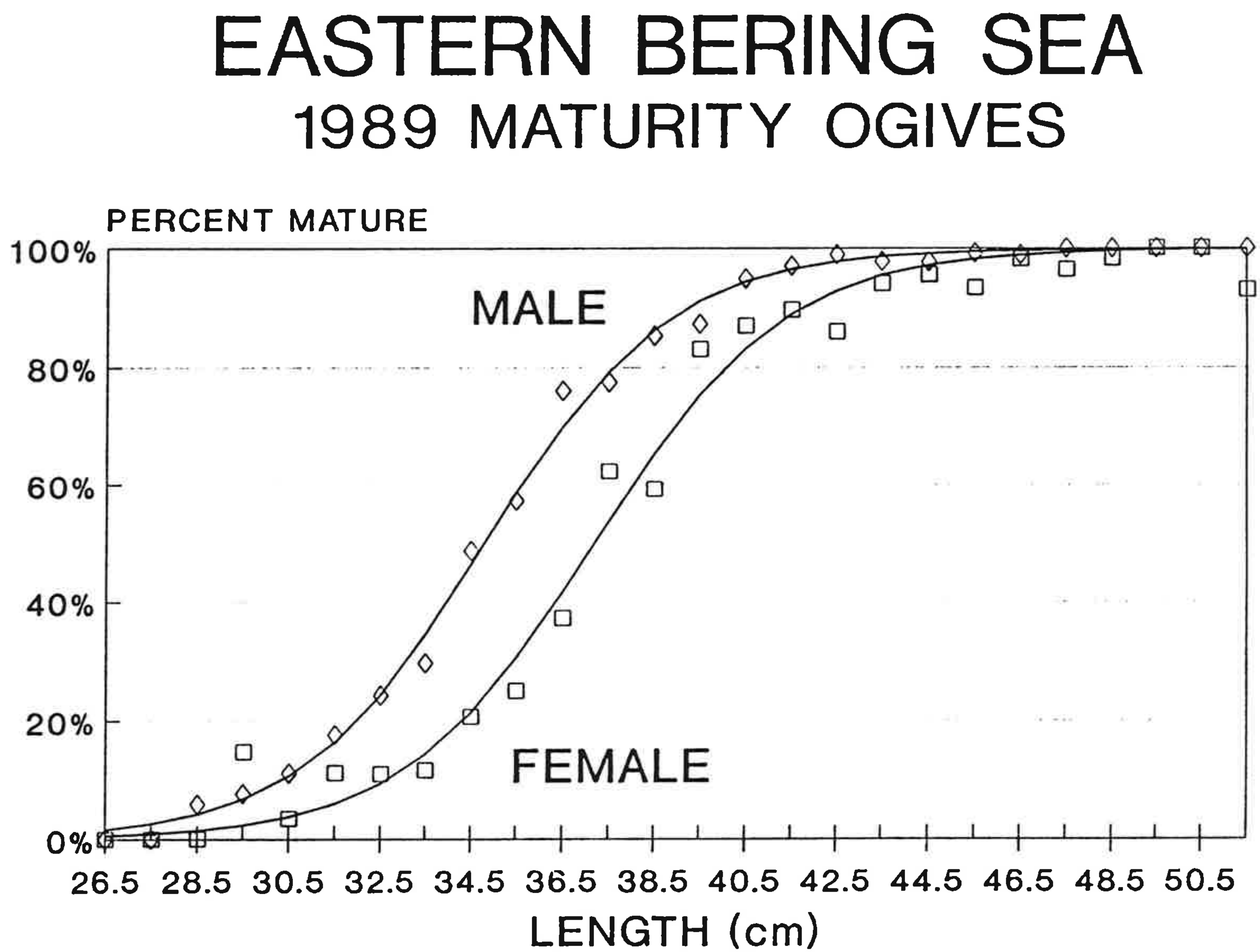


Figure 9.-- Length-maturity relationship for eastern Bering Sea pollock, 1989 (from Fadeev 1989).

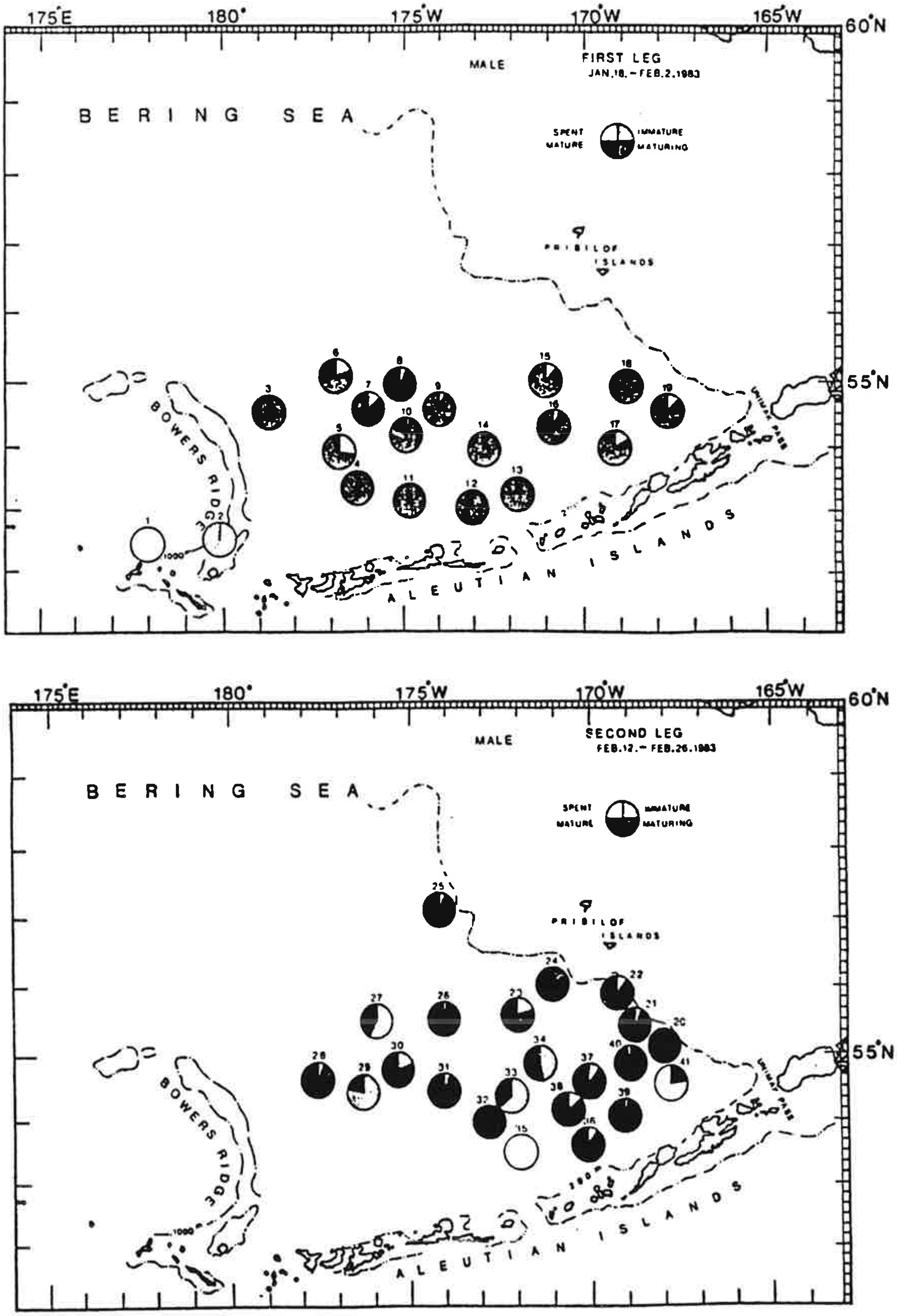


Figure 10.-- Maturity composition of male and female pollock caught by midwater trawl in the Aleutian Basin during the spawning period, 1983 (from Okada 1983).

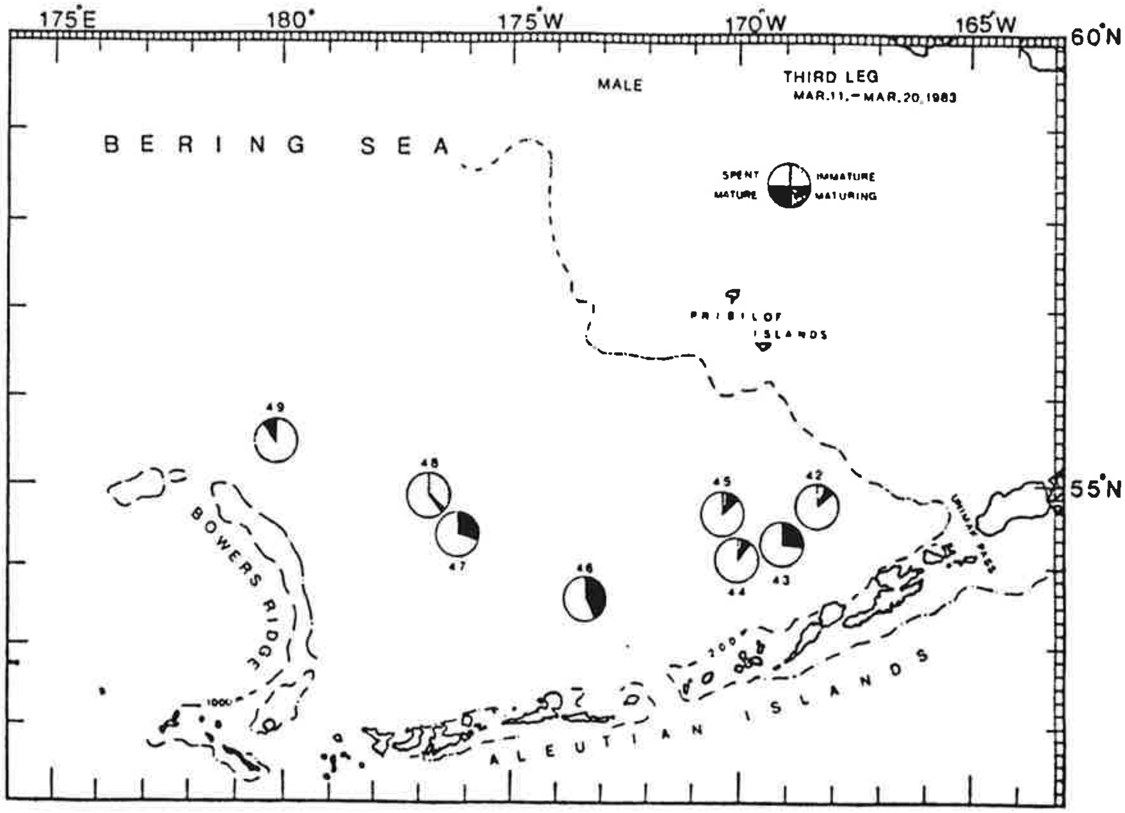
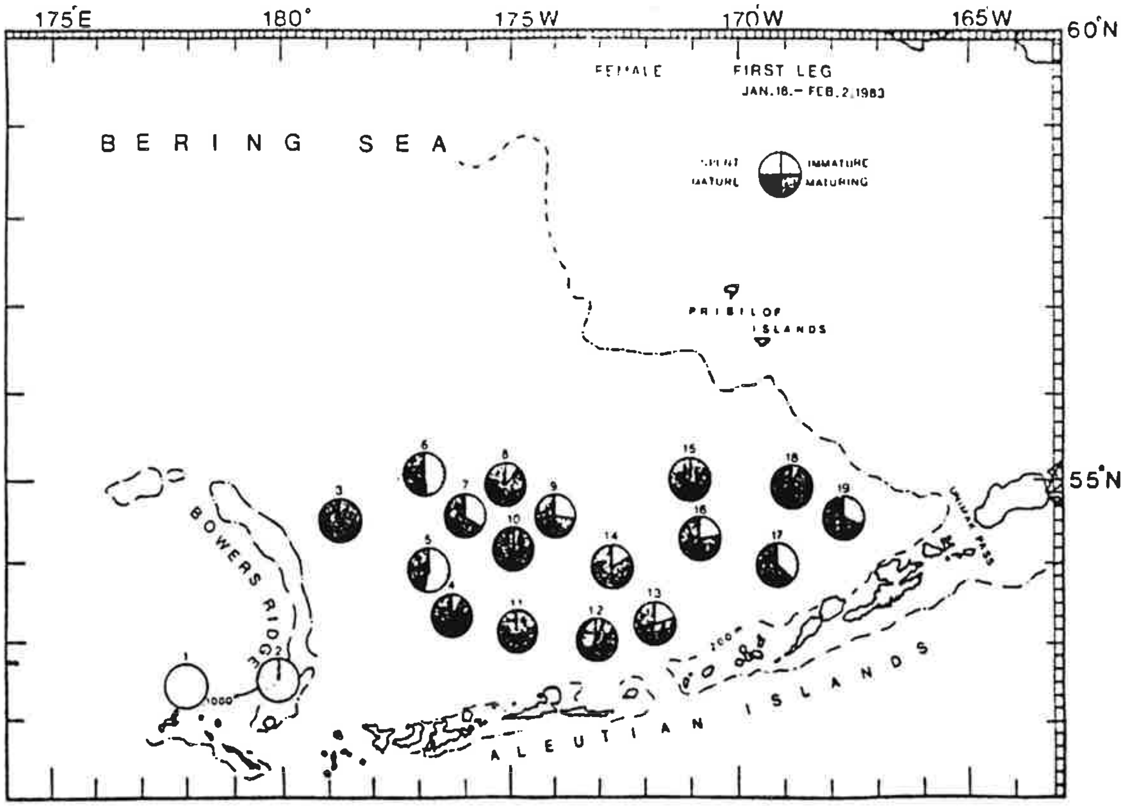


Figure 10.-- (continued).



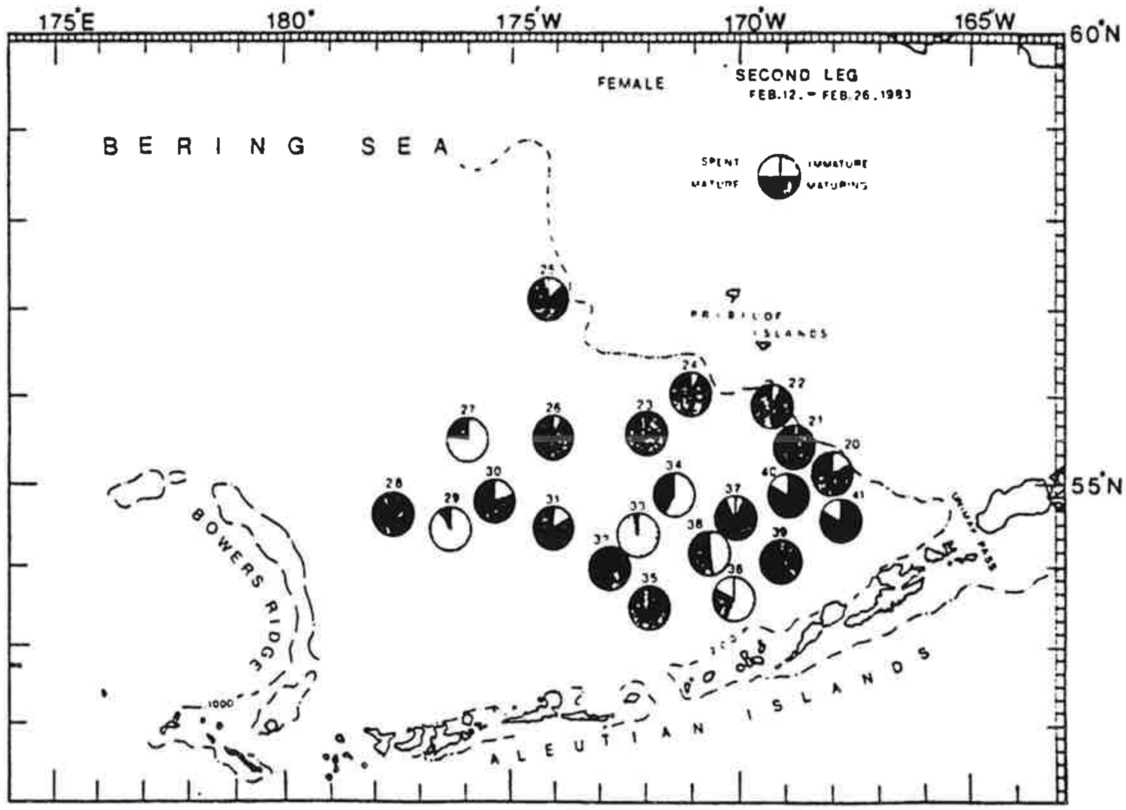


Figure 10.-- (continued).

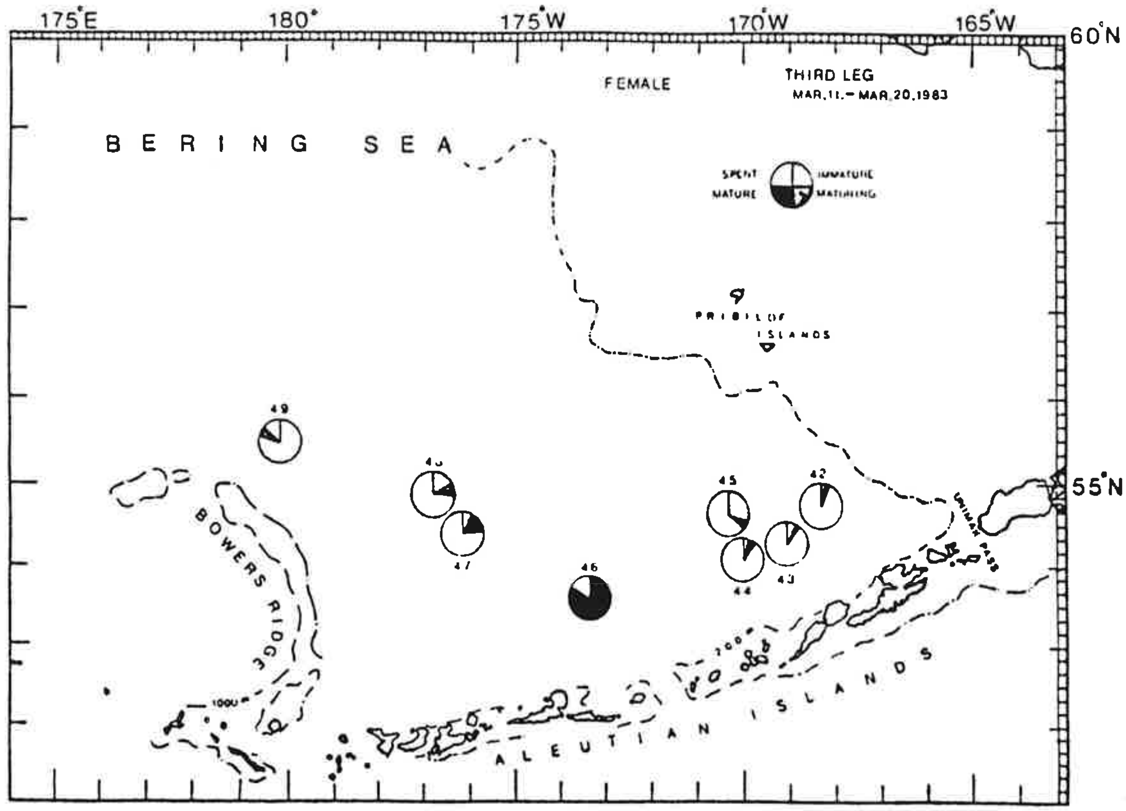


Figure 10.-- (continued).

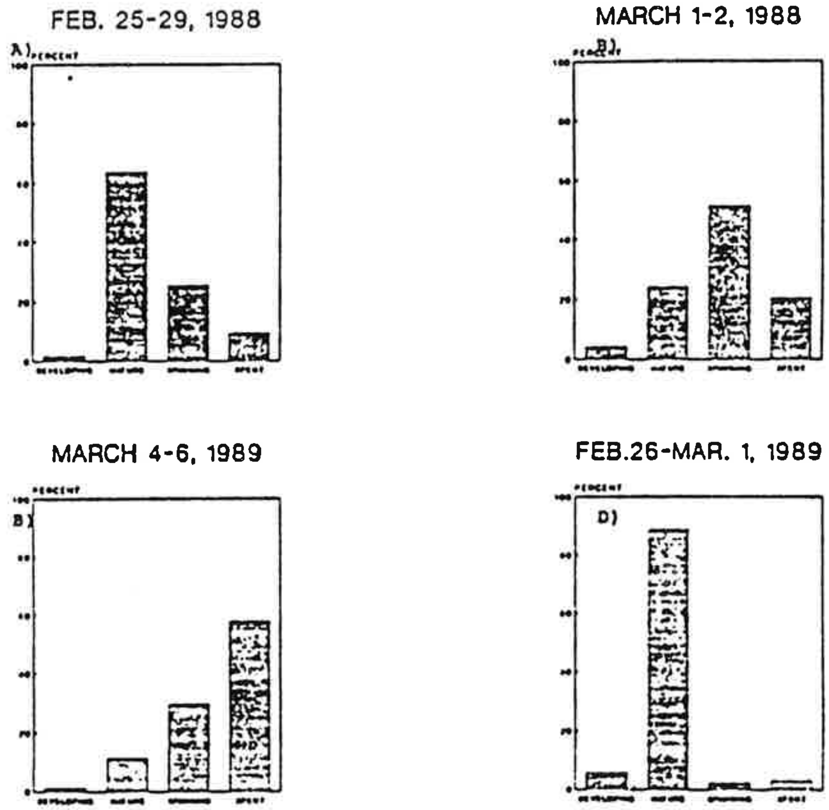


Figure 11.-- Maturity distributions of females from walleye pollock aggregations near Bogoslof Island in 1988 (A,B) and in 1989 (C) and from walleye pollock aggregations in the southern eastern Bering Sea shelf north of Unimak Island (D) (from Traynor 1989).

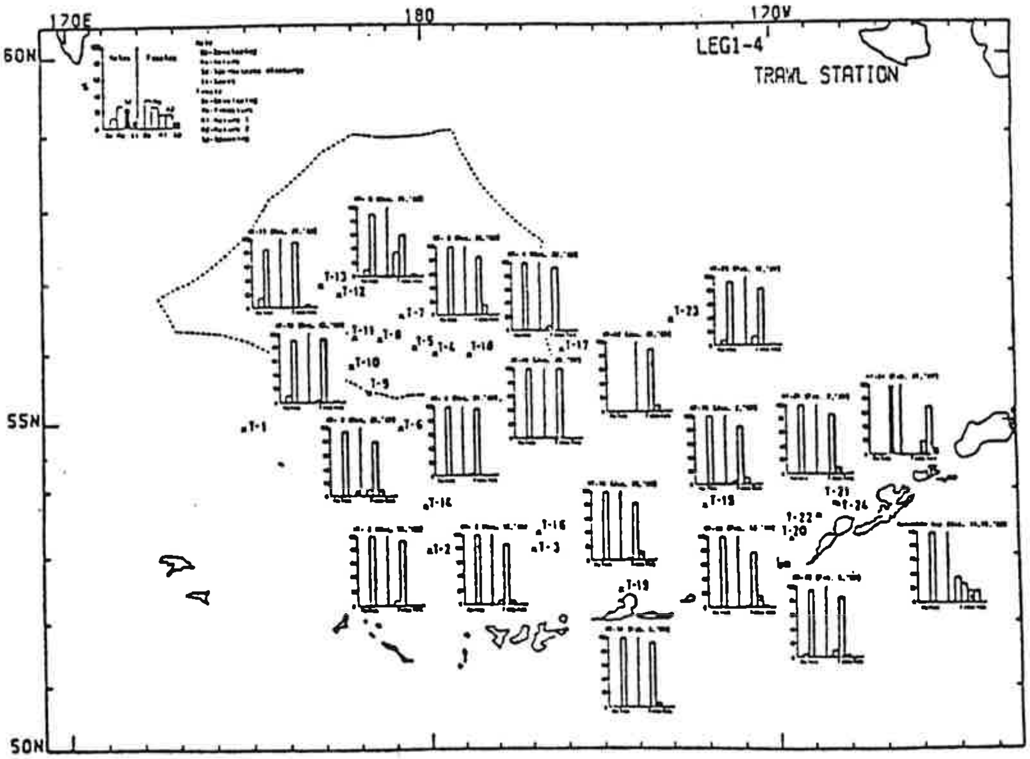


Figure 12.-- Composition of maturity stages of pollock gonads by sampling station observed during the Japan-U.S. joint acoustic/midwater trawl survey by Kaiyo maru in the Aleutian Basin from December of 1999 to March of 1989 (from Teshima and Sasaki 1990).

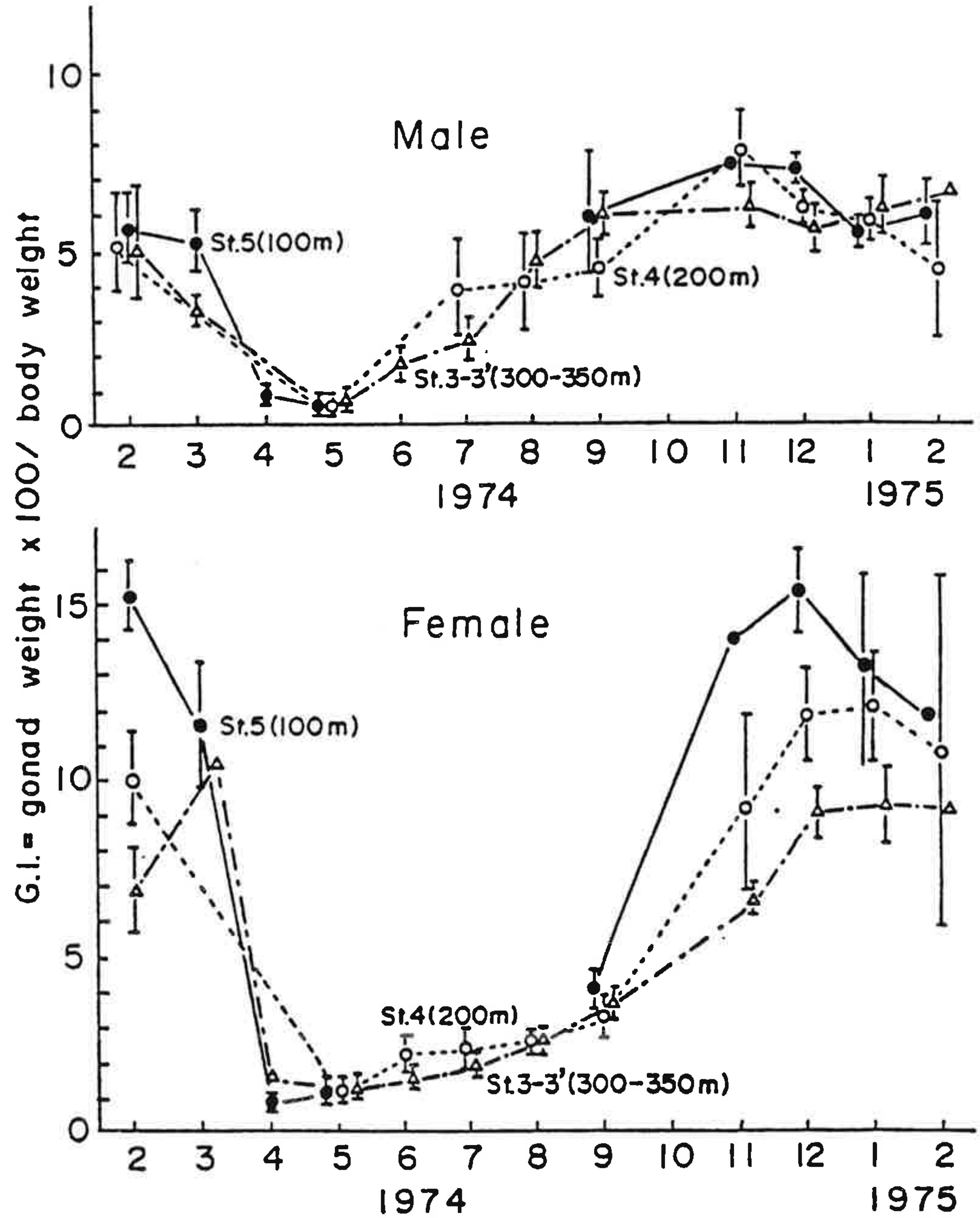


Figure 13.-- Monthly variation of gonad index (gonad weight x 100/body weight) by sex of adult pollock (from Maeda 1986).

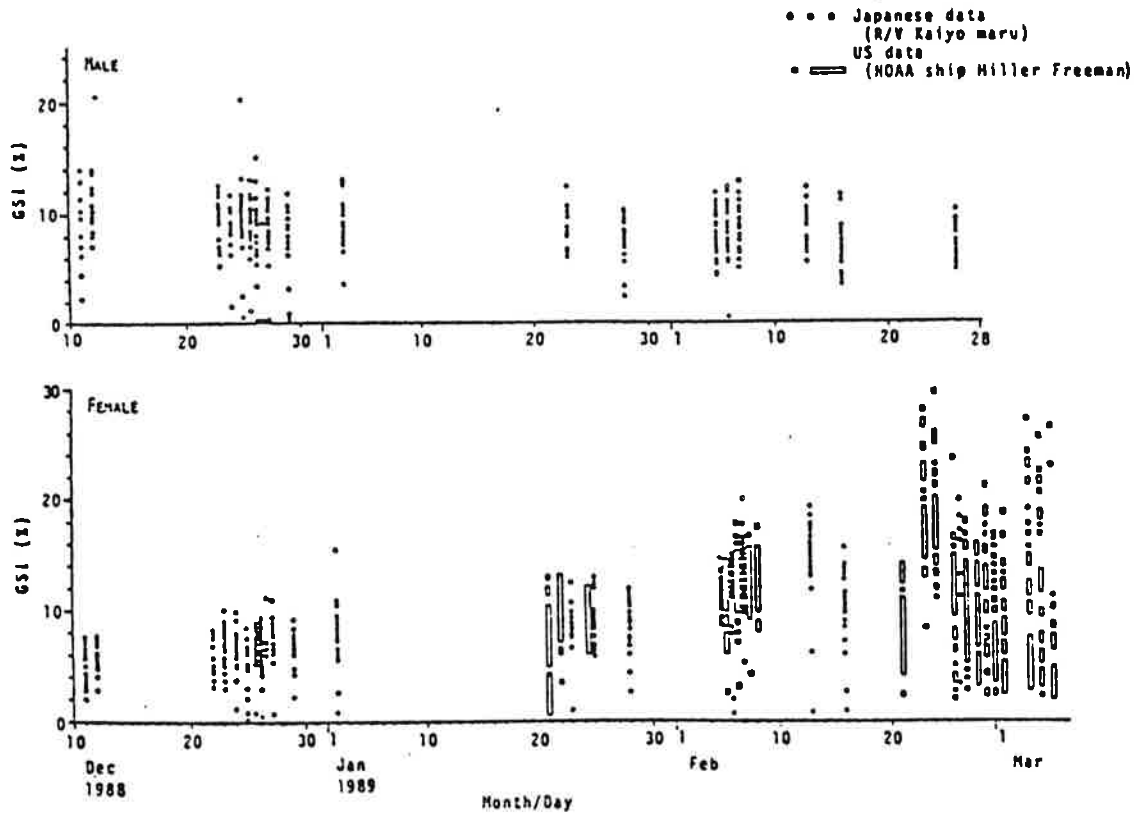


Figure 14.-- Changes of gonadosomatic index (GSI) of pollock in the Aleutian Basin during the period from December of 1988 to March of 1989 (from Teshima and Sasaki 1990).

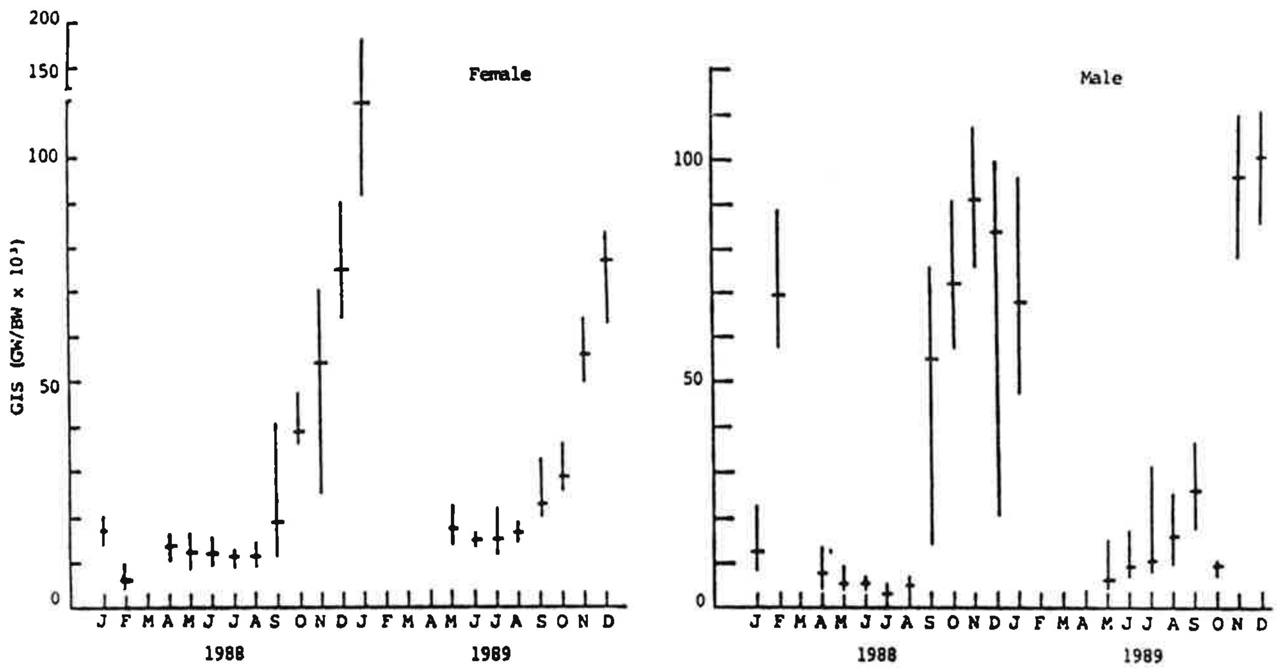
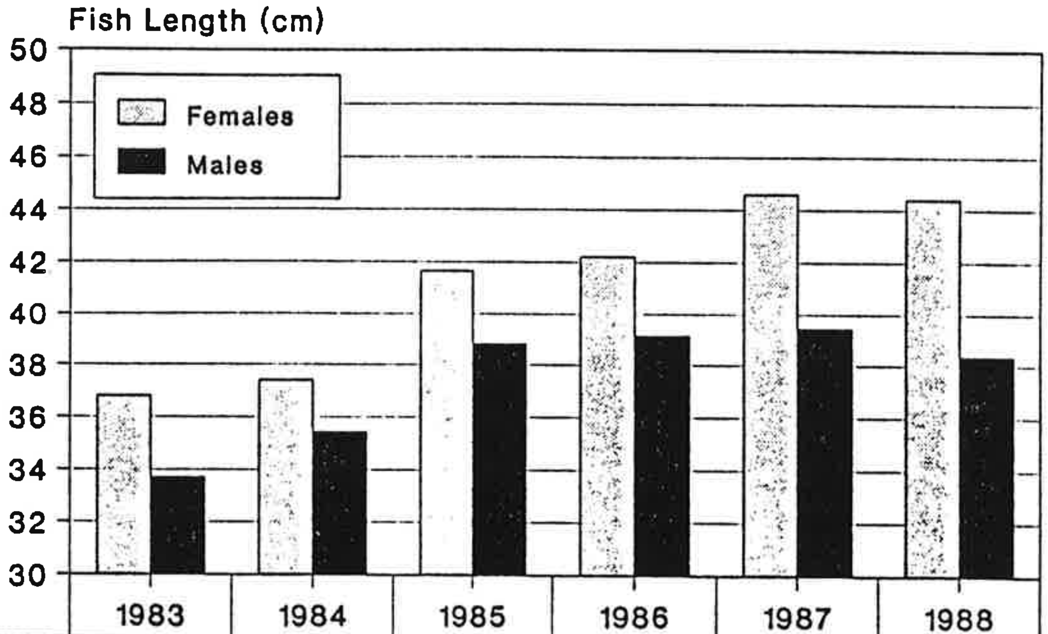


Figure 15.-- Time series of monthly gonadosomatic index (GSI = GW/BW x 1000) of walleye pollock sampled from Korean trawlers in the high seas of the Bering Sea for 1988-1989. Bar represents a range of 1st to 3rd quartile and cross 50th percentile value (from Korean delegation this meeting).



	1983	1984	1985	1986	1987	1988
Females	36.81	37.41	41.67	42.21	44.59	44.41
Males	33.7	35.44	38.81	39.13	39.44	38.34

Year

Figure 16.-- Interannual variation in estimates of length at 50% maturity for male and female pollock from the Gulf of Alaska (from Megrey 1989a).

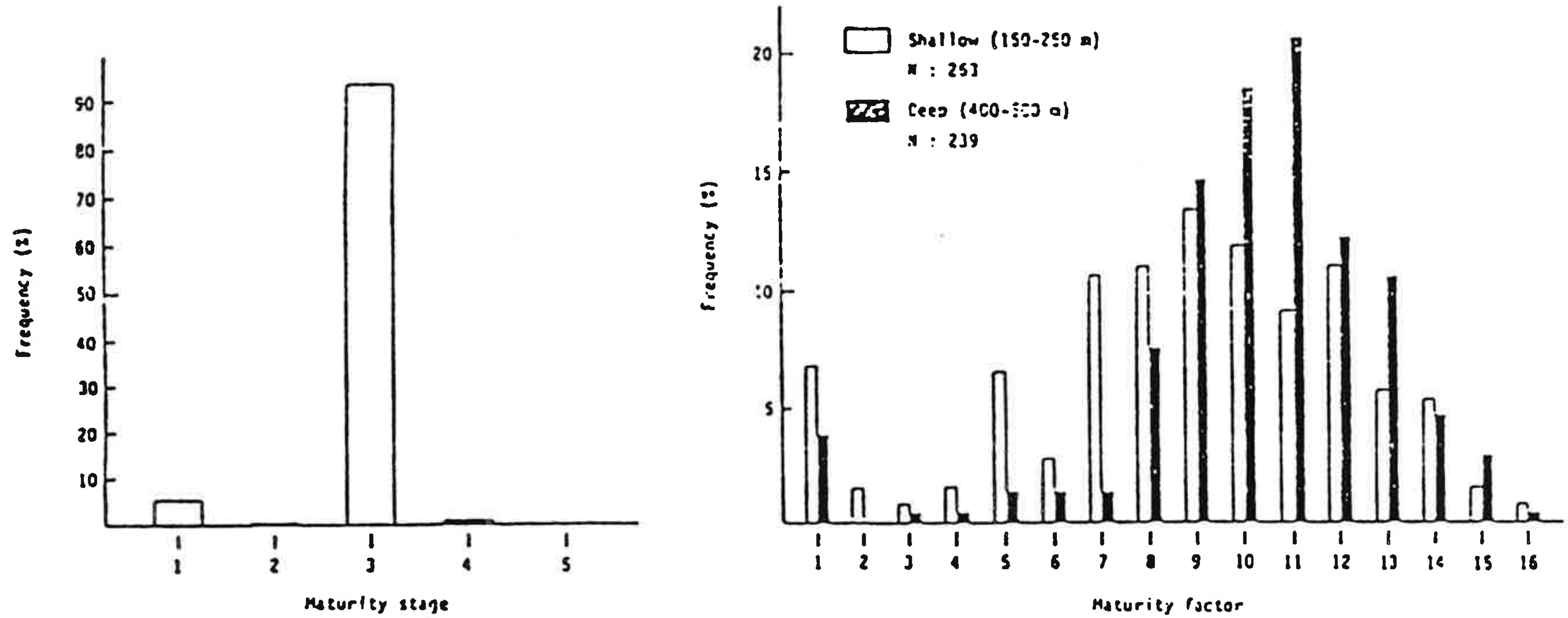
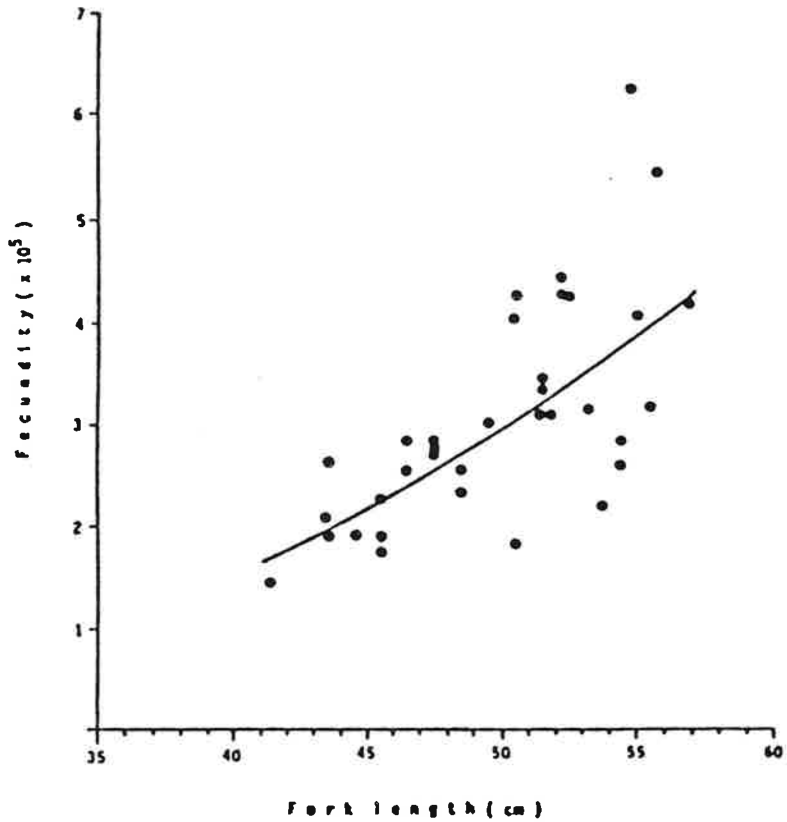


Figure 17.-- Frequency distribution of maturity stage of female pollock caught in midwater trawl survey by Kaiyo maru in the international waters of the Bering Sea from January 29 to February 6 of 1990 (1-immature; 2-maturing; 3-mature; 4-spawning; 5-spent) (left panel). Frequency distribution of maturity factor of female pollock by depth layer in midwater trawl survey by Kaiyo maru in the international waters of the Bering Sea from January 29 to February 6 of 1990. Maturity factor defined as (GW/BW x 100): GW is gonad weight in g and BW is body weight in g. (from Sasaki 1990.



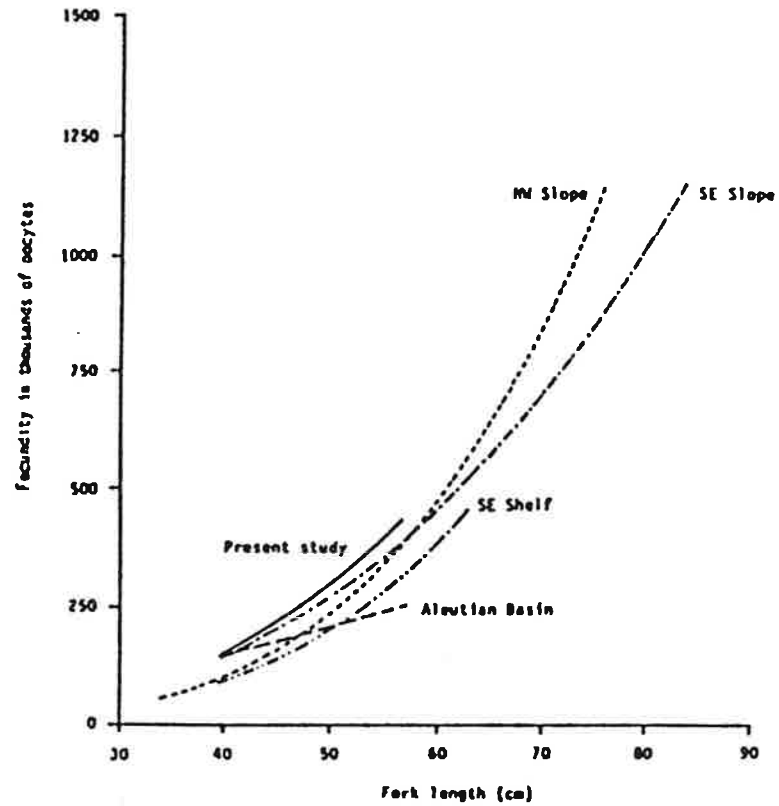


Figure 18.-- Length-fecundity relationship from the international waters of the Bering Sea and comparison to length fecundity relationships in five areas from the eastern Bering Sea (from Teshima et al. 1989)

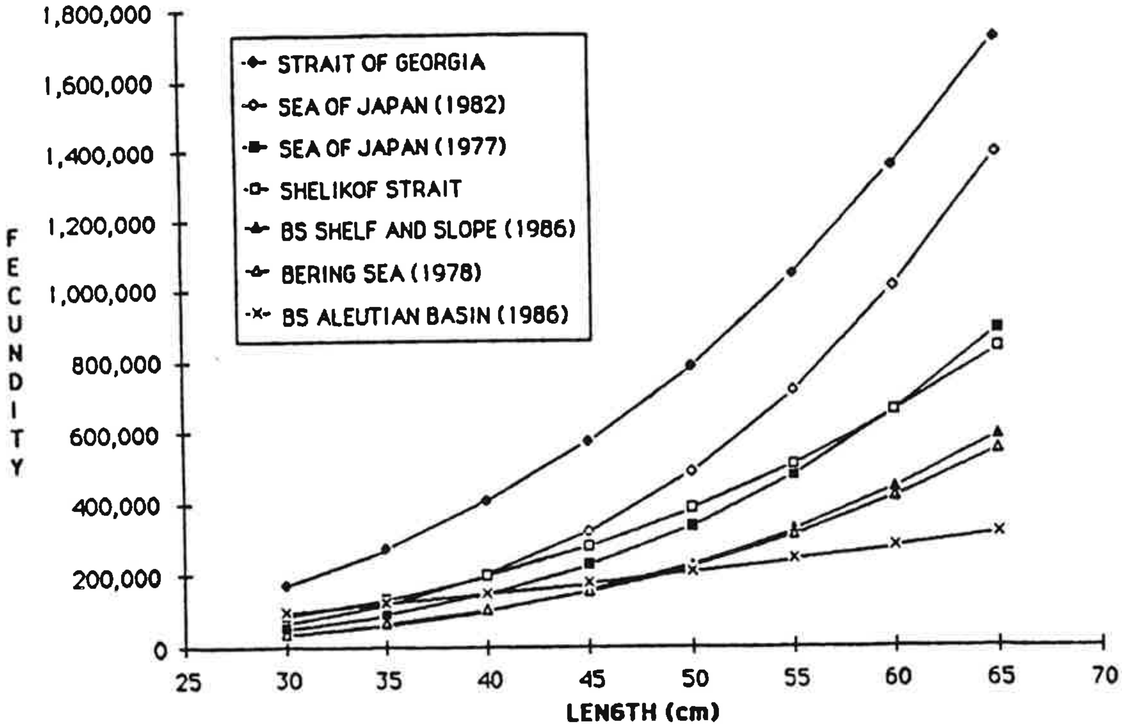
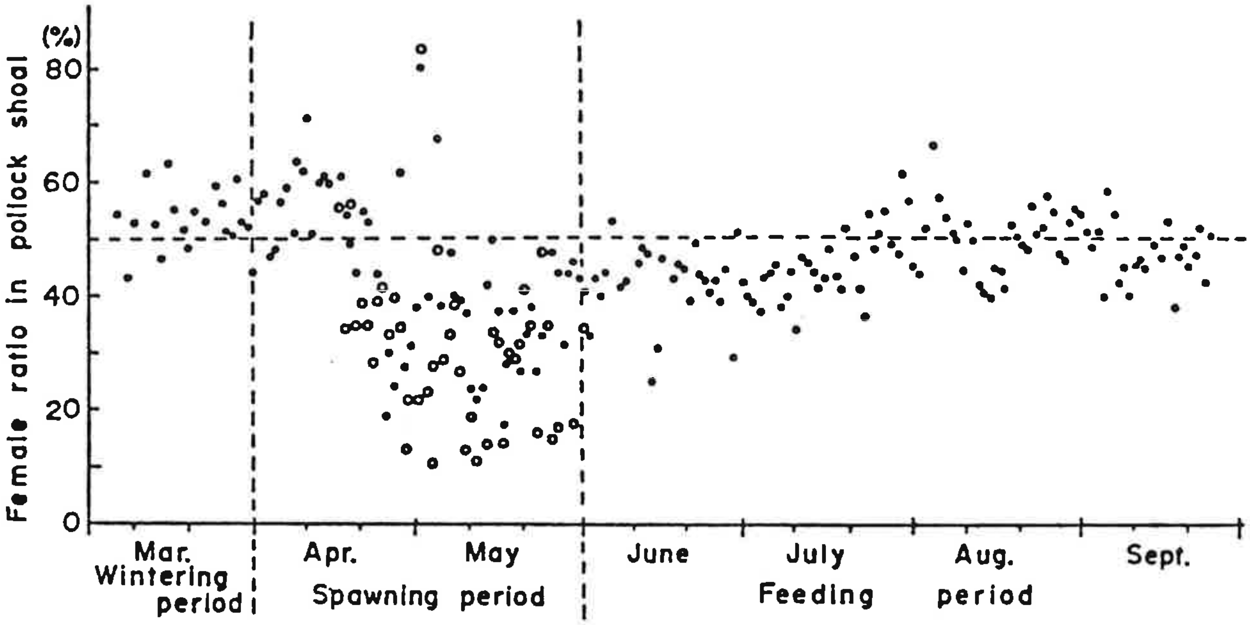


Figure 19.-- Fecundity-length relationship for walleye pollock from different regions in the North Pacific Ocean (from Miller et al. 1986).



● : female ratio in immature and mature fishes.
o : female ratio in mature fishes.

Figure 20.-- Seasonal variations of the sex ratio of pollock caught by bottom trawl in the eastern Bering Sea (from Maeda 1986).

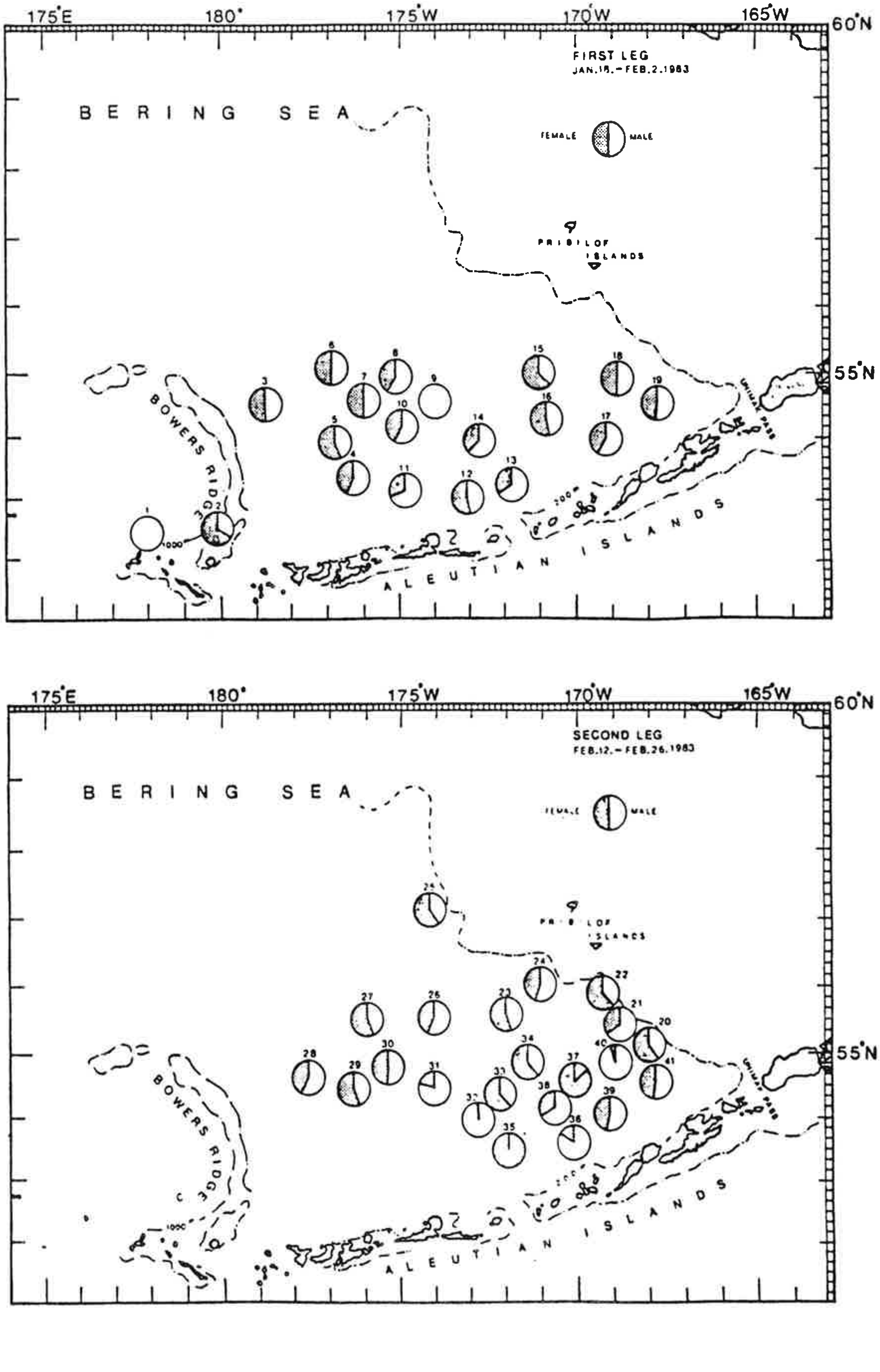


Figure 21.-- Sex ratios of pelagic pollock caught by midwater trawls in the Aleutian Basin during the spawning period, 1983 (from Okada 1983)

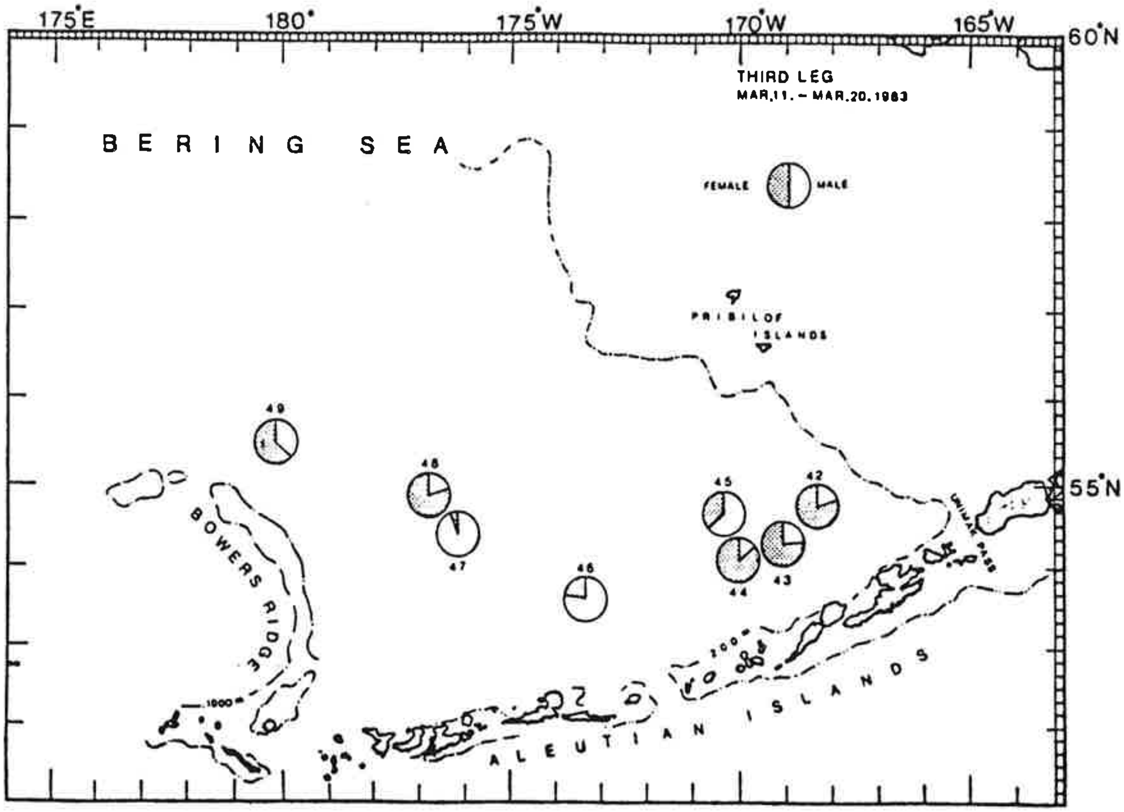


Figure 21.-- (continued).

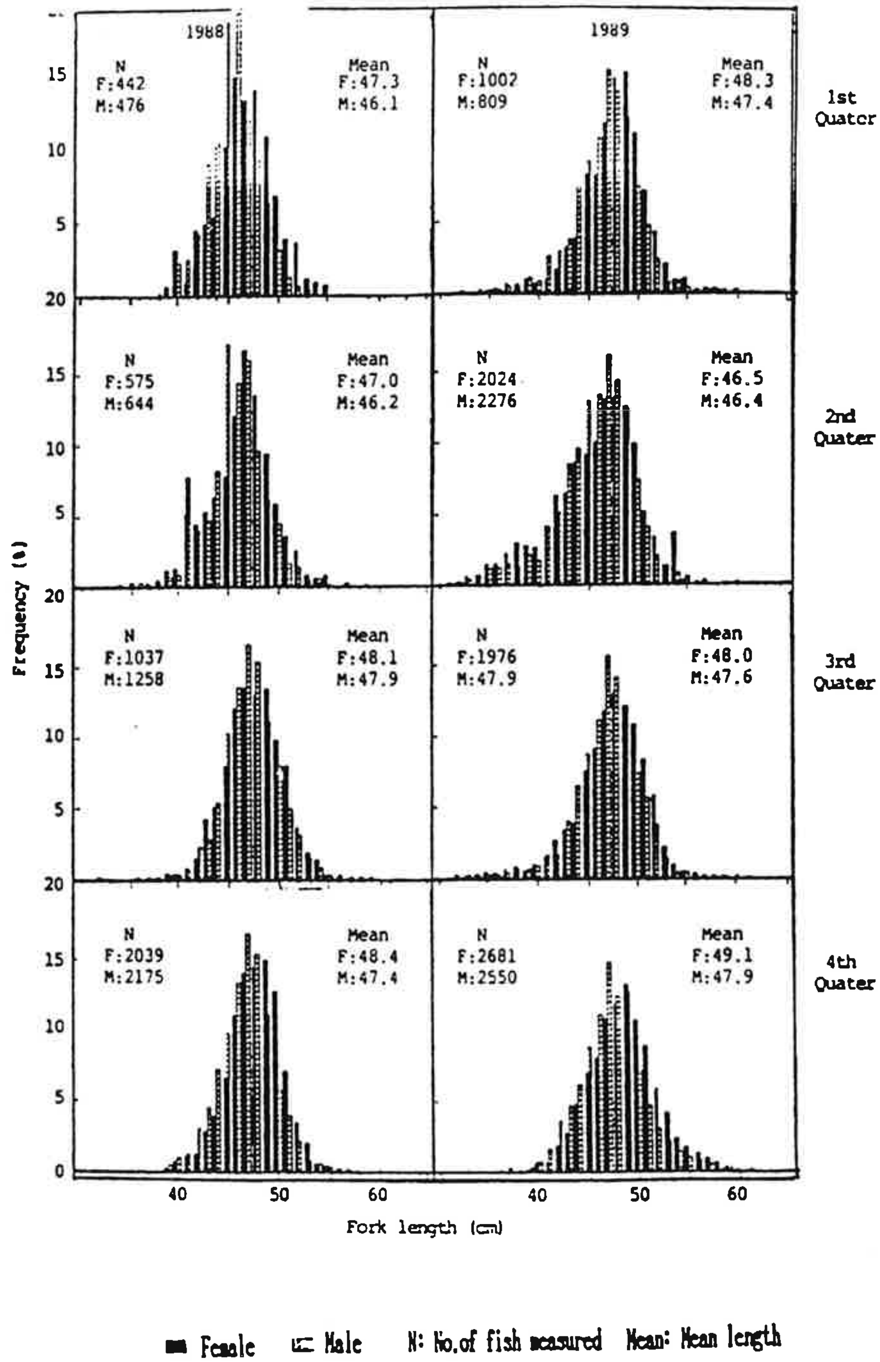


Figure 22.-- Quarterly length composition of walleye pollock in the high seas of the Bering Sea caught by Korean trawlers from 1988 to 1989 (from Korean delegation this meeting).

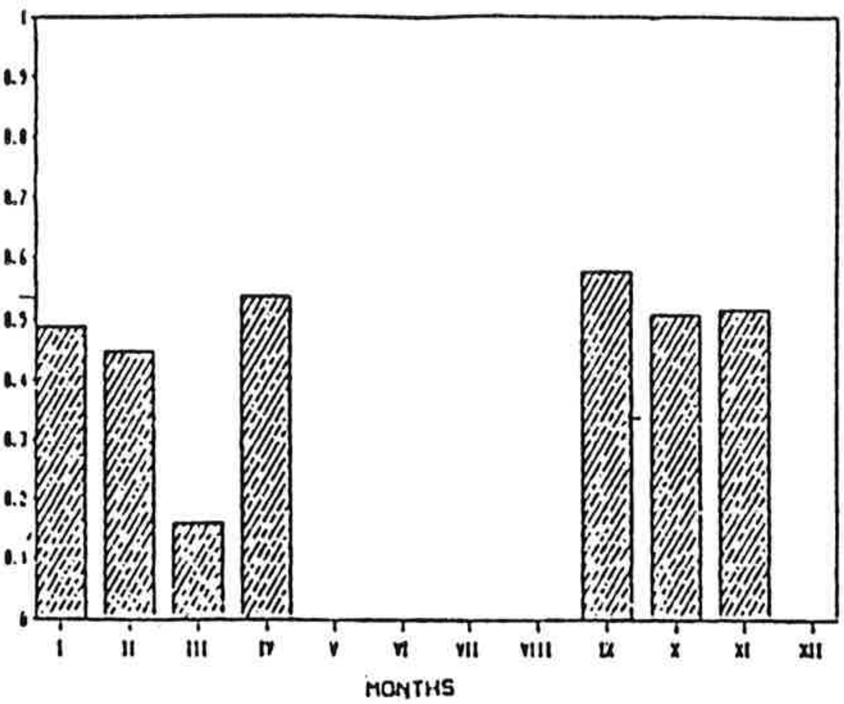


Figure 23.-- Male-to-female ratio of pollock caught in the international waters of the Bering Sea in 1989 (from Kowalewska-Pahlke 1990).

EASTERN KAMCHATKA POLLOCK

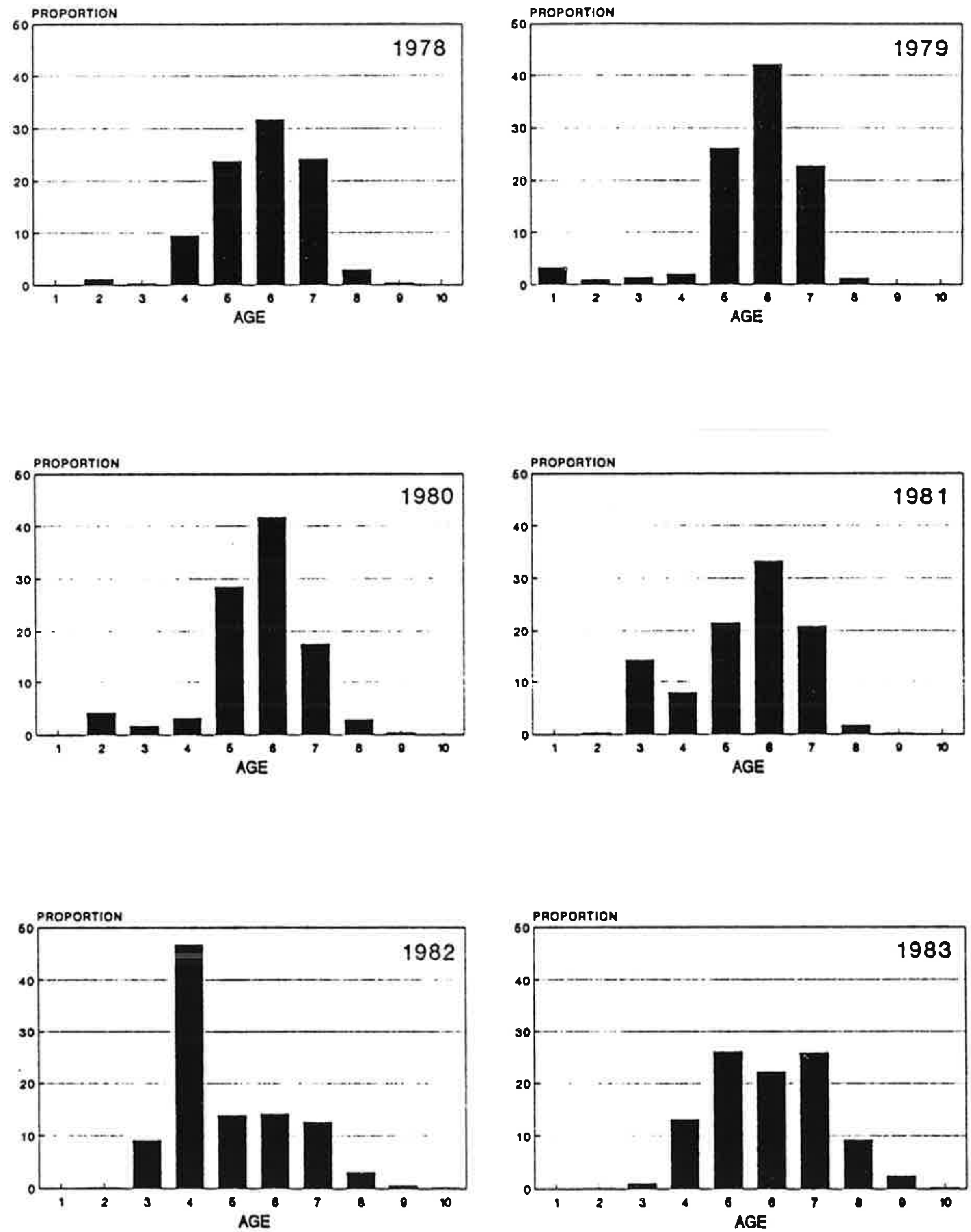


Figure 24.-- Age composition estimates of walleye pollock from eastern Kamchatka, 1978-1987 (from Zolotov and Antonov 1989).

EASTERN KAMCHATKA POLLOCK

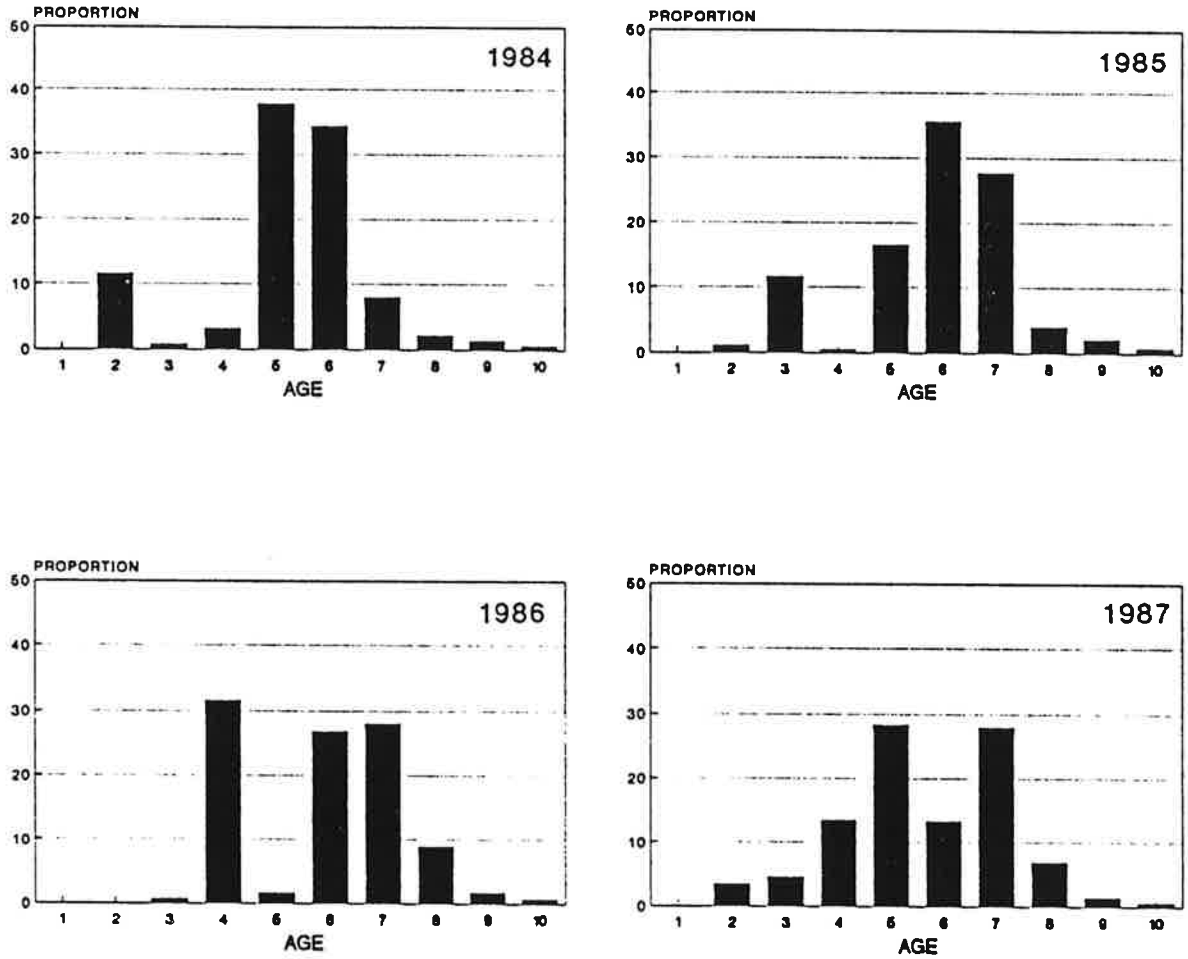
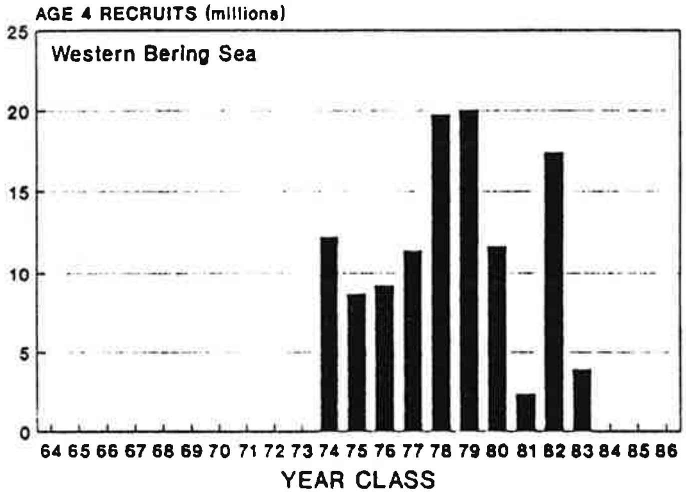
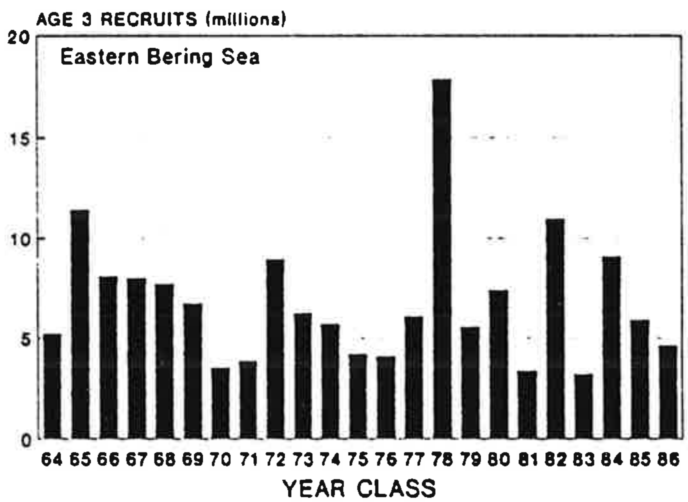


Figure 24.-- (continued).



Source: Balykin 1989



Source: Wespestad et al. 1990

Figure 25.-- Comparison of recruitment trends from the eastern and western Bering Sea.

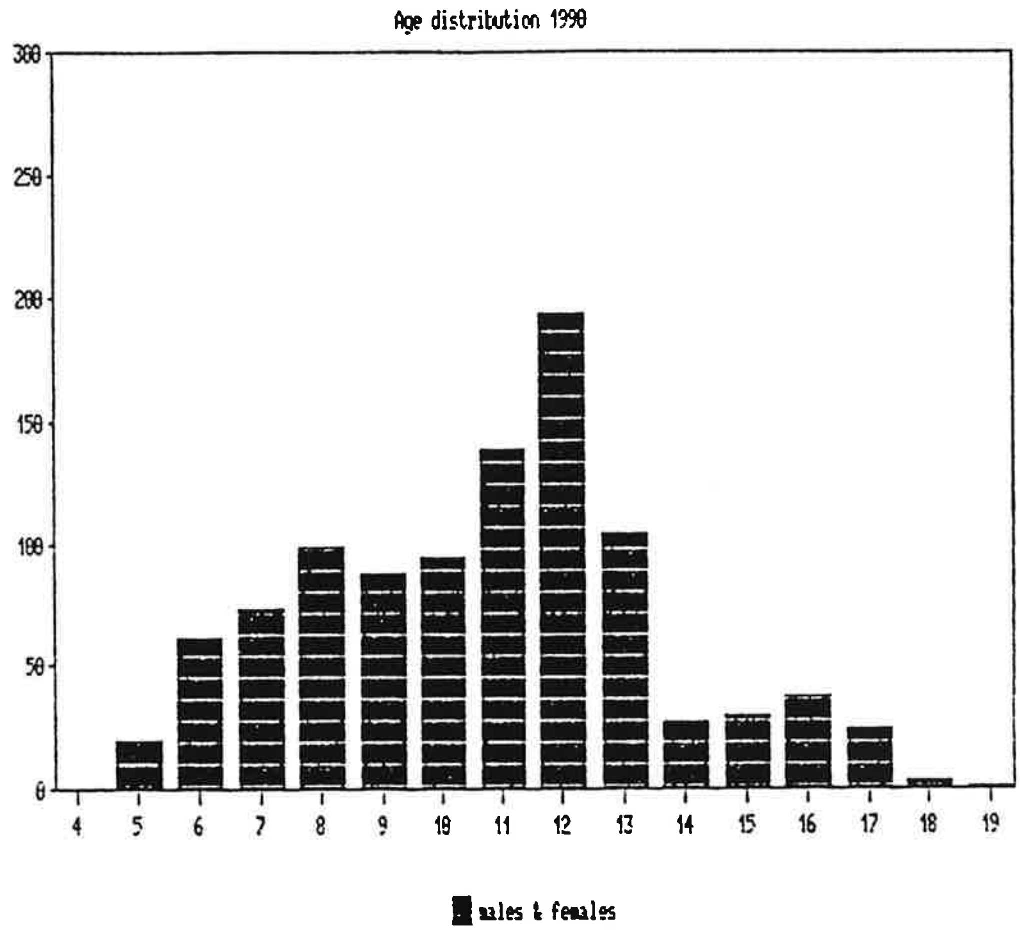


Figure 26.-- Age composition of male and female pollock from the international waters of the Bering Sea, 1990 (from Polish delegation this meeting).

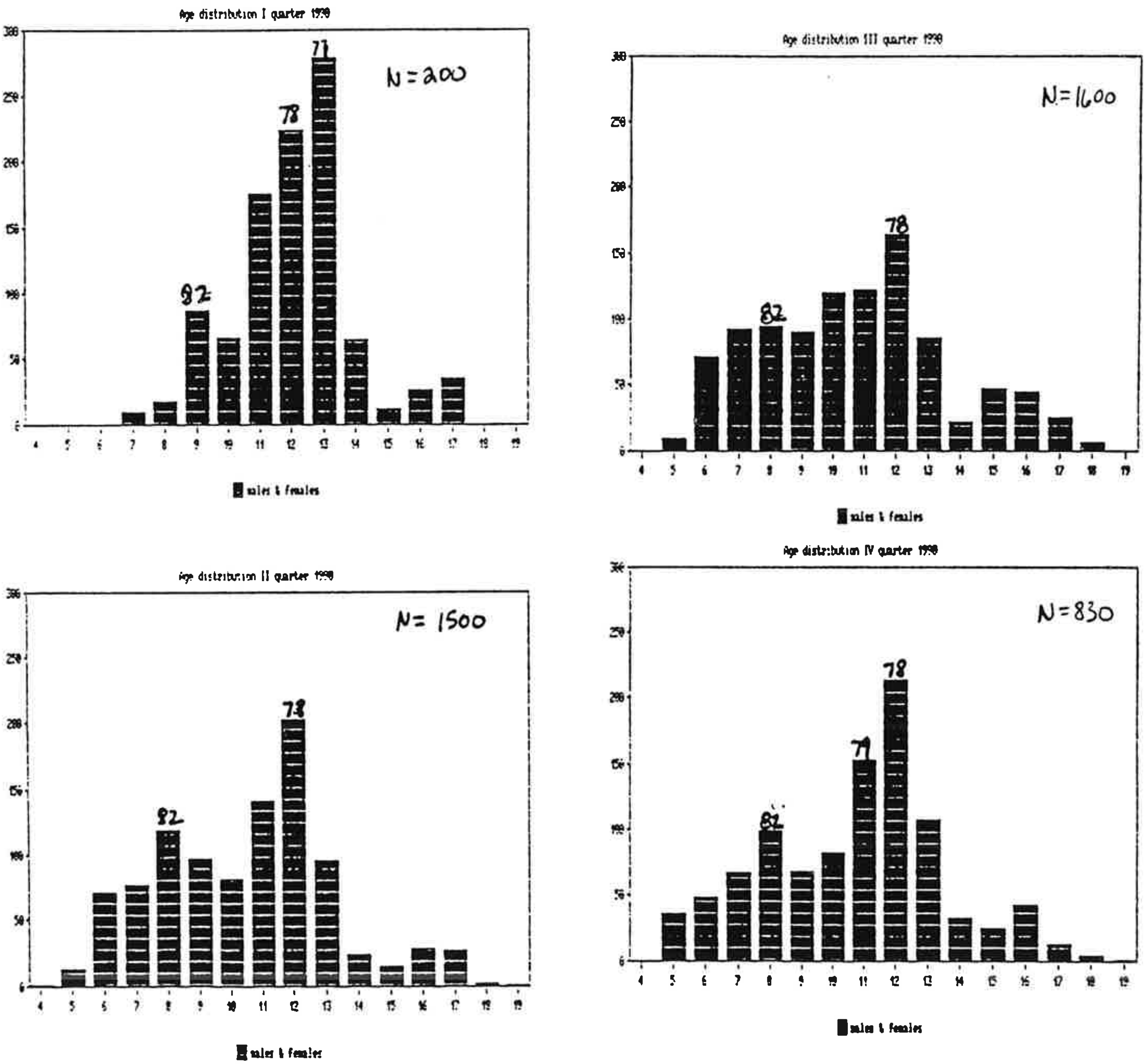


Figure 27.-- Quarterly age composition of male and female pollock from the international waters of the Bering Sea, 1990 (from Polish delegation this meeting).

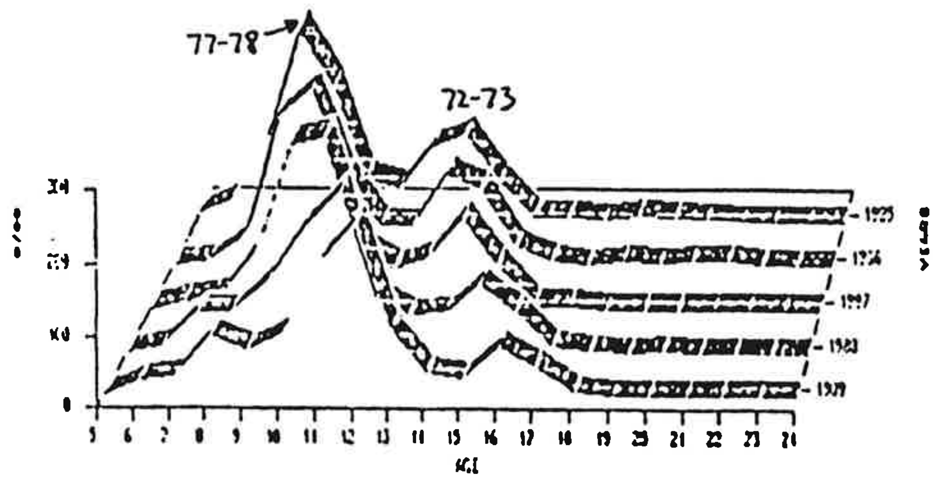


Figure 28.-- Age composition of pollock from Polish catches in international waters of the Bering Sea in 1985-1989 (from Kowalewska-Pahlke 1990).

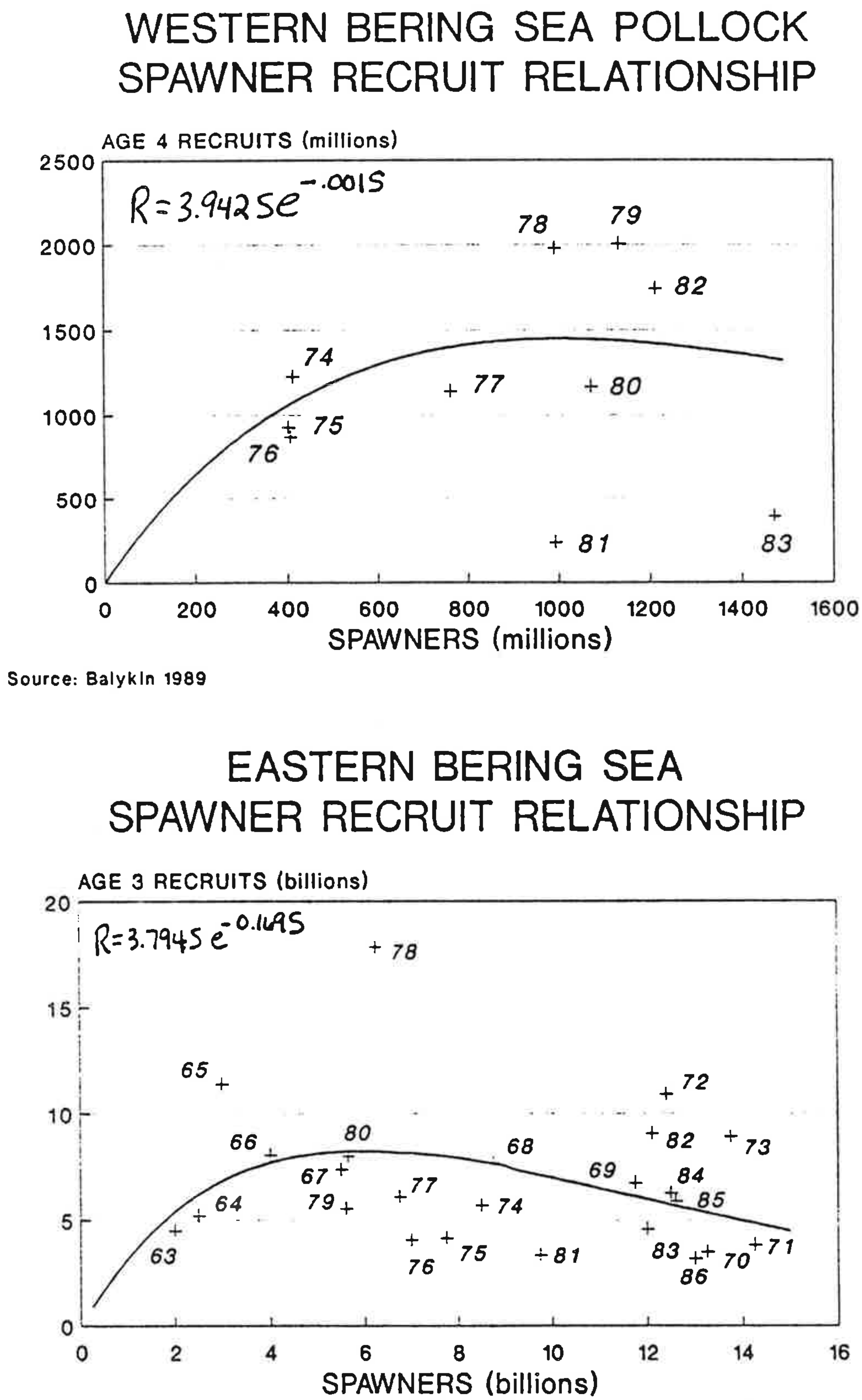


Figure 29.-- Comparison of spawner-recruit relationships for eastern and western Bering Sea walleye pollock.

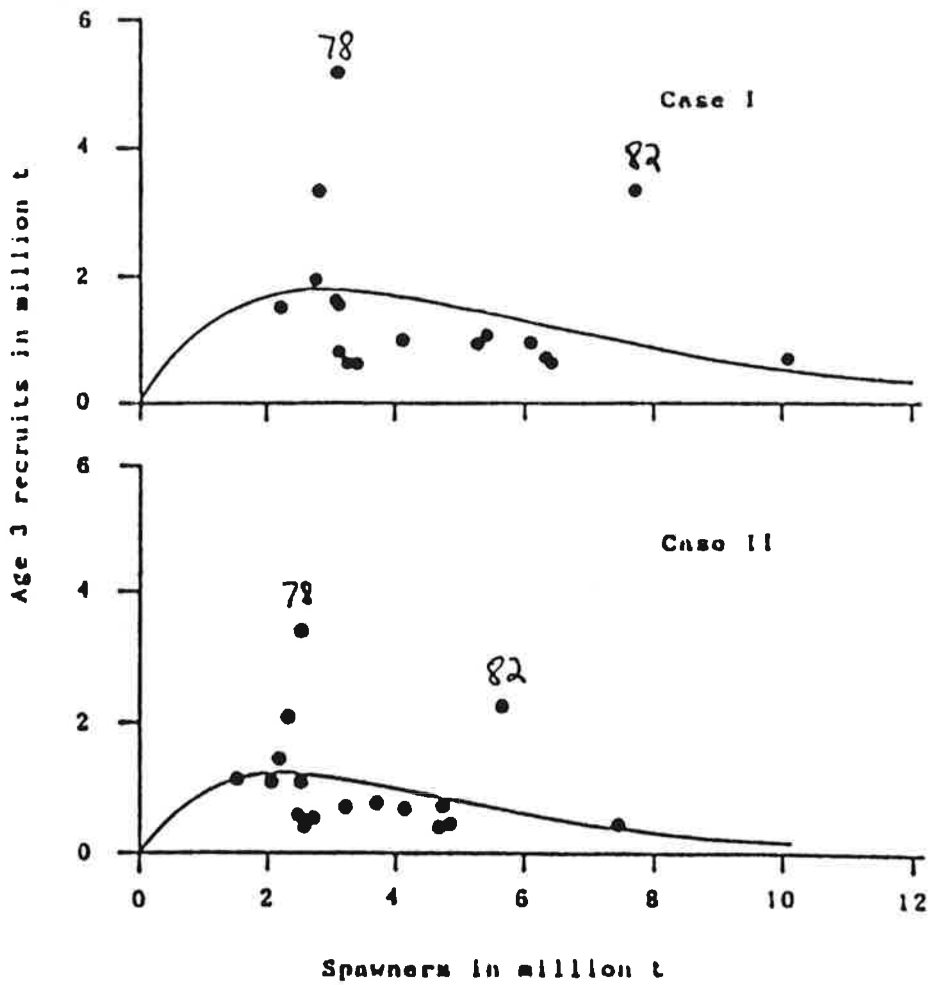


Figure 30.-- Spawners and age 3 recruits relationship in biomass of the eastern bering Sea continental shelf pollock stock (from Mito 1990).

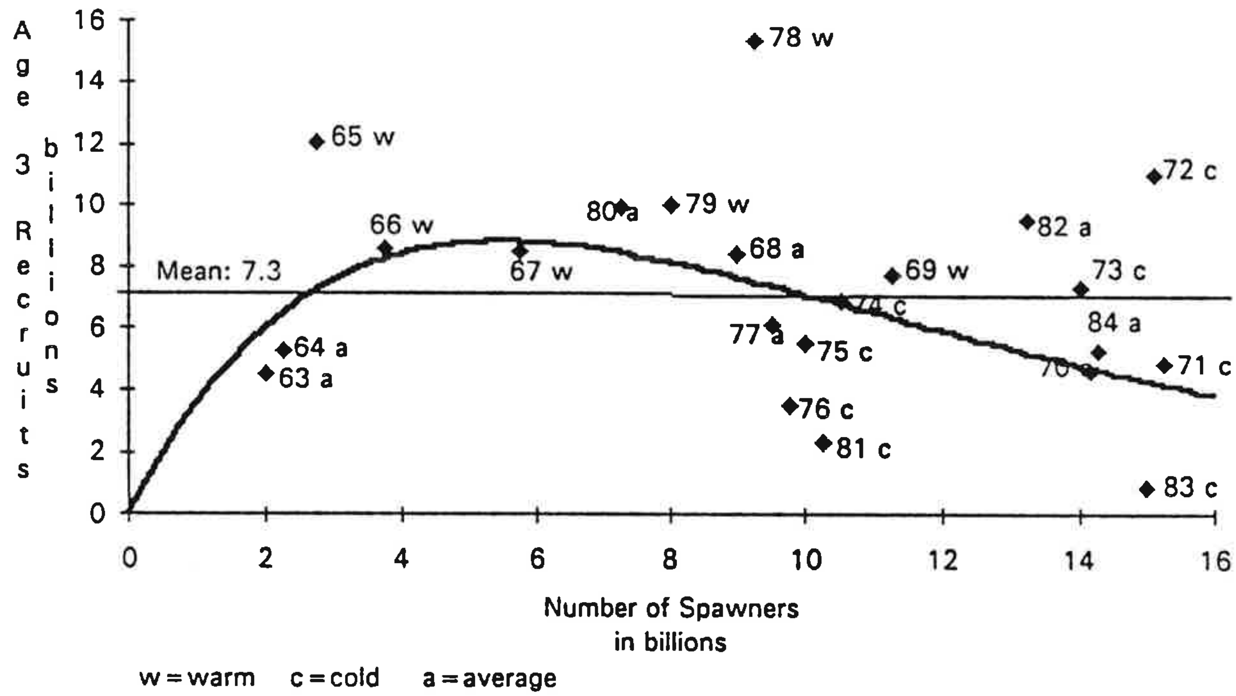


Figure 31.-- Eastern Bering Sea pollock spawner-recruit relationship with environmental correlate (from Wespestad 1988, unpublished).

MODULE B

Module B: Fishery Statistics

Facilitator: Richard Bakkala

INTRODUCTION

This module of the workshop reviews the fishery statistics for Bering Sea walleye pollock. Information is presented on the availability and detail of catch and effort and catch at age data and catch-per-unit effort estimates by year and for each of the three major regions of the Bering Sea. These catch and effort and catch and age data will be made available on computer disk to each of the national delegations attending the workshop.

EASTERN BERING SEA--ALEUTIAN ISLANDS REGION

Catch and Effort Statistics

There have been three sources of catch and effort data since the target fishery for pollock began in this region in 1964. They were from statistics reported by the foreign fisheries in 1964-79, from U.S. observer and foreign reported data in 1980-86, and from the Pacific coast Fisheries Information Network (PACFIN) since 1987.

Catch and effort statistics available for the eastern Bering Sea and Aleutian Islands regions during the years 1964 to 1979 are listed in Table 1. During these years most of the catch and effort data originated from the fishing nations. An exception was the 1968-72 catch data from the Republic of Korea which were estimated from U.S. surveillance over flights and boardings of Korean fishing vessels by U.S. surveillance personnel.

Throughout this period, the most complete and detailed catch and effort data was from Japanese fisheries (Table 1). This detail was not usually available from other nation's fisheries until 1977 when detailed reporting of catch and effort data was required by the United States through the Magnuson Conservation and Fishery Management Act.

Total annual all nation catches in 1964-79 are given in Figure 1. Japanese fisheries took the majority of the catch in each of these years, usually exceeding 80%. Figure 1 also illustrates the seasonality of Japanese catches which didn't change substantially throughout this period. All nation catches peaked at nearly 1.9 million t in 1972 and then begin to decline as some restrictions were placed on the fisheries through bilateral agreements between the United States and the various fishing nations. After the implementation of the Magnuson Conservation and Fisheries Management Act in 1977 and the United States assumed management authority over the fisheries in their 200-mile exclusive economic zone, catches of pollock were reduced to less than 1.0 million t.

Starting in 1980, catch and effort data begin to be estimated by the U.S. Observer Program at the Alaska Fisheries Science Center. These were a blend of observer estimates and foreign reported data. When the observer coverage for a week-area-vessel class exceeded 20% and the observer catch estimate differed by more than 10% from the foreign reported catch, the observer estimate was used. When the observer coverage was less than 20%, foreign reported data was used. These observer generated "best blend" catch data were used in the years 1980-86. They also include effort data and detailed information on location of catches and vessel and gear type.

Joint ventures also begin operating in 1980 in the eastern Bering Sea--Aleutians regions. These fisheries involved U.S. catcher boats delivering catches to foreign processing vessels. Catches were estimated in the joint venture fisheries in the same manner as on foreign fishing vessels.

Figure 2 illustrates the seasonality of catches in 1980-86 when "best blend" catch data were used and the magnitude of catches each year. This figure also illustrates the rapid transition of the fishery in this period. In 1980, only 1% of the catch was taken by joint venture fisheries, but by 1986 70% of the total catch was taken by joint ventures.

In 1987, catch data began to be estimated by PACFIN (Pacific Coast Fisheries Information Network). These estimates were derived by integrating weekly catch reports from three sources: U.S. observer reports from foreign and joint venture vessels, State of Alaska reports from fish tickets collected at ports of landings from the domestic fishery, and radio reports (through the NMFS Regional Office in Juneau) from domestic catcher-processors which remained at sea for extended periods of time. The years since 1987 have been another period of rapid transition in the pollock fishery (Fig. 3). In 1987, 83% of the catch was taken by joint venture fisheries, but by 1990 the U.S. domestic fishery took 98% of the catch. In 1991 all of the pollock catch was allocated to U.S. domestic fisheries.

United States domestic fisheries have not been required to report catch data in as much area detail as has been available from the observer program. They have reported catches by the management areas shown in Figure 4. Domestic fisheries have also not reported effort data.

Catch-Per-Unit Effort

Catch-per-unit effort (CPUE) based on Japanese catch and effort data were used until 1985 to examine trends in abundance of eastern Bering Sea pollock. Three measures of CPUE were developed: a U.S. method (Alton and Fredin 1974), a Japanese method (Okada et al. 1982), and a joint U.S.-Japanese method referred to as the INPFC method (Low and Ikeda 1980). The Japanese and U.S. methods used data from Japanese pair trawl vessels. The main difference between these methods was that the Japanese method only used data where pollock was the dominant species in the catch, whereas the U.S. method used all data where pollock were caught. The INPFC method used data from the five Japanese vessel-gear types known to target on pollock and the area-time periods which consistently accounted for most pollock catches.

The three measures of CPUE show similar trends in abundance of pollock (Fig. 5). Increasing abundance during the late 1960s with a peak in the late 1960s or early 1970s followed by a decline and then fairly stable abundance between about 1975 and 1981. Abundance then increased again during the 1980s. These trends have been found to correlate well with results from cohort analysis. More recent series of CPUE data have not been developed because of the rapid transition in the fishery since 1985 (Figures 2 and 3).

Catch at Age Data

Catch at age data for eastern Bering Sea pollock in 1964-89 are available on computer files at the Northwest and Alaska Fisheries Center. They consist of the following data. Catch data for the years 1964 to 1979 are those reported by the foreign fisheries. Those for 1980-86 are from U.S. observer "best blend" estimates, and those for 1987-89 from PACFIN estimates. Length-frequency data used to derive the catch at age estimates were collected by Japanese fisheries in 1964-72 and by the U.S. observer program in later years. Although age data were also available from the Japanese fishery, they were based on age readings from scales rather than the more widely accepted readings from otoliths. Therefore, an average age-length key based on otolith collections by U.S. observers over the years 1973 to 1977 was applied to the Japanese length data from 1964 to 1972 to develop catch at age data in those years. In all later years, annual age-length keys from U.S. observer otolith collections were used. In estimating catch at age, length-frequency samples from the fishery were expanded to the total number in daily catches and summed within nation-vessel classes, areas, and sexes by quarter. For nation-vessel classes and area cells without length data, the most representative length-frequency information was used. Quarterly age-length keys combined over nation-vessel classes were applied to the quarterly length-frequencies to produce quarterly catches at age by area and sex which were then summed to provide annual estimates. Average weight at age data from Smith (1981) were used to convert numbers-at-age to weight at age.

ALEUTIAN BASIN

Catch and Effort Statistics

Two fisheries have operated in the Aleutian Basin, a U.S. fishery in the vicinity of Bogoslof Island (see area 515, Fig. 4) and a non-U.S. fishery in the international zone or "donut hole". The U.S. fishery has operated in the Bogoslof Island area since

1987 in early months of the year when pollock concentrate in this area for spawning. All of the catch taken by U.S. catcher boats in 1987 and 1988 were delivered to non-U.S. processors in joint venture operations. In 1990, all of the catch was taken and processed by U.S. vessels (Fig. 6). A U.S. fishery may have operated in the Bogoslof area early in the year in 1989 although methods of reporting catches may not have allowed separation of the Bogoslof Island catches from those in the eastern Bering Sea. No effort data is available from the Bogoslof Island fishery in 1987-89, but is available from the 1990 fishery through a domestic fishery observer program.

Japanese and Republic of Korea fisheries began to operate on a limited scale in the Aleutian Basin in 1980. They operated in both the U.S. EEZ waters of the Basin and the international zone initially, but increasingly in the international zone in later years. In 1985, fisheries from Poland and the People's Republic of China and in 1986 the U.S.S.R joined these other nations in the Basin fisheries. In 1986, all nation catches in the international zone began to reach major proportions exceeding 1.0 million t (Table 2). They have continued to increase reaching 1.5 million t in 1989.

Catch and effort data available from non-U.S. fisheries operating in the Aleutian Basin are listed in Table 3. Complete and detailed catch and effort data has been provided for all years of fishing by Japan, Poland, and the People's Republic of China. The Republic of Korea has provided this detailed data for 1988 and 1989. Korea has provided annual catches for 1980-82 and annual catch and effort data by month for 1983-87. The U.S.S.R. has provided annual catches by 1/2°lat. and 1°long. blocks for 1986-90. However, only 60 to 70% of the Soviet fishing vessels have provided catch data in this detail so the catches are not complete.

Catch-Per-Unit Effort

Relative abundance of pollock in the international zone from catch and effort data provided by the fishing nations is illustrated in Figure 7. The longest series of data is from the Japanese fisheries. These data show a sharp increase in CPUE from 1983 to 1986. However, this increase has been attributed entirely to improvements in midwater fishing gear and knowledge of the distribution of pollock in the international zone rather to an increase on abundance of pollock (Sasaki and Yoshimura 1987). These authors, in a later report (Yoshimura and Sasaki 1990), state that these improvements in fishing techniques continued to occur after 1986. Thus, the decline in CPUE from Japanese fishery data after 1986 is strong evidence of a decline in abundance of pollock in the international zone. This decline is also reflected by CPUE data from other nation's fisheries.

Catch at Age Data

Catch at age data have been developed for pollock in the international zone for the years 1985-88 based on Polish length and age data (Horbowy and Janusz 1990). Data were made available at the current workshop which may allow improved estimates of catch at age for the overall fishery. Japan has provided annual length frequency data from their fishery and from their various research vessel surveys in the Basin. Age and length frequency data are also available from U.S. research vessel surveys in the Basin during 1988 and 1989.

WESTERN BERING SEA

Catch and Effort Statistics

Annual catch data for the western Bering Sea have been provided by the U.S.S.R. as shown in Table 2. At the current workshop, the Soviet delegation provided estimates of total annual catch and effort by three major regions of the western Bering Sea for the years 1986-90. The three major regions are the western Bering Sea shelf and slope west of 174°E, the northwestern Bering Sea shelf and slope (east of 174°E), and the Aleutian Basin. They additionally provided catch data by 1/2°lat. and 1°long. blocks for all of these areas, although the catches are not complete because only 60-70% of the fishing vessels reported catches in this detail.

They will provide similar information for the years 1980 to 1986 when they return to the U.S.S.R.

Catch at Age

To develop catch at age data for the western Bering Sea fisheries, the Soviet delegation suggested it would be appropriate to use the age data presented by Balykin (1988) as shown in Table 4.

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Table 1.--Catch and effort data available for pollock in the eastern Bering Sea and Aleutian Islands regions, 1964-79.

Fishing nation	Years	Data available
Japan	1964-79	Catch and effort data by 1/2°lat. and 1°long. statistical blocks and by month, vessel class, and gear type.
U.S.S.R	1967-72	Annual catches by the major regions eastern Bering Sea and Aleutians.
	1973-76	Catch and effort data by month, vessel class, and gear type by the major regions eastern Bering Sea and Aleutians.
	1977-79	Catch and effort data by 1/2°lat. and 1°long. statistical block and by month, vessel class, and gear type.
Republic of Korea	1968-75	Catches estimated from U.S. surveillance over flights and boardings by U.S. surveillance personnel.
	1976-79	Catch and effort data by 1/2°lat. and 1°long. statistical blocks and by month, vessel class, and gear type.
Poland	1979	Catch and effort data by 1/2°lat. and 1°long. statistical blocks and by month, vessel class, and gear type.
People's Republic of China	1977-79	Catch and effort data by 1/2°lat. and 1°long. statistical blocks and by month, vessel class, and gear type.

Table 2.--Walleye pollock catches in the Bering Sea in thousands of metric tons.

	Donut Hole Zone						U.S. EEZ	U.S.S.R. EEZ
Year	P.R.O.C.	JAPAN	R.O.K.	P.P.R.	U.S.S.R.	Donut hole total	All nations	
1980		2.4	12.5				958.3	
1981		.2	0				973.5	
1982		1.2	2.9				955.9	
1983		4.1	66.6				982.4	
1984		100.9	80.3			181.2	1,098.8	756
1985	1.6	136.5	82.4	115.8		336.3	1,178.8	662
1986	3.1	698.0	164.0	163.2	41.0	1,069.3	1,189.4	838
1987	16.5	803.5	231.0	230.3	158.0	1,439.3	1,253.5	688
1988	18.4	750.0	268.6	298.7	135.0	1,470.7	1,228	1,253
1989	31.1	654.9	342.3	268.6	219.0	1,515.9	1,386.0	961

P.R.O.C. - People's Republic of China.
R.O.K. - Republic of Korea.
P.P.R. - Polish People's Republic.
EEZ - Exclusive Economic Zone.

Table 3.--Pollock catch and effort data from the International Zone, 1980-1990.

Fishing nation	Years	Data available
Japan	1980-89	catch and effort by 1/2°lat. and 1°long. blocks, month, vessel type and gear type
Republic of Korea	1980-82	annual catches, no effort
	1983-87	catch and effort by month
	1988-89	catch and effort by 1/2°lat. and 1°long. blocks, month, vessel type, and gear type
Poland	1985-90	catch and effort by 1/2°lat. and 1°long. blocks, month, vessel type and gear type
People's Republic of China	1985-89	catch and effort by 1/2°lat. and 1°of China long. blocks, week, vessel type, and gear type
U.S.S.R.	1986-90	annual catches by 1/2°lat. and 1°long. blocks

Table 4. Age composition of the western Bering Sea walleye pollock in trawl catches (%).

Year	Age, years											
	0+	1.1+	2.2+	3.3+	4.4+	5.5+	6.6+	7.7+	8.8+	9.9+	10.10+	11.11+
1978	0.4	12.8	12.7	14.2	17.1	21.9	16.4	3.5	0.5	0.5	-	-
1979	2.8	16.4	32.1	2.8	2.5	16.5	16.0	6.3	3.6	0.7	0.2	0.1
1980	0.07	4.4	36.0	14.3	9.2	4.6	17.3	10.3	2.6	0.7	0.5	0.03
1981	-	-	2.4	38.1	19.1	16.4	12.9	8.0	1.9	1.1	0.1	-
1982	-	0.2	7.1	40.5	42.7	5.3	2.0	1.8	0.3	0.1	-	-
1983	3.8	13.9	1.5	8.0	21.3	27.9	12.0	8.0	2.5	0.8	0.2	0.1
1984	-	0.2	3.2	7.6	18.0	37.4	18.8	11.1	2.4	1.0	0.2	0.1
1985	-	5.7	5.0	19.0	1.7	26.8	29.6	9.0	2.0	0.6	0.5	0.1
1986	0.1	1.0	5.0	6.8	32.8	5.0	23.7	20.2	4.2	0.9	0.3	
1987	-	1.6	4.2	28.9	14.2	31.1	9.0	6.0	2.9	1.5	0.6	

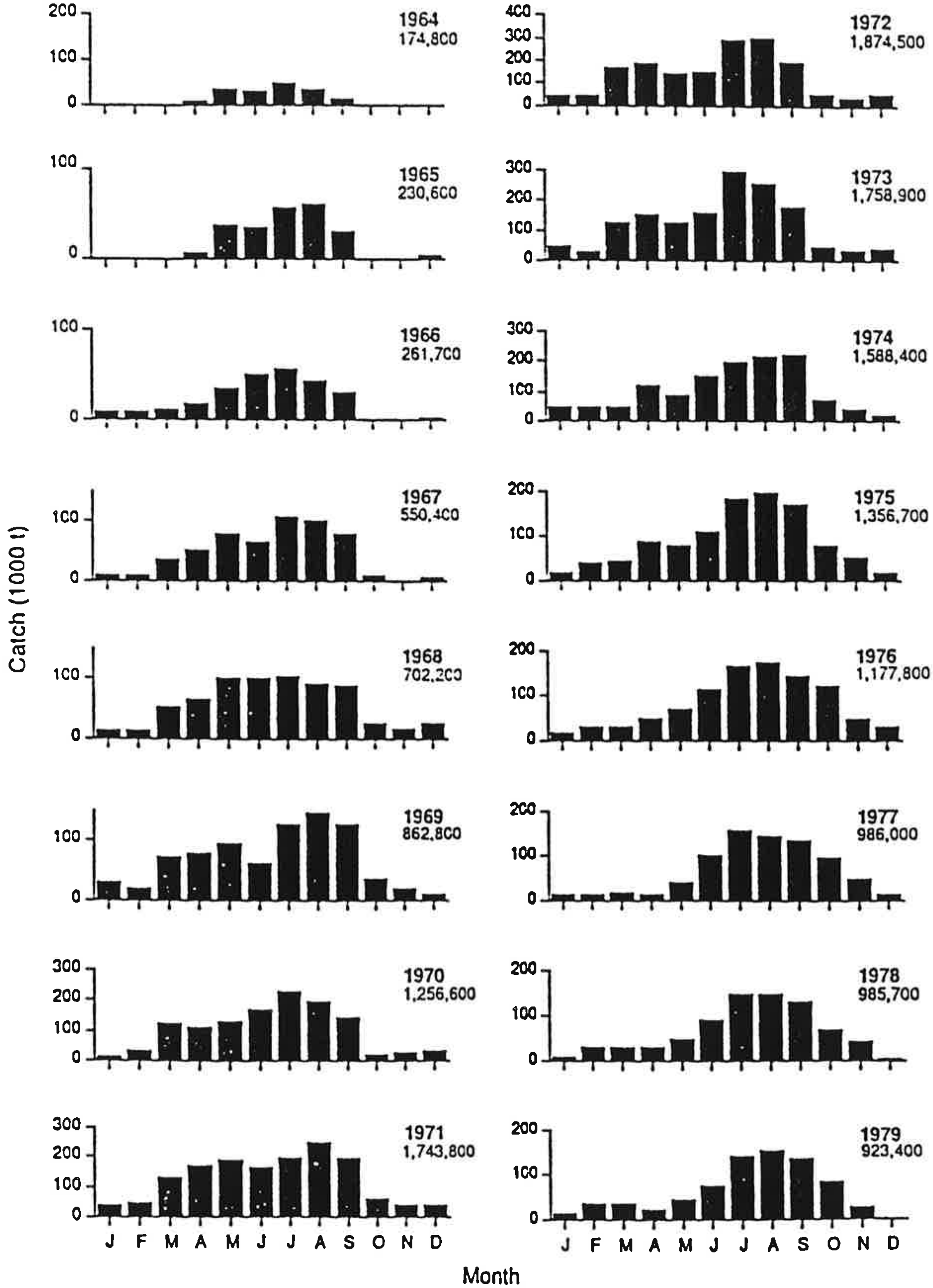

Figure 1.--Japanese catches of pollock by month in the eastern Bering Sea and Aleutians, 1964-79.

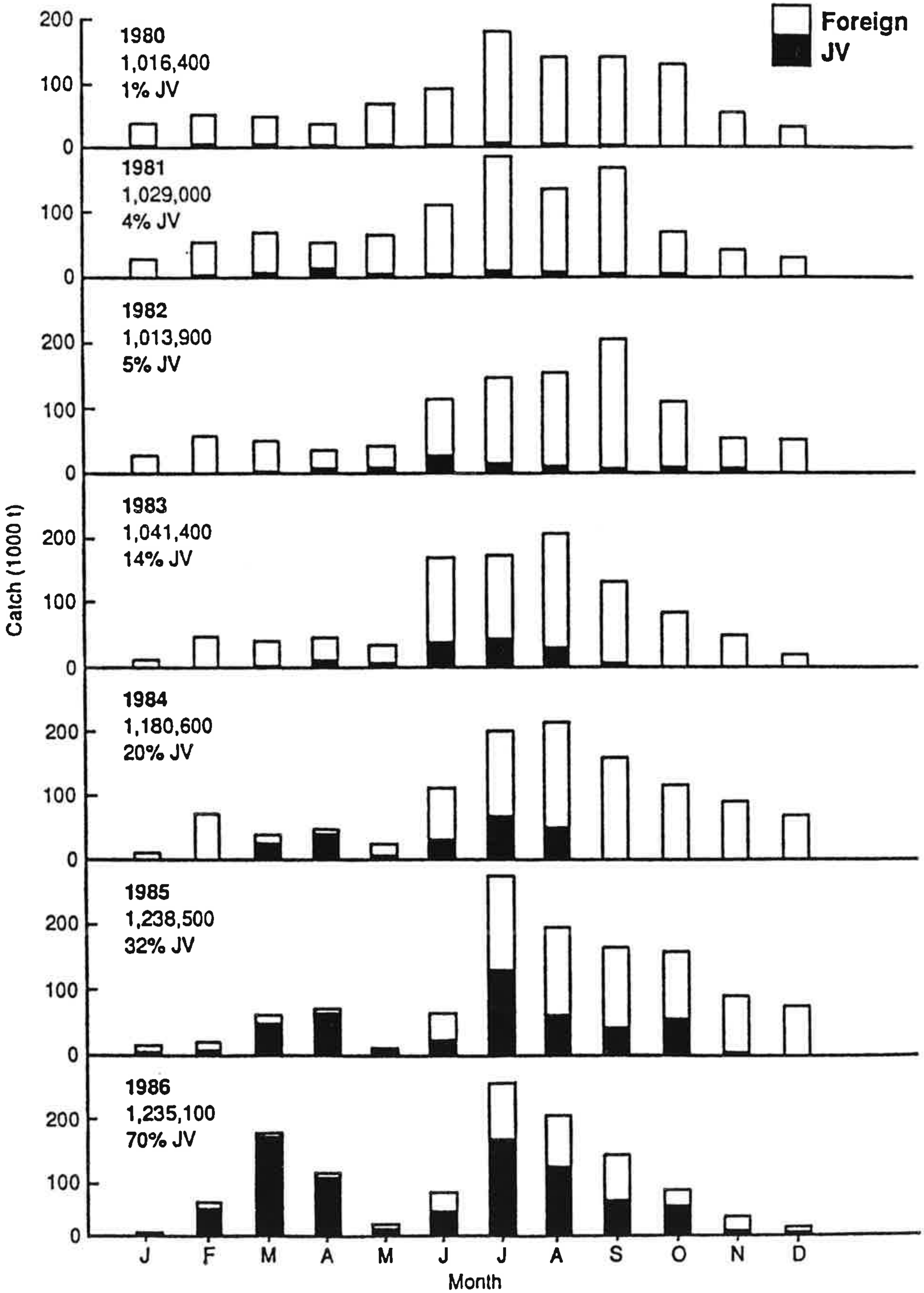

Figure 2.--Foreign and joint venture catches of pollock by month in the eastern Bering Sea and Aleutians, 1980-86.

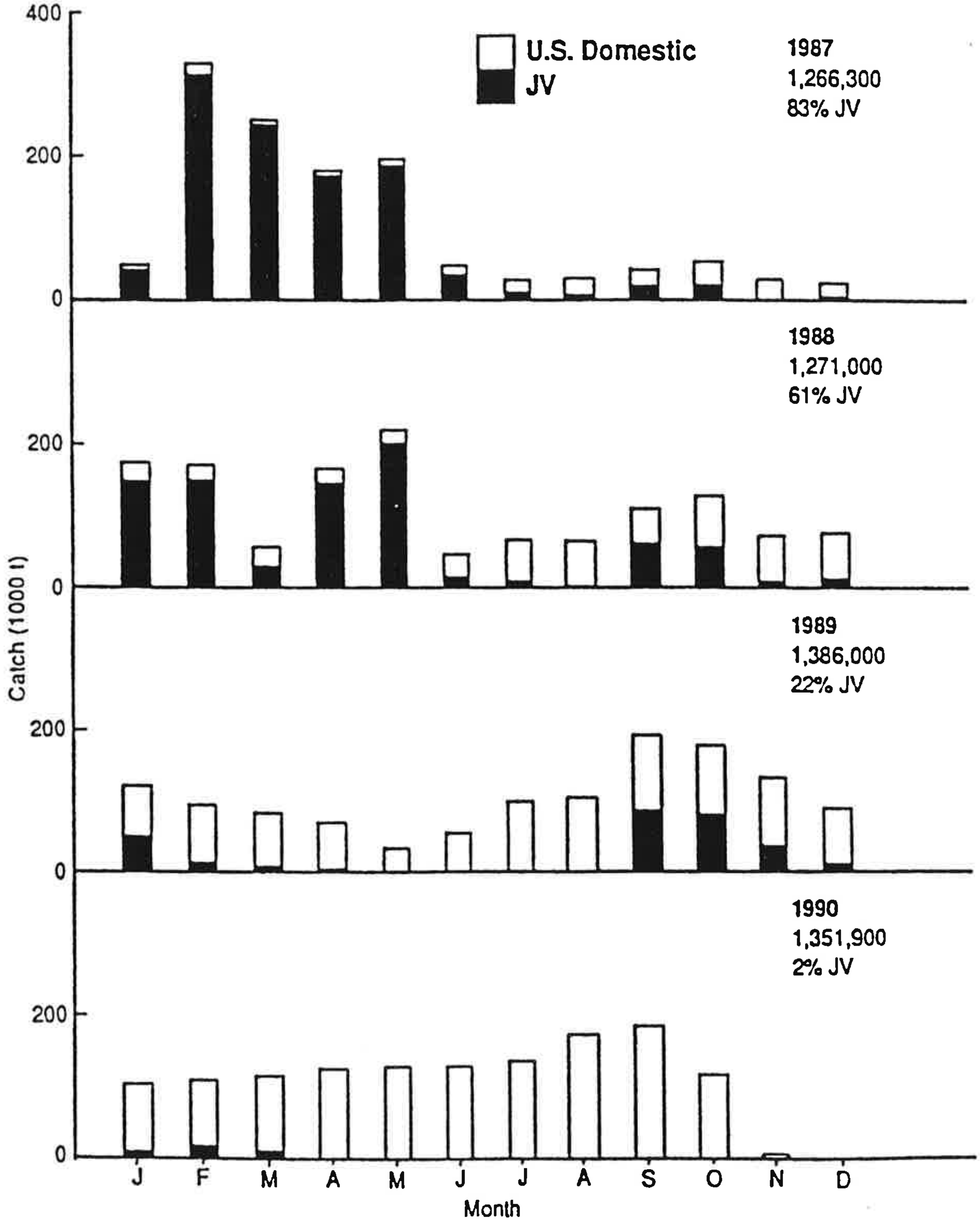

Figure 3.--United States joint venture and domestic catches of pollock in the eastern Bering Sea and Aleutians 1987-90.

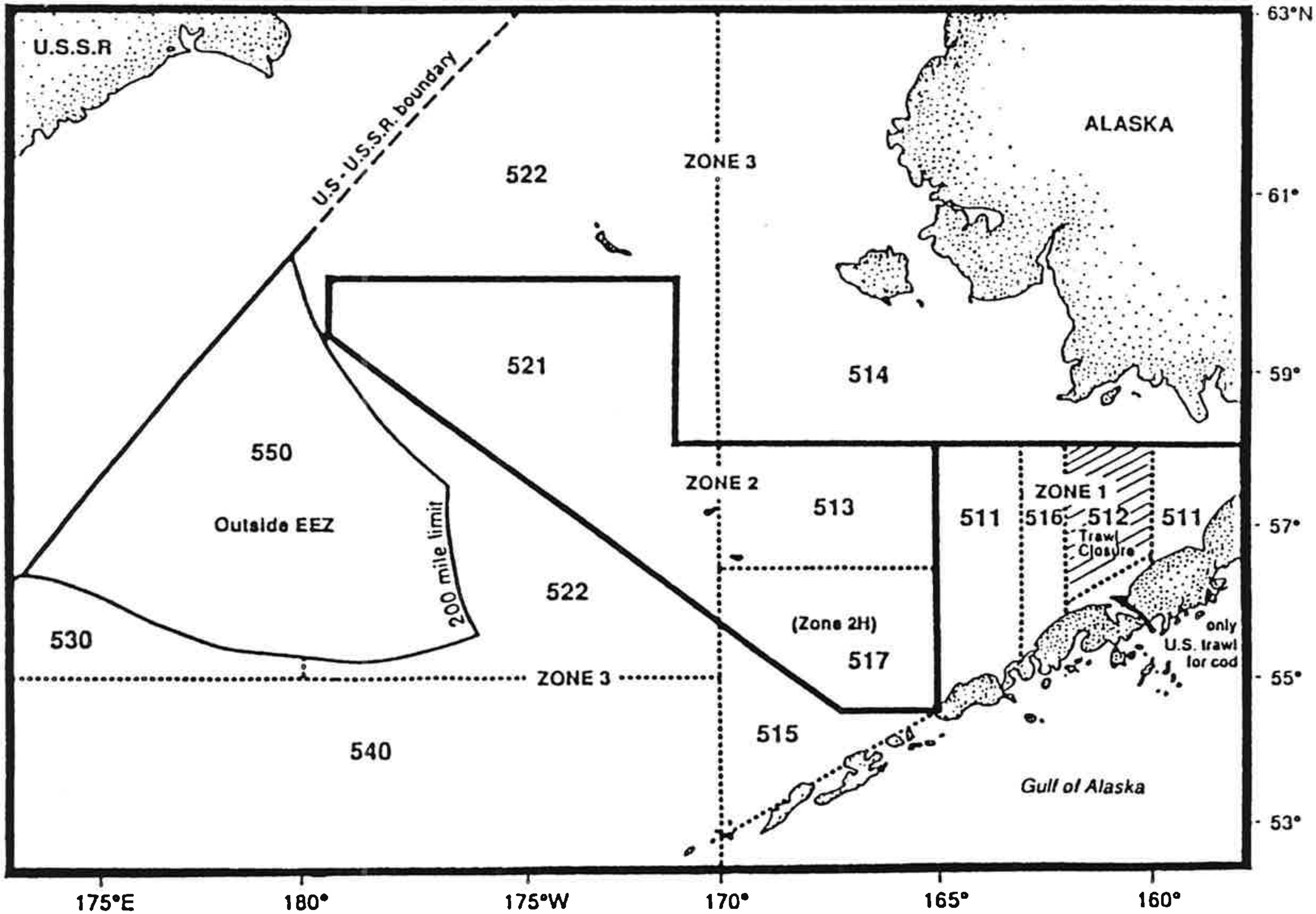

Figure 4.--Groundfish management areas in the U.S. Exclusive Economic Zone of the Bering Sea.

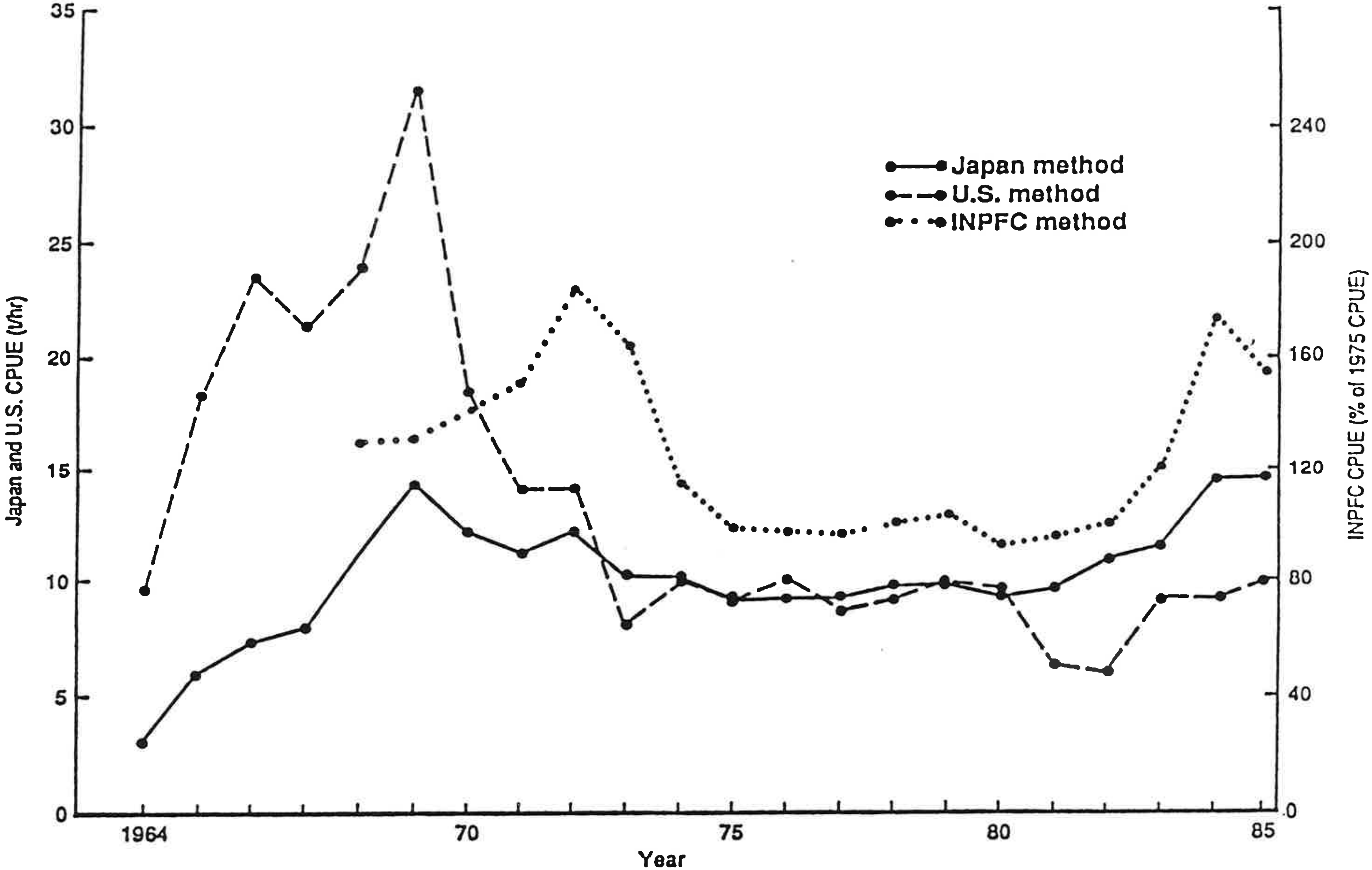

Figure 5.--Trends in abundance of pollock in the eastern Bering Sea as shown by three indices of abundance based on Japanese fisheries data.

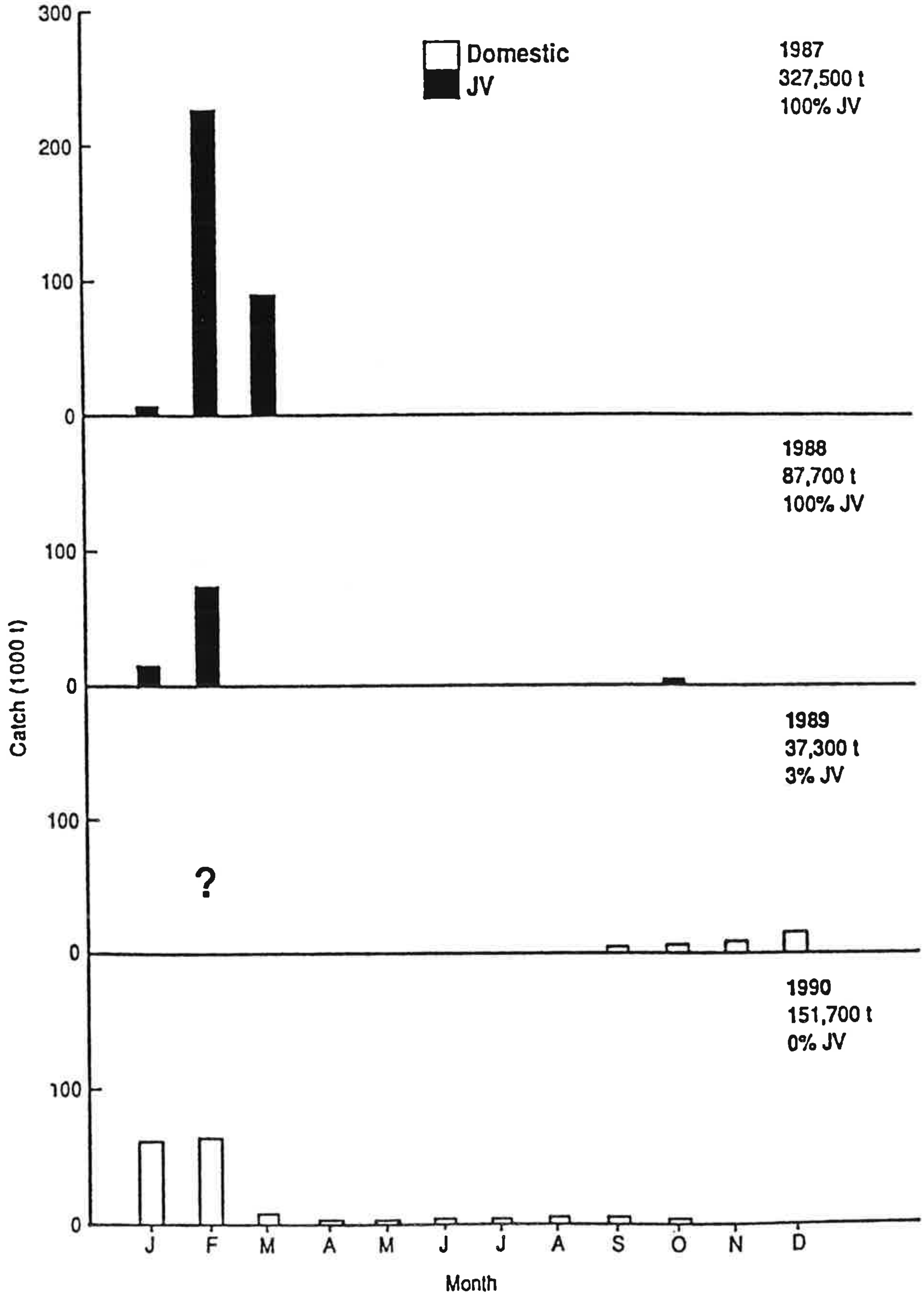

Figure 6.--Catches of pollock in the vicinity of Bogoslof Island by U.S. joint venture and domestic fisheries.

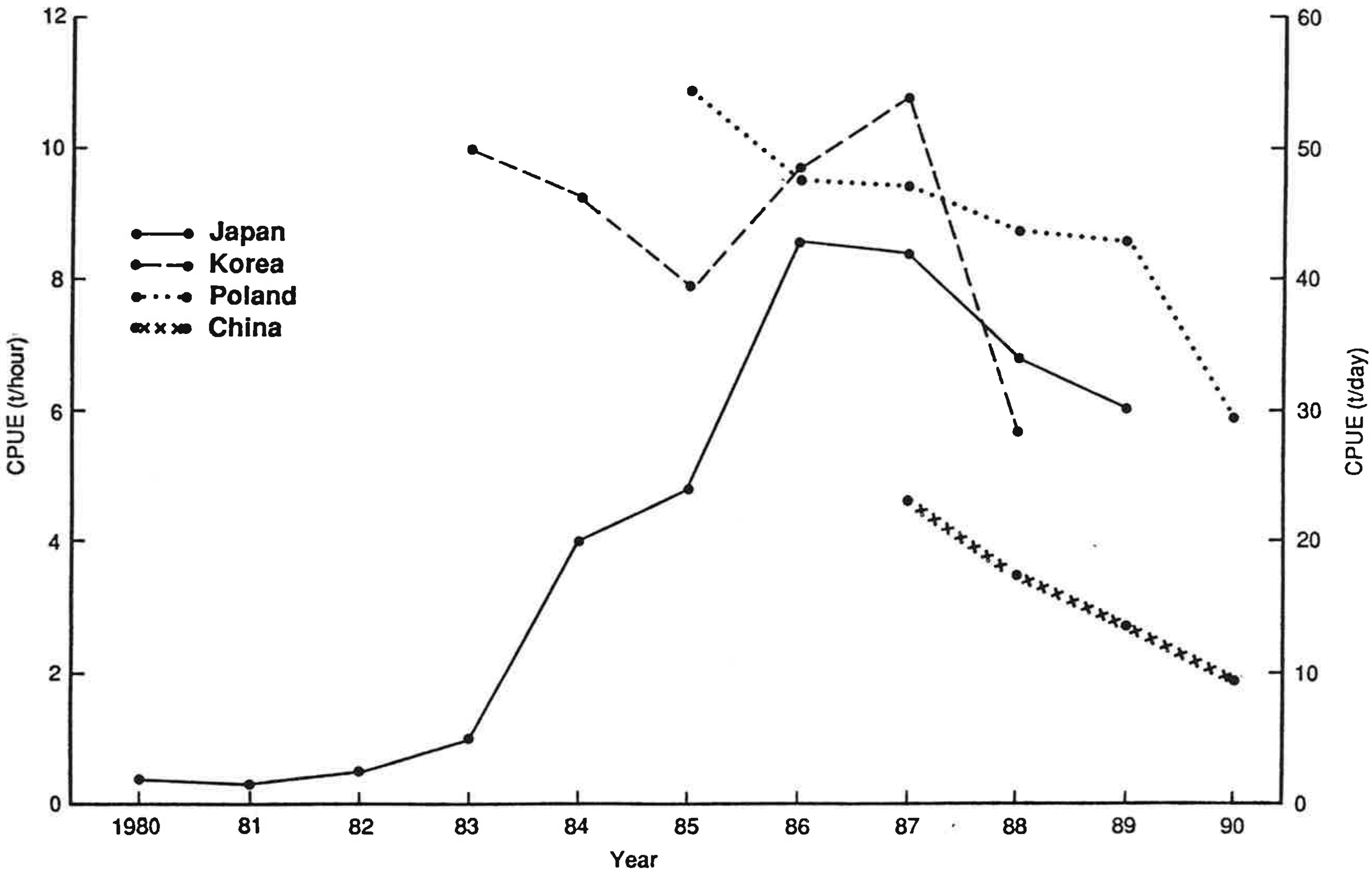

Figure 7.--Catch-per-unit effort (CPUE) for pollock in international waters of the Aleutian Basin as shown by catch and effort data from the four major fisheries in this area. The CPUE values are in terms of metric tons per hour for the Japanese, Korean, and People's Republic of China fisheries and metric tons per day for the Polish fishery.

MODULE C

Module C: Mortality Rates

Facilitator: Dr. Anne Babcock Hollowed

1.0 INTRODUCTION

Workshop discussions regarding estimation of natural mortality focused on several subjects. The session began with a review of current methods for estimating natural mortality. Following this discussion, natural mortality rates for pollock derived using different methods were compared. Several new estimates were introduced to provide examples of the range of coefficients that could be generated using methods based on catch analysis or life history parameters. The session ended with a discussion of attempts to distinguish the influence of predators as a separate source of natural mortality.

2.0 REVIEW OF METHODOLOGY

Three methods are currently used to estimate natural mortality rates (M) of fish populations: catch analysis, life history co-variates, and estimation of predation (Vetter, 1988). The advantages and disadvantages of each method were discussed.

2.1 Catch Analysis Methods

Estimation of natural mortality from catch data are based on measures of the decline in abundance of groups of fish over two or more time intervals. Two types of catch analysis methods were reviewed; methods based on trends in catch-at-age, and tagging studies.

Catch analysis techniques based on catch-at-age data include catch curve analysis, and monitoring a single cohort through time. Catch curve analysis is based on the assumption that abundance decreases exponentially with age. Logarithmic conversion of catch-at-age data results in a relatively linear decrease during most exploited ages, after an initial increase in vulnerability (Vetter 1988). The slope of the best fit line of the descending limb of the logarithm of catch-at-age provides and estimate of total mortality. If fishing mortality (F) is small, then F is approximately zero and total mortality (Z) is assumed to be due to natural mortality alone. If F is non-trivial, M can be estimated by determining Z at various levels of fishing effort. Then using the relationship between Z and effort, the value of Z at zero effort (M) can be approximated (Sillman 1943, Beverton and Holt 1957, Paloheimo 1961, Lander 1962, Chapman and Murphy 1965, Paulik and Robson 1969, Gulland 1983, Butler and MacDonald 1979).

If auxiliary abundance data is available from surveys, the total mortality (Z) of a cohort can be calculated. Total mortality can be partitioned into components of fishing and natural mortality in the following manner. Let $N_i(t)$ be the estimate of the total population of cohort i in year t. Total mortality is estimated as:

$$Z_i(t, t+1) = - \ln(N_i(t+1) / N_i(t))$$

The exploitation rate ($E_i(t, t+1)$) can be estimated from the ratio of the catch ($C_i(t, t+1)$) taken from year after the estimate of $N_i(t)$ and prior to the estimate of $N_i(t+1)$ as:

$$E_i(t, t+1) = C_i(t, t+1) / N_i(t)$$

The exploitation rate can be equated to Baronov's catch equation:

$$C_i(t, t+1) / N_i(t) = F_i(t,t+1) [1 - \exp(-Z_i(t,t+1)] / Z_i(t,t+1)$$

which can be solved for $F_i(t,t+1)$. Natural mortality $M_i(t,t+1)$ can then be estimated by subtracting F from Z.

The advantage catch analysis techniques which utilize catch-at-age data for estimating mortality is that data is readily accessible from the fishery. The major disadvantages of this method are: a) that fish must aged without error, b) populations must be closed to migration, c) natural mortality must be relatively constant between age groups, and d) compensatory relationships between stock abundance and M, and F and M must not be present (Table 1).

The second type of catch analysis method for estimating natural mortality is mark recapture (Jones 1979, Brownie et al. 1985). The major advantages of mark recapture methods are: a) the studies focus on relative rather than absolute changes in abundance, b) immigration is less of a problem, c) if large number of fish can be marked, differences between groups (i.e. ages, sexes, or areas) can be studied (Table 1). The major disadvantages of mark recapture studies are: a) mark induced effects on mortality, behavior and vulnerability to capture must be considered, and b) some marks may be lost (Table 1). In the case of Bering Sea pollock, it may be difficult to bring fish to the surface without harming the fish.

2.2 Life History Methods

Life history methods for estimating M are based on the theoretical relationships between life history parameters and M (Table 2). The major advantage of these methods are: a) the data requirements are minimal, and b) they are useful for demonstrating broad trends across species (Table 1). The major disadvantages of using this type of technique are: a) the estimates of M are imprecise, and b) the method can not be used to detect age specific differences in mortality (Table 1).

2.3 Predation Methods

When trophic interactions between species are known, the components of natural mortality attributed to predation can be determined. Natural mortality is estimated as the sum of a constant rate of non-predatory, non-fishing mortality plus the total estimated flux of prey relative to each of the major predators (Majkowski 1981, Pope and Knights 1982, Laevastu et al. 1982).

Predation methods that incorporate trophic interactions are useful because age specific and year specific differences in mortality can be studied. The disadvantages of predation methodology are: a) it is often difficult to define vulnerability and prey preference functions, b) time series of abundance may not be available for species that are not commercially exploited, and c) the technique is most applicable when trophic interactions are simple (i.e. predators have few alternative prey) and predation is the major factor controlling prey abundance (Table 1).

3.0 ESTIMATES OF NATURAL MORTALITY FOR POLLOCK

3.1 Published Estimates of Natural Mortality Rate

Several different estimates of age specific natural mortality have been presented for Bering Sea pollock (Bakkala et. al. 1987, Horbowy and Janusz 1990, Mito 1989, Mito 1990, Zolotov and Antonov 1989) (Table 3). The largest differences between each of these estimates occurs at younger ages. The high estimates of natural mortality at age three presented by Mito (1989, 1990) resulted from the inclusion of mortality due to cannibalism.

Dr. Mito described the methods he employed to estimate M. Mito (1989) assumed that there were three stocks of pollock; a western continental shelf stock, an eastern continental shelf stock and a basin stock (Figure 1). He assumed that the eastern and western continental shelf stocks spawned, developed, grew and migrated on the shelf and slope areas, whereas, it was assumed that the Basin stock spawned in the Aleutian Basin, grew on the continental shelf and slope areas and returned to the basin at age 5 or 6 (Figure 1).

Mito (1989) calculated the 1989 estimate of M for fish age 4+ as follows. The decline in abundance of fish age 6 and older was monitored using estimates of total abundance from the 1979, 1982, and 1984 joint U.S. / Japan cooperative groundfish surveys. Based on this analysis total mortality (Z) was estimated to be 0.45. An estimate of fishing mortality was derived from the population number and the catch in number using Japanese multivessel trawl survey results and Japanese catch data. Mito estimated natural mortality was 0.35 by subtracting F from Z.

Dr. Mito explained that the natural mortality for age 3 fish was much higher than 0.35 because of the influence of cannibalism. He calculated the number of age 4 fish in the eastern continental shelf stock by back calculating from the abundance of age 6 fish assuming Z was equal to 0.45. The number of age 4 fish in the Basin stock was estimated as the difference between the abundance of age 4 fish from the multi-vessel trawl surveys and the back calculated abundance of age 4 fish in the eastern continental shelf stock. The number of age 3 and younger fish was back-calculated by estimating the number of fish consumed by cannibalism and by assuming natural mortality was 0.35. The estimate of cannibalism depended on the abundance of older fish in the population (Figure 2). Based on this data Mito (1990) assumed that natural mortality of 3-year-old fish due to cannibalism was on average 0.65 (0.5 in Mito 1990).

Mito (1990) presented two series of age specific natural mortality. The methods used to estimate M for ages 4+ were similar to those described above. The first estimate (0.38) was obtained by estimating fishing mortality (0.07) on the 1972-1976 year classes based on Japanese catch-at-age data. Natural mortality (0.38) was estimated by subtracting fishing mortality from the estimate of total mortality (0.45) used earlier. The second estimate of natural mortality (0.29) was calculated in a similar manner, however, F (0.16) was estimated using catch-at-age data from age determination conducted in the U.S and the results of U.S.- Japan cooperative surveys.

Dr. Wespestad briefly described the technique he used to estimate natural mortality. His estimates were derived by iteratively changing natural mortality and fishing mortality coefficients to obtain the best fit to the survey abundance-at-age estimates and the observed catch-at-age data.

Horbowy and Janusz (1990) estimated natural mortality of pollock in the Aleutian Basin of the Bering Sea using catch curve analysis. The analysis was based on 1985 catch-at-age data when the exploitation rate was low. The slope of the catch curve -0.37 provided an estimate of total mortality (Figure 3). The authors assumed that M would range from 0.2 - 0.3 and suggested that a value of 0.2 should be applied to the Aleutian Basin pollock stock (Table 3).

4.0 APPLICATION OF CATCH ANALYSIS AND LIFE HISTORY METHODS

Applications of catch analysis and life history methods for estimating M were presented.

4.1 Application of Catch Analysis Methods

Natural mortality was calculated by subtracting fishing mortality from total mortality. Estimates of F and T were derived by monitoring the decay of a cohort over time as described in section 2.1. Values of M derived from estimates of population and exploitation rates were made using abundance estimates from the 1979, 1982, 1985, and 1988 U.S. / Japan bottom trawl and hydroacoustic surveys. To avoid problems associated with gear selectivity, only data for fully recruited age groups (age 4 to 9) were used. Catch estimates were made by assuming that the catch was evenly divided into the first and second half of the year. Annual time steps were initiated in the middle of the year since the surveys were conducted in the summer. Estimates of natural mortality for different cohorts had mean values from 0.346 to 0.429 with an average of 0.375 (Table 4).

4.2 Application of Life History Methods

Estimates of natural mortality were calculated using the methods of Alverson and Carney (1975) and Pauly (1980). Alverson and Carney (1975) suggested that a first approximation of natural mortality rate (M) could be based on the time a cohort maximizes its aggregate weight and the theoretical age maximum. The relationship between these factors is mathematically described as:

$$M = 3K / [\exp(0.38 * T_{max} * K) - 1]$$

Where T_{max} is the maximum observed age in an unfished population, and K is the von Bertalanffy growth parameter.

Pauly (1980) noted that the growth parameter K is directly related to longevity and that temperature should influence natural mortality. Using multiple regression techniques he related von Bertalanffy growth parameters and ambient water temperature to M.

$$\log_{10}(M) = -0.0066-0.279(\log_{10}(L_\infty))+0.6543(\log_{10}(K))+0.4634(\log_{10}(T))$$

where L_∞ is the asymptotic length parameter of the von Bertalanffy growth equation, and T is the mean ambient temperature.

Estimates of Bering Sea pollock natural mortality were derived using the techniques described and parameters from various sources. Growth parameters were obtained from the analysis of length at age data collected from surveys in 1979, 1981, 1982, 1985, 1986, 1988, and 1989. Temperature was assumed to be 3°C which corresponds to the temperature at which CPUE (number / hectare) was maximized (Figure 4). The maximum theoretical age was assumed to be 14.

Estimates of natural mortality based on the Alverson and Carney (1975) method ranged from 0.23 to 0.45 (Table 5). The mean value of M for males and females was 0.33 and 0.36 respectively (Table 5).

There was some concern that the estimate of maximum age (T_{max}= 14) was not representative of the old fish observed in the Aleutian Basin. For comparison, the analysis was repeated using a maximum age of 25. The estimates of M from this analysis were much lower ranging from 0.06 to 0.21 (Table 6). The mean value of M for males and females was 0.12 and 0.14 respectively (Table 6).

The average estimates of natural mortality for males and females calculated using the Pauly method were 0.17 and 0.15 respectively (Table 7). These estimates were similar to values derived using the Alverson and Carney (1975) method when T_{max} was 25 years (Table 6).

4.3 Summary of Estimates of Natural Mortality

Estimates of natural mortality for walleye pollock range from 0.06 to 0.59 (Table 8). In general, most estimates were between 0.25 and 0.35. Based on this information the estimate of M = 0.3 presented by Wespestad et. al. (1990) appears to be reasonable for fish age 4 and above. The Korean delegation suggested that given the uncertainty in the true estimate of natural mortality, a range of values should be utilized in stock assessments.

Some participants advocated using 0.3 for the shelf stocks and 0.2 for the basin stock. Several scientist questioned the validity of this assumption. If pollock in the Basin represent a separate stock with distinct growth patterns and longevity then applying a lower natural mortality to these fish may be justified. However, if pollock in the Basin represent some fraction of the shelf stock, or if the Basin fish are migrating through the basin then a single natural mortality coefficient should be employed. Additional information on the stock structure of Bering Sea pollock is necessary to resolve this issue.

5.0 APPLICATION OF PREDATION METHODS

Considerable effort has been devoted to the study of trophic interactions between major fish species in the Bering Sea. A total of 81,007 stomachs were examined at the Alaska Fisheries Science Center since 1983 (Table 9). Of these, over 32,000 pollock stomachs were examined (Table 9). The availability of information on the feeding habits of marine fish in the Bering Sea provides an opportunity for identifying the components of natural mortality. Bax and Laevastu (1990) provided an example of this type of compartmentalization of mortality. These authors estimated 60.6% of the predation mortality of pollock was attributed to cannibalism (Figure 5).

In order incorporate information on predation mortality, estimates of the predation pressure at age or size must be evaluated. Gorbatenko and Dolganova (1989), Livingston (1989), and Mito (1989) all studied the feeding behavior of pollock. Gorbatenko and Dolganova (1989) studied the feeing behavior of sexually mature walleye pollock in various regions of the Okhotsk Sea in autumn. These authors found the adult pollock preyed on a wide range of food items. Euphausiids were the main group of zooplankton consumed and juvenile fishes and squids were probably secondary food items. Gorbatenko and Dolganova (1989) also noted that the primary prey item consumed varied considerably by region (Figure 6). The size range of juvenile pollock consumed by adult pollock in the Okhotsk Sea ranged from 30-140mm.

Livingston (1989) studied the food habits of pollock from 1981 - 1987. She observed that pollock 40cm and above had a higher frequency of cannibalism than smaller pollock. The incidence of cannibalism was most prevalent in the autumn season followed by summer, winter and spring. Because of the patchiness of sampling it was difficult to define geographical trends in cannibalism. However, cannibalism was observed most frequently in the middle shelf area with bottom depths between 50-100m (Figures 7-11). The size range of pollock found in the stomachs of adult pollock varied by season (Figure 12). The modal size of pollock cannibalized in autumn was approximately 75mm; the size range of age 0 and 1 year old pollock. Estimates of the number of pollock cannibalized shows appears to be related to year class strength (Figure 13).

Mito (1990) presented data that conflicts with the results of Livingston (1990). Based on an analysis of approximately 32,000 stomachs, Mito examined year, season and size effects on the incidence of cannibalism of Bering Sea pollock. The results of this analysis indicated that in addition to 0 and 1 year old fish, age 2 and 3 year old fish were also observed in the diet (Figure 14). Mito estimated age specific rates of mortality by cannibalism for shelf and basin populations (Table 10). These results show mortality due to cannibalism remains high at ages 2 and 3.

Honkalehto (1989) attempted to account for three important sources of natural mortality among fish populations; cannibalism, predation by marine mammals and other natural mortalities. The results of this study show the mean biomass at length would may be underestimated when cannibalism and marine mammal predation are not incorporated into assessment models.

Honkalehto (1989) applied a theoretical technique to estimate the critical size range of prey consumed by adult pollock. The critical size ratio technique was developed by Ursin (1973). The critical size ratio describes the prey size preference of predators as a log-normal frequency distribution of predator-weight divided by prey-weight. Honkalehto (1989) utilized the mean predator:prey weight ratio for cannibalistic silver hake (<u>Merluccius</u> <u>bilinearis</u>) estimated by Hahm and Langton (1980). Silver hake were assumed to exhibit feeding capabilities similar to walleye pollock. Using this relationship the mean size and the size at plus or minus one standard deviation (α) could be estimated. Assuming that the logarithm of the predator to prey ratio was 7.2 and the standard deviation was 2.11 (i.e. estimated values for silver hake), the majority of pollock cannibalized would be age 0 and 1 (Table 11).

6.0 SUMMARY

Estimates of natural mortality of pollock derived from catch analysis or life history methods were generally between 0.25 and 0.35. Therefore, the estimate of M = 0.3 presented by Wespestad et. al. (1990) appears to be reasonable for fish age 4 and above. The presence of old fish in the Aleutian Basin presented a dilemma for the workshop participants. Some participants advocated using a lower natural mortality rate for fish in the Basin. Other participants suggested that a single rate must be used until there is clear evidence that the Basin fish belong to a separate stock. Conflicting data regarding cannibalism of two and three year old fish was also presented. Mito (1990) found that in addition to 0 and 1 year old fish, 2 and 3 year old fish were cannibalized. Livingston (1989) and Gorbatenko and Dolganova (1989) found only 0 and 1 year old fish were consumed. Further studies are necessary to provide answers to these problems. Considering the uncertainty associated with the current estimates of natural mortality, a prudent approach may be to conduct stock assessments using a range of natural mortality coefficients.

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Table 1. Advantages and disadvantages of different methods of estimating natural mortality.

1. **Catch Analysis**

Grouping by Age:

Advantages: data readily accessible from fishery.

Disadvantages:
a. Groups must be adequately identifiable.
b. Populations must be closed to migration.
c. M must be relatively constant between age groups.
d. Compensatory relationships between stock abundance and M and fishing mortality and M must not be present.

Mark Recapture:

Advantages:
a. Concentration on measuring relative rather than absolute differences in abundance.
b. Immigration is not a problem.
c. With large sample sizes analysis of differences between groups can be examined (including differences at age, between sexes or between areas).

Disadvantages:
a. Mark induced effects on mortality, behavior, vulnerability to capture must be considered.
b. Mark loss.
c. Difficulty of tagging pollock in the Bering Sea.

2. **Estimation From Life History Parameters:**

Advantages:
a. Minimal data requirements.
b. Useful in demonstrating broad trends across species.

Disadvantages:
a. Estimates are imprecise.
b. Can not detect age specific differences in mortality.

3. **Predation Models:**

Advantages:
a. Age specific and year specific differences in mortality can be studied.

Disadvantages:
a. Difficulties in defining vulnerability an prey preference functions.
b. Requires time series of abundance for many species that are not commercially exploited.
c) The technique is most applicable when trophic interactions are simple (i.e. predators have few alternative prey) and predation is the major factor controlling prey abundance.

Table 2. Studies relating instantaneous rate of natural mortality to life history traits in fish. From Vetter (1988).

Life History Traits	Species	Source
[1]T_{max}, [2]K, [3]L_{∞}, metabolic rate, reproduction	various	Beverton and Holt 1959
T_{max}, K, L_{∞}, L_{asm}, fishing	clupeids, engraulids	Beverton 1963
[5]W_{∞}	general	Ursin 1967
T_{max}, [6]T_{maxb}, K,	general	Alverson and Carney 1975
growth rate	young fish	Ware 1975
L_{asm}, gonad size, conditon	gadoids	Jones and Johnston 1977
T_{max}	general	Blinov 1977
gonad/body weight index, [7]ASM, T_{max}, L_{∞}	general	Gunderson 1980, and Gunderson and Dygert 1988
W_{∞}, L_{∞}, K, water temperature	175 stocks	Pauly 1980
energy cost of reproduction	general	Myers and Doyle 1983
T_{max}	various	Hoenig 1983
weight	various	Peterson and Wroblewski 1983
K, L_{∞}, L_{asm}	various	Roff 1986

[1]Maximum age.
[2]von Bertalanffy growth parameter.
[3]Maximum length.
[4]Length at age of sexual maturity.
[5]Maximum weight.
[6]Age at occurrence of cohort's maximum biomass.
[7]Age of sexual maturity.

Table 3. Estimates of age specific natural mortality.

Age	Bakkala[1]	Mito 89[2]	Mito 90 I[3]	Mito 90 II[3]	Zolotov[4]	Horbowy
2	0.45	-	-	-	-	-
3	0.30	1.00	0.88	0.79	1.02	0.20
4	0.30	0.35	0.38	0.29	0.65	0.20
5	0.30	0.35	0.38	0.29	0.37	0.20
6	0.30	0.35	0.38	0.29	0.15	0.20
7	0.30	0.35	0.38	0.29	0.16	0.20
8	0.30	0.35	0.38	0.29	0.21	0.20
9	0.30	0.35	0.38	0.29	0.30	0.20

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Table 4. Estimates of natural mortality based catch analysis methods for monitoring the abundance of a cohort through time. The analysis was conducted by monitoring abundance and catch of fish over a three year interval using data from the 1979, 1982, 1985, and 1988 U.S.-Japan cooperative hydroacoustic and trawl surveys of the eastern Bering Sea and commercial catch data from the eastern Bering Sea.

Period	Ages	Catch (millions)	[1]U C / N	[2]F 3 yrs	[3]Z 3 yrs	[4]M annual
79 - 82	4 - 7	655.035	0.410	0.883	1.794	0.304
79 - 82	5 - 8	480.948	0.366	0.720	1.553	0.278
79 - 82	6 - 9	236.561	0.468	0.858	1.367	0.170
82 - 85	4 - 7	2,434.561	0.203	0.406	1.599	0.398
82 - 85	5 - 8	588.611	0.164	0.402	2.181	0.593
82 - 85	6 - 9	125.119	0.216	0.456	1.744	0.429
85 - 88	4 - 7	577.012	0.367	0.387	0.105	unr
85 - 88	5 - 8	821.059	0.175	0.350	1.597	0.416
85 - 88	6 - 9	568.473	0.174	0.360	1.681	0.440
Mean	4 - 7	-	-	-	-	0.351
Mean	5 - 8	-	-	-	-	0.429
Mean	6 - 9	-	-	-	-	0.346

[1] Exploitation rate [2] Fishing mortality rate
[3] Total mortality [4] Natural mortality

Table 5. Parameters used to estimate natural mortality based on the Alverson and Carney method.

Year Class	Nation	Gear	Sex	Tmax	K	M
1979	US		M	14	0.21	0.31
1979	Japan		M	14	0.08	0.45
1981	US		M	14	0.21	0.31
1981	Japan		M	14	0.27	0.25
1982	US	Btm Trw	M	14	0.16	0.36
1982	US	Midwater	M	14	0.28	0.24
1982	Japan		M	14	0.18	0.34
1985	US/JPN	Btm Trw	M	14	0.14	0.38
1985	US	Midwater	M	14	0.30	0.23
1986	US	Btm Trw	M	14	0.13	0.39
1988	US	Btm Trw	M	14	0.20	0.32
Mean			M			0.33

Year Class	Nation	Gear	Sex	Tmax	K	M
1979	US		F	14	0.21	0.31
1979	Japan		F	14	0.12	0.40
1981	US		F	14	0.21	0.31
1981	Japan		F	14	0.18	0.34
1982	US	Btm Trw	F	14	0.15	0.37
1982	US	Midwater	F	14	0.21	0.31
1982	Japan		F	14	0.12	0.40
1985	US/JPN	Btm Trw	F	14	0.14	0.38
1985	US	Midwater	F	14	0.18	0.34
1986	US	Btm Trw	F	14	0.11	0.41
1988	US	Btm Trw	F	14	0.15	0.37
Mean			F			0.36

Table 6. Parameters used to estimate natural mortality based on the Alverson and Carney method.

Year Class	Nation	Gear	Sex	Tmax	K	M
1979	US		M	25	0.21	0.10
1979	Japan		M	25	0.08	0.21
1981	US		M	25	0.21	0.10
1981	Japan		M	25	0.27	0.07
1982	US	Btm Trw	M	25	0.16	0.13
1982	US	Midwater	M	25	0.28	0.06
1982	Japan		M	25	0.18	0.12
1985	US/JPN	Btm Trw	M	25	0.14	0.15
1985	US	Midwater	M	25	0.30	0.06
1986	US	Btm Trw	M	25	0.13	0.16
1988	US	Btm Trw	M	25	0.20	0.11
Mean			M			0.12

Year Class	Nation	Gear	Sex	Tmax	K	M
1979	US		F	25	0.21	0.10
1979	Japan		F	25	0.12	0.17
1981	US		F	25	0.21	0.10
1981	Japan		F	25	0.18	0.12
1982	US	Btm Trw	F	25	0.15	0.14
1982	US	Midwater	F	25	0.21	0.10
1982	Japan		F	25	0.12	0.17
1985	US/JPN	Btm Trw	F	25	0.14	0.15
1985	US	Midwater	F	25	0.18	0.12
1986	US	Btm Trw	F	25	0.11	0.18
1988	US	Btm Trw	F	25	0.15	0.14
Mean			F			0.14

Table 7. Parameters used to estimate natural mortality based on the Pauly method.

Year Class	Nation	Gear	Sex	TEMP	K	L_∞	M
1979	US		M	3	0.21	66.90	0.18
1979	Japan		M	3	0.08	118.40	0.08
1981	US		M	3	0.21	72.00	0.18
1981	Japan		M	3	0.27	59.90	0.22
1982	US	Btm Trw	M	3	0.16	78.50	0.15
1982	US	Midwater	M	3	0.28	53.70	0.23
1982	Japan		M	3	0.18	67.00	0.17
1985	US/JPN	Btm Trw	M	3	0.14	82.10	0.13
1985	US	Midwater	M	3	0.30	52.60	0.25
1986	US	Btm Trw	M	3	0.13	81.81	0.13
1988	US	Btm Trw	M	3	0.20	63.60	0.18
Mean			M				0.17

Year Class	Nation	Gear	Sex	TEMP	K	L_∞	M
1979	US		F	3	0.21	69.51	0.18
1979	Japan		F	3	0.12	105.64	0.11
1981	US		F	3	0.21	75.80	0.18
1981	Japan		F	3	0.18	74.30	0.16
1982	US	Btm Trw	F	3	0.15	85.00	0.14
1982	US	Midwater	F	3	0.21	63.20	0.19
1982	Japan		F	3	0.12	86.10	0.12
1985	US/JPN	Btm Trw	F	3	0.14	89.80	0.13
1985	US	Midwater	F	3	0.18	63.50	0.17
1986	US	Btm Trw	F	3	0.11	93.05	0.11
1988	US	Btm Trw	F	3	0.15	74.50	0.14
Mean			F				0.15

Table 8. Comparison of natural mortality estimates for fish age 4 and above.

Method	Methodology	Location	Sex	Range	Mean
Alverson and Carney (1975)	Life History Parameters	Eastern Bering Sea	Female	0.31 - 0.41	0.36
	Tmax equal to 14 years	Eastern Bering Sea	Male	0.23 - 0.45	0.33
Alverson and Carney (1975)	Life History Parameters	Eastern Bering Sea	Female	0.10 - 0.18	0.14
	Tmax equal to 25 years	Eastern Bering Sea	Male	0.06 - 0.21	0.12
Pauly (1980)	Life History Parameters	Eastern Bering Sea	Female	0.11 - 0.19	0.15
		Eastern Bering Sea	Male	0.08 - 0.22	0.17
Present Study	Catch Analysis	Eastern Bering Sea		0.17 - 0.59	0.38
Mito (1989, 1990)	Catch Analysis	Eastern Bering Sea		0.29 - 0.38	-
Horbowy and Janusz (1990)	Catch Analysis	Aleutian Basin		-	0.20
Wakabayashi growth parameter	Life History Parameters	Hokkaido, Japan		0.20 - 0.32	-
Hollowed and Megrey (1990)	Life History Parameters	Gulf of Alaska		0.22 - 0.32	-
Zolotov and Antonov (1989)	Unknown	Kamchatka & Kuril Is.		0.15 - 0.65	-
Bakkala et. al. (1987)	Catch Analysis	Eastern Bering Sea		-	0.30

Table 9. Number of stomachs scanned and analyzed by the Alaksa Fisheries Science Center from 1983 - 1990.

Species	Scanned	Analyzed	Total
Yellowfin sole	683	12,115	12,798
Walleye pollock	25,194	7,500	32,694
Pacific cod	545	10,125	10,670
Arrowtooth flounder	174	4,974	5,148
Greenland turbot	435	2,192	2,627
Flathead sole	1,059	6,436	7,495
Pacific halibut	0	624	624
Rock sole	660	584	1,244
Alaska plaice	643	430	1,073
Other species	6,441	193	6,634
Total	35,834	45,173	81,007

Table 10. Estimates of mortality rates by cannibalism by Mito (1990).

Age	Continental Shelf M Cannibalism	Basin M Cannibalism
0	1.48 (89%)	1.58 (89%)
1	0.93 (73%)	1.31 (79%)
2	2.36 (87%)	3.01 (90%)
3	0.66 (65%)	0.00

Table 11. Geometric mean weight at length form Bering Sea walleye pollock and estimates of mean size of prey based on the critical size ratio technique.

Length (cm)	Predator[1] Weight range (g)	(g)	Mean Weight (g)	Prey[2] Mean (g)	$-\alpha$ (g)	$+\alpha$ (g)
0-5	0.007 -	0.90	0.16	-	-	-
6-10	1.55 -	7.11	2.65	-	-	-
11-15	9.45 -	23.78	14.60	0.011	0.001	0.089
16-20	28.80 -	56.00	40.00	0.030	0.004	0.246
21-25	64.76 -	108.82	84.00	0.063	0.008	0.517
26-30	122.30 -	187.26	151.00	0.113	0.014	0.930
31-35	206.46 -	296.31	256.00	0.191	0.023	1.576
36-40	322.24 -	440.96	374.00	0.279	0.034	2.303
41-45	474.59 -	626.15	543.00	0.405	0.049	3.344
46-50	668.48 -	856.83	755.00	0.564	0.068	4.649
51-55	908.86 -	1137.94	997.00	0.744	0.090	6.140
56-60	1200.70 -	1474.41	1298.00	0.969	0.117	7.993
61-65	1548.80 -	1871.13	1658.00	1.238	0.150	10.210
66-70	1958.10 -	2333.02	2076.00	1.550	0.188	12.784
71-75	2433.60 -	2864.96	2530.00	1.889	0.229	15.580
76-80	2980.20 -	3471.84	3043.00	2.272	0.275	18.739
81-85	3602.60 -	4158.55	3677.00	2.745	0.333	22.643

1. Length - weight relationship $L = a\ W^b$ a=0.0075, b=2.977 from Smith (1981).

2. Estimated prey weight from critical size ratio where the critical size (CZ) equals $\ln(W_{pred} / W_{prey}) = CZ$.

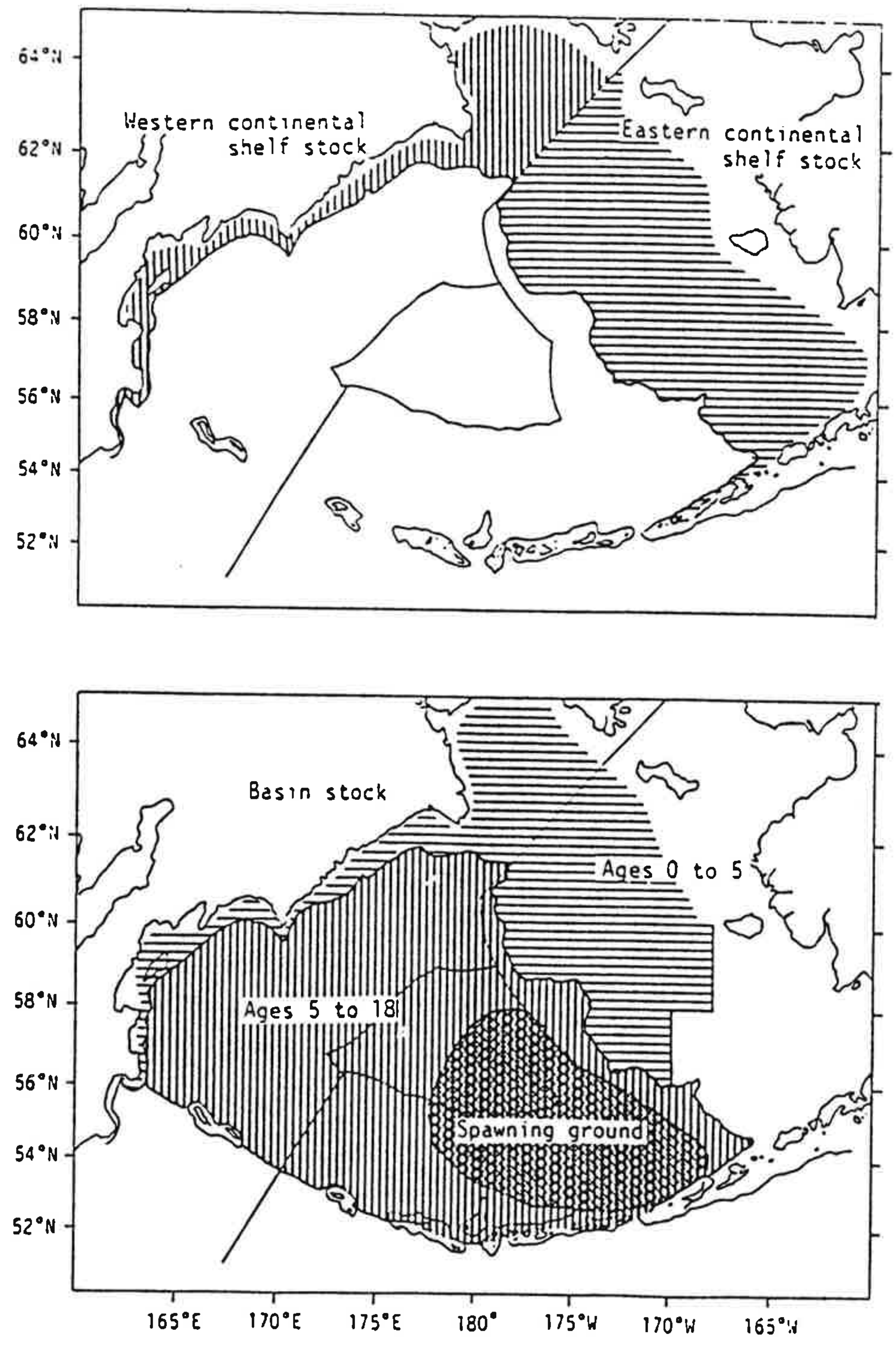

Figure 1. Schematic distribution of the assumed three stocks of pollock in the Bering Sea. From Mito (1990).

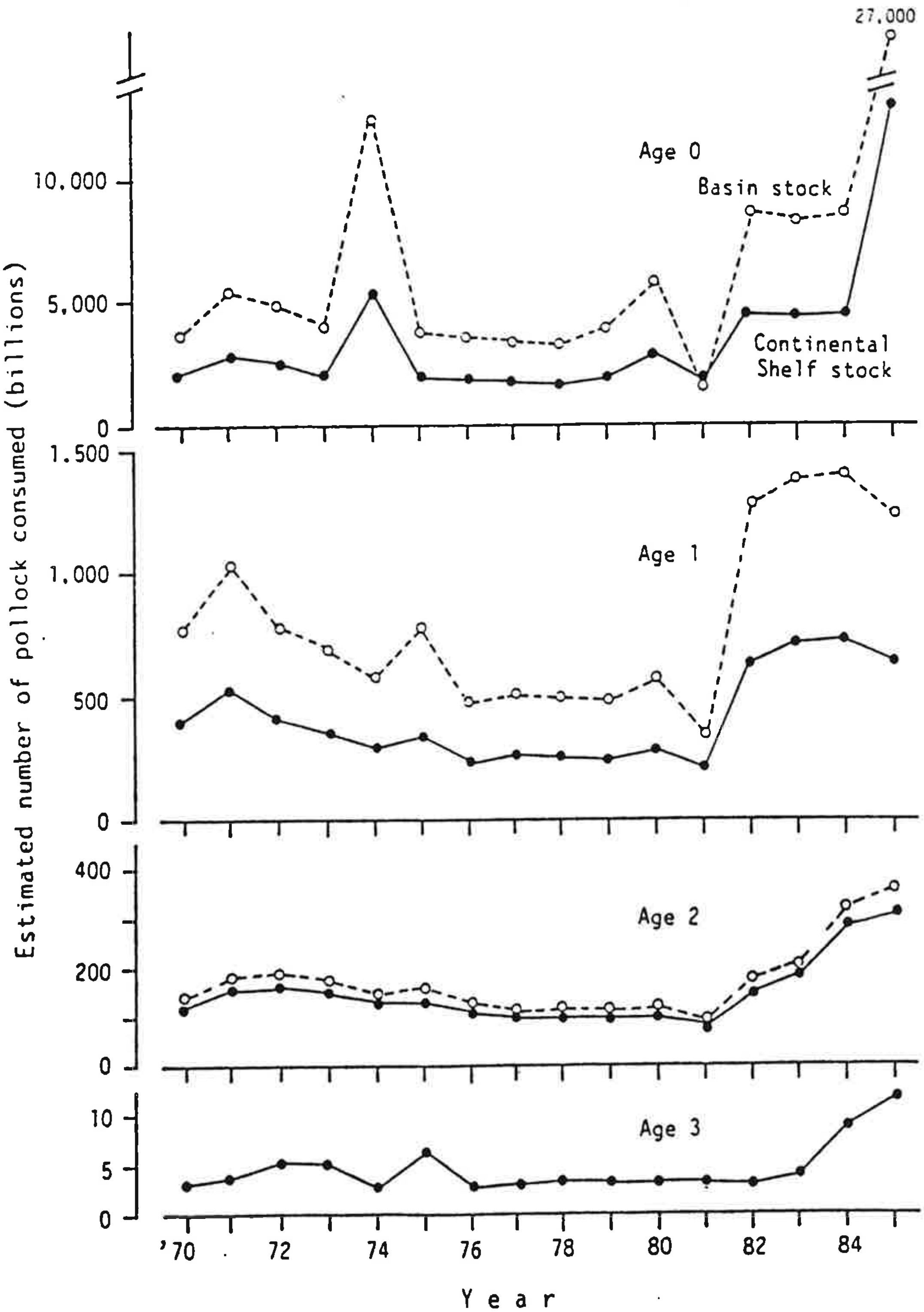

Figure 2. Annual change of consumption number of cannibalism by stock and age of pollock in the Bering Sea. From Mito (1990).

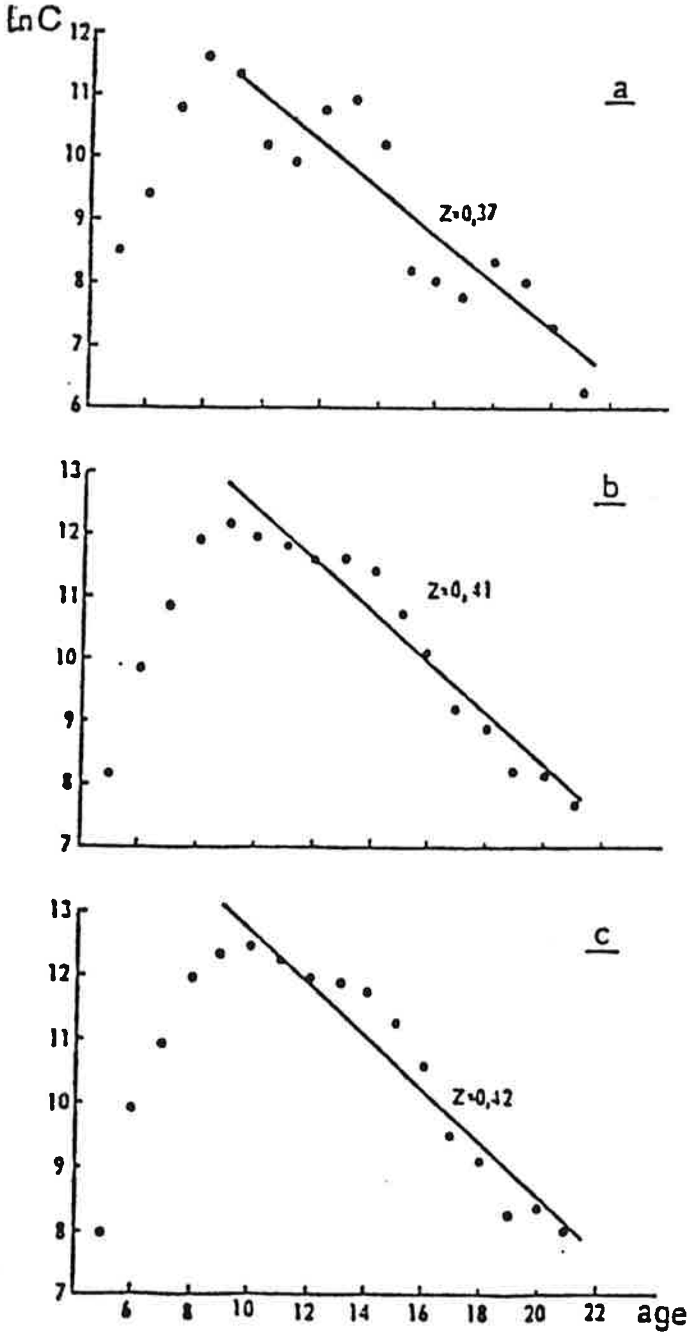

Figure 3. Catch curves for walleye pollock taken in international waters of the Bering Sea.: a) catch curve for 1985, b) mean catch curve for 1985-1989, and c) mean catch curve for 1986-1989. From Horbowy and Janusz (1990).

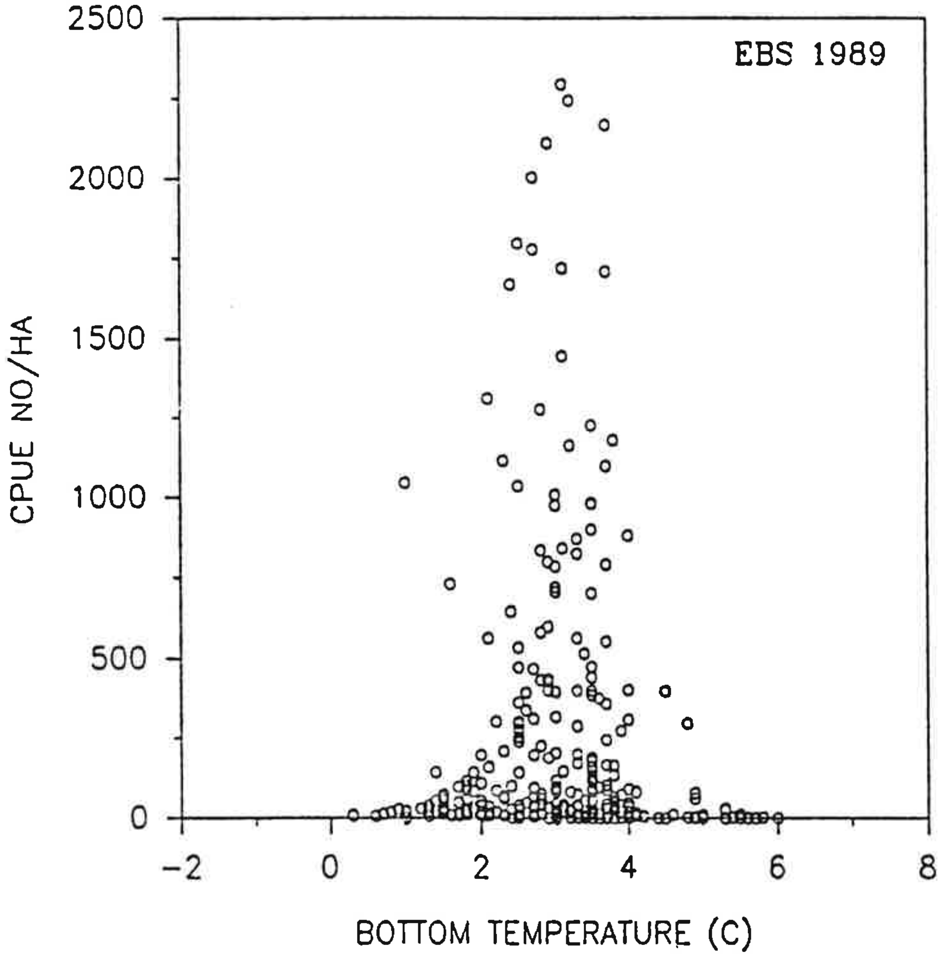

Figure 4. Catch per unit effort (CPUE) of pollock from the 1989 Eastern Bering Sea bottom trawl survey in relation to ambient temperature.

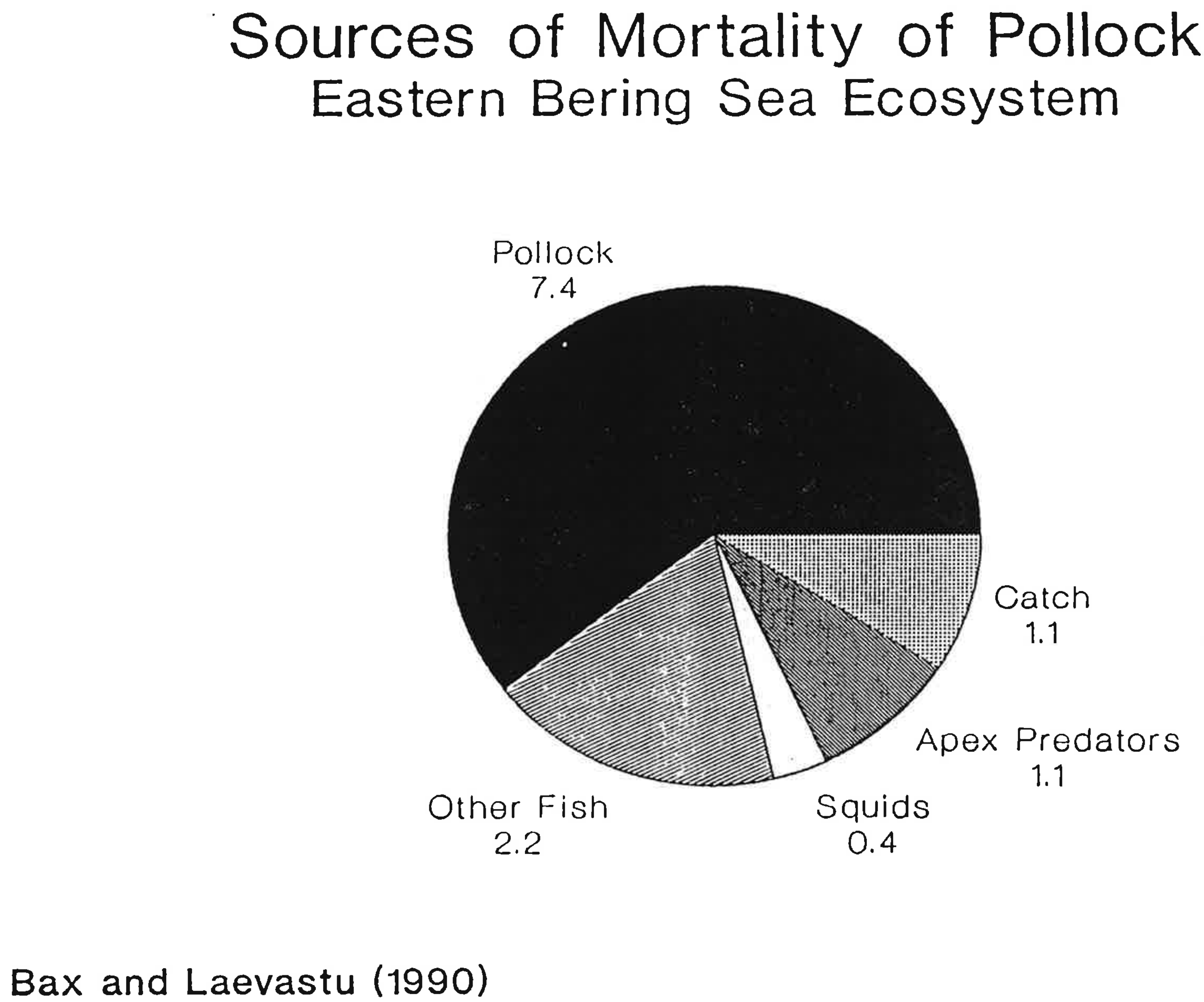

Figure 5. Estimated sources of predation mortality for pollock in the Bering Sea. From Bax and Laevastu (1990).

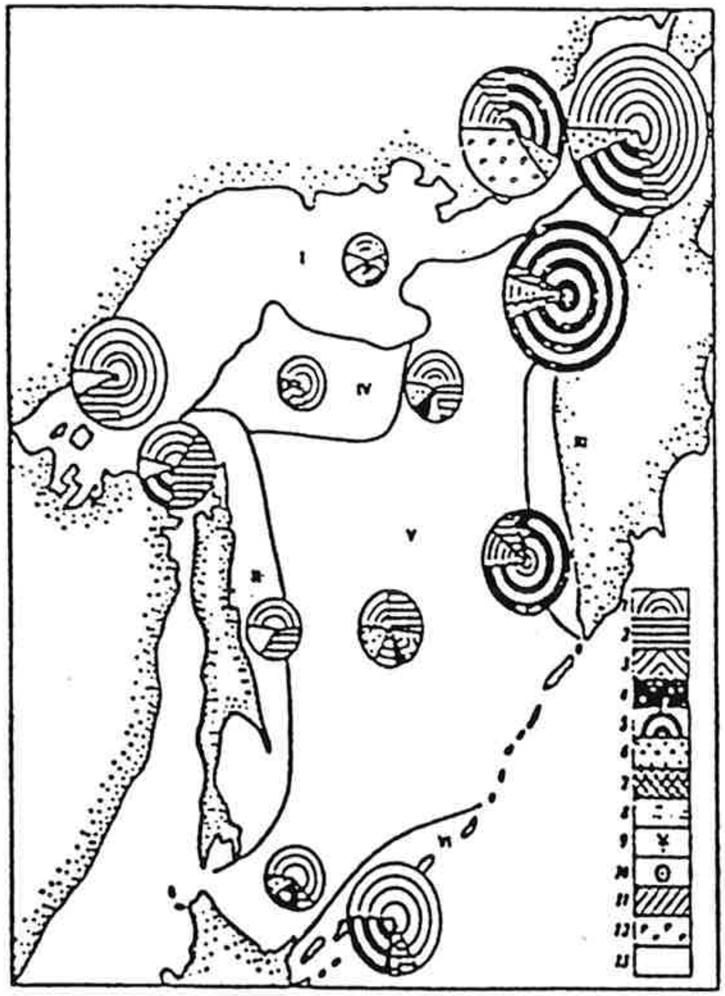

Figure 6. Composition of the food of the sexually mature walleye pollock (% by weight) in the various regions of the Okhotsk Sea (see Table 1 for the designation of the regions). 1) Euphausiids; 2) amphipods; 3) chaetognaths; 4) squids; 5) fishes; 6) copepods; 7) coelenterates; 8) pteropods; 9) crab larvae; 10) mysids; 11) ctenophores; 12) decapods; 13) miscellaneous. The area of each circle corresponds to the stomach content index: 80-130‰ for a radius of 5mm, 130-1809 for 10mm, 180-230 for 15mm. From Gorbatenko and Dolganova (1989).

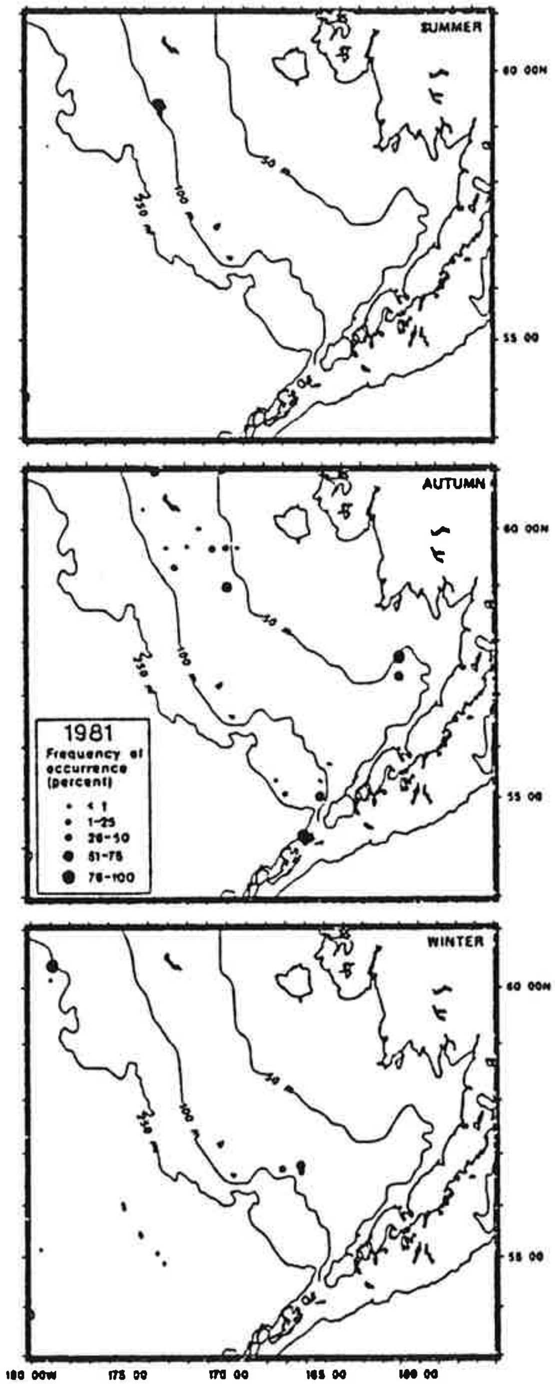

Figure 7. Percent frequency of occurrence of cannibalism by walleye pollock, Theragra chalcogramma, by geographic location during summer, autumn, and winter of 1981 in the eastern Bering Sea using stomach collection data. From Livingston (1989).

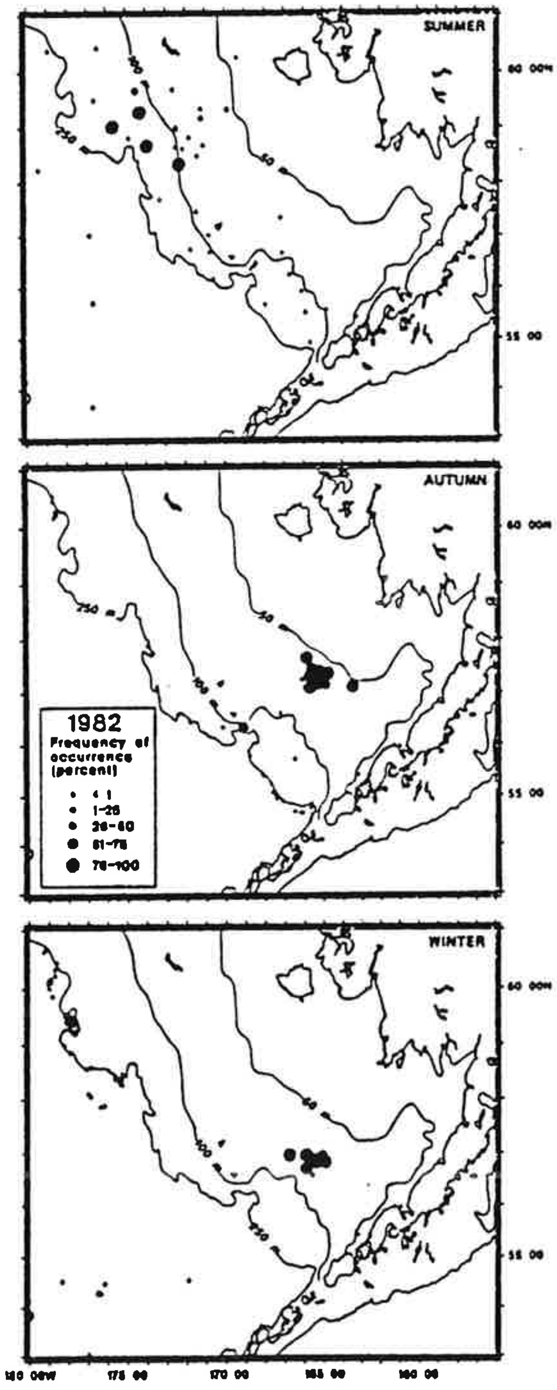

Figure 8. Percent frequency of occurrence of cannibalism by walleye pollock, <u>Theragra</u> <u>chalcogramma</u>, by geographic location during summer, autumn, and winter of 1982 in the eastern Bering Sea using stomach collection data. From Livingston (1989).

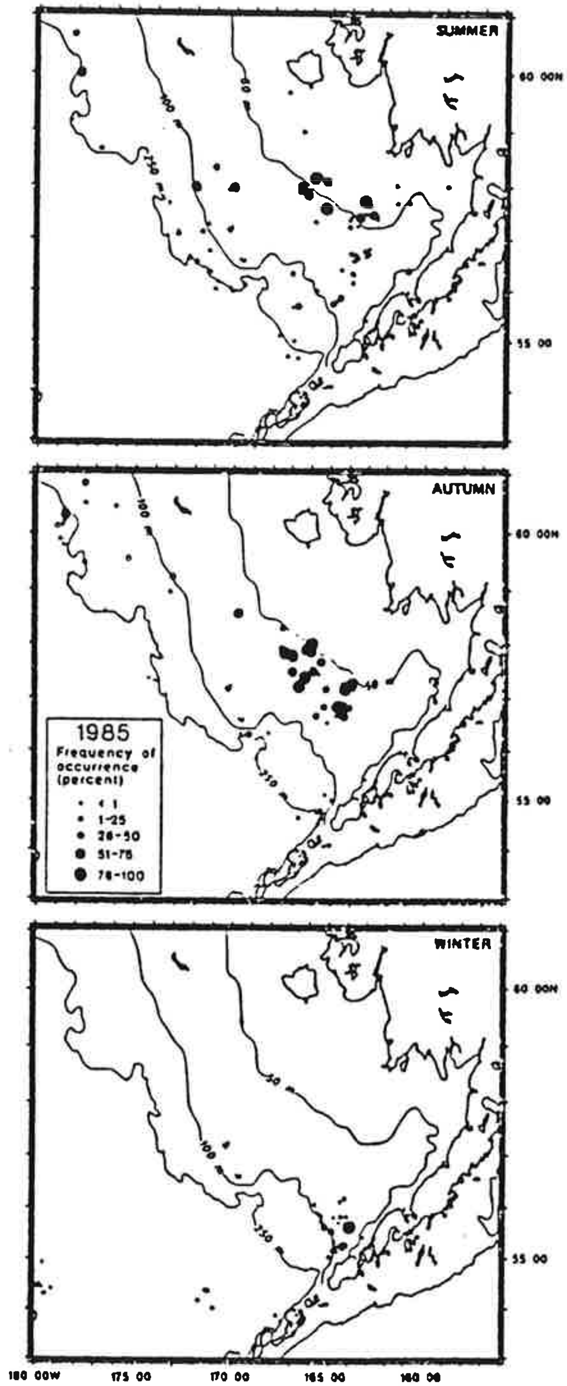

Figure 9. Percent frequency of occurrence of cannibalism by walleye pollock, Theragra chalcogramma, by geographic location during summer, autumn, and winter of 1985 in the eastern Bering Sea using stomach collection data. From Livingston (1989).

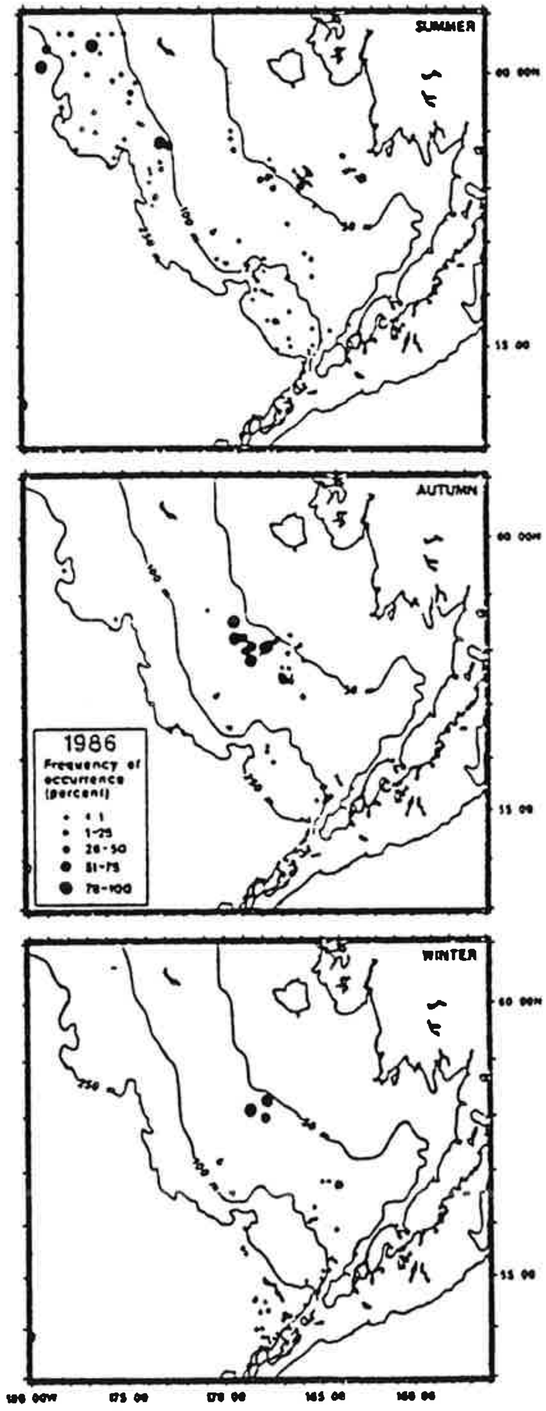

Figure 10. Percent frequency of occurrence of cannibalism by walleye pollock, <u>Theragra</u> <u>chalcogramma</u>, by geographic location during summer, autumn, and winter of 1986 in the eastern Bering Sea using stomach collection data. From Livingston (1989).

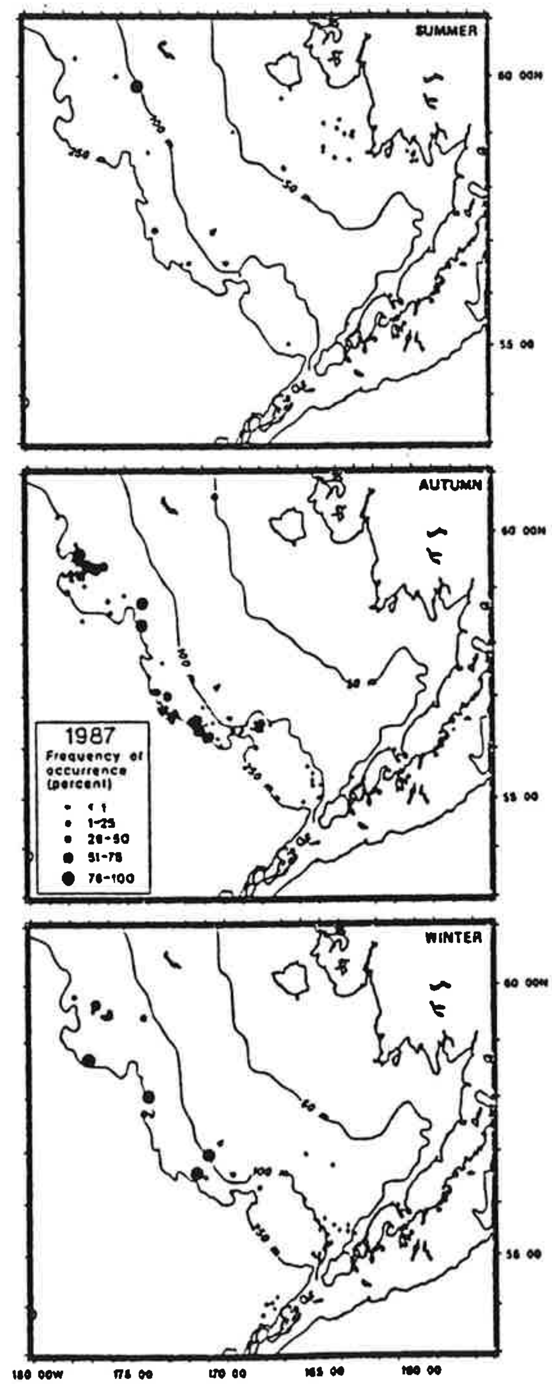

Figure 11. Percent frequency of occurrence of cannibalism by walleye pollock, Theragra chalcogramma, by geographic location during summer, autumn, and winter of 1987 in the eastern Bering Sea using stomach collection data. From Livingston (1989).

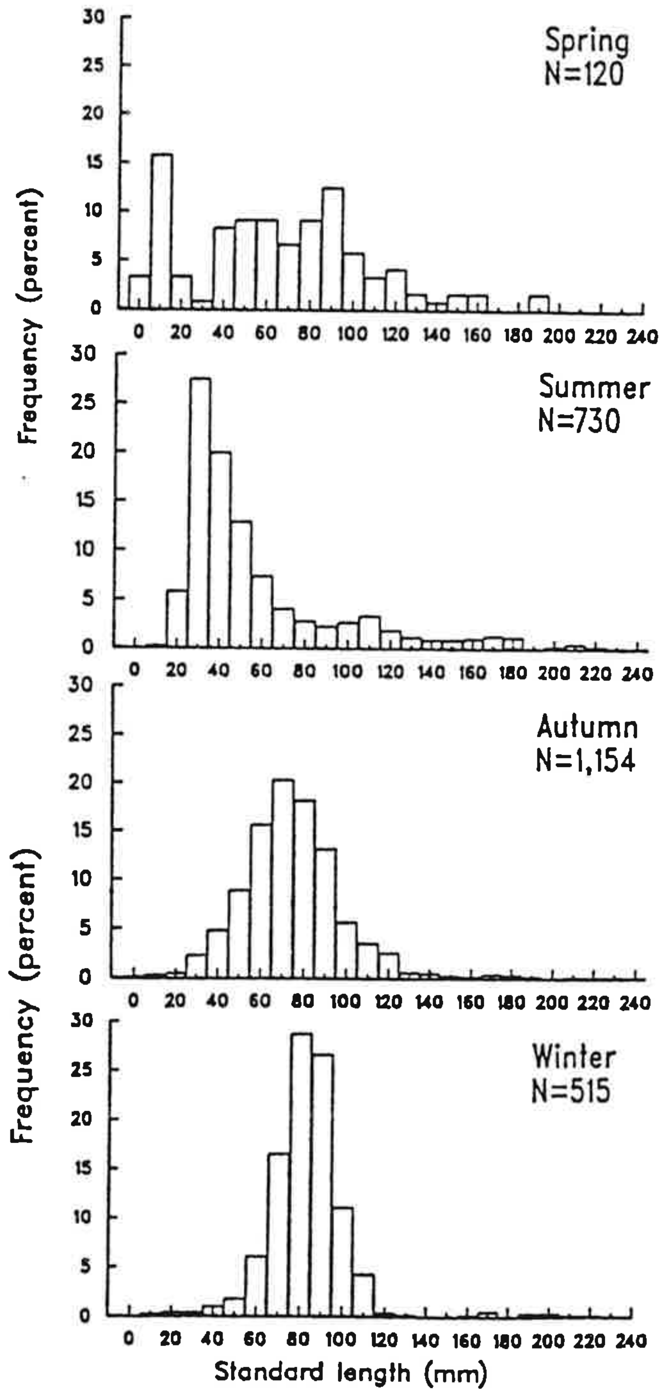

Figure 12. Seasonal size frequency distribution of juvenile walleye pollock, Theragra chalcogramma, consumed by adults in the eastern Bering Sea from quantitative scan data and stomach collections taken from 1981-1987. From Livingston (1989).

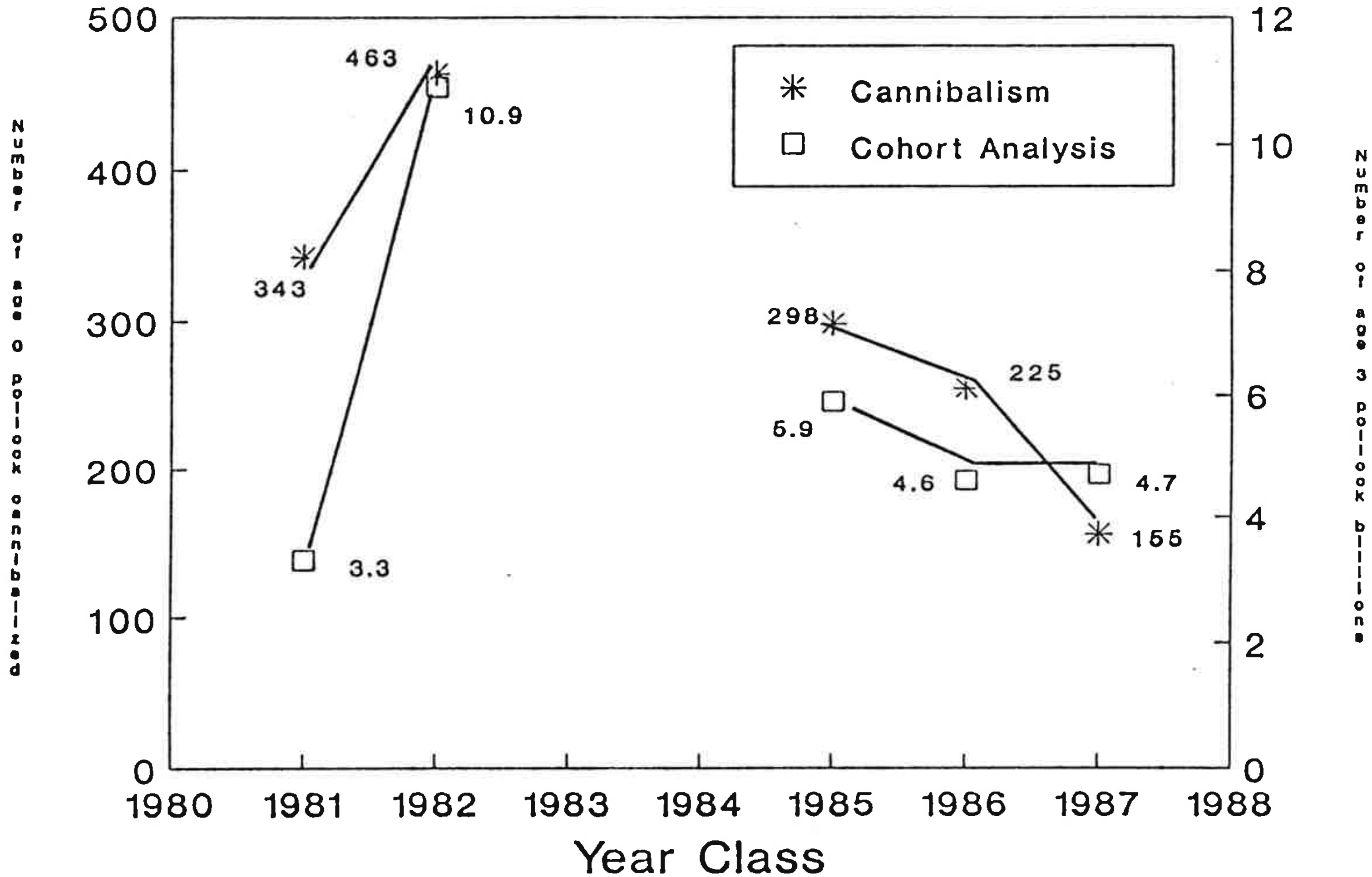

Figure 13. Total number of age 0 walleye pollock, <u>Theragra chalcogramma</u>, cannibalized during autumn compared with cohort analysis estimates of the age 3 population for each yearclass from the years 1981-1982 and 1985-1987 in the eastern Bering Sea.

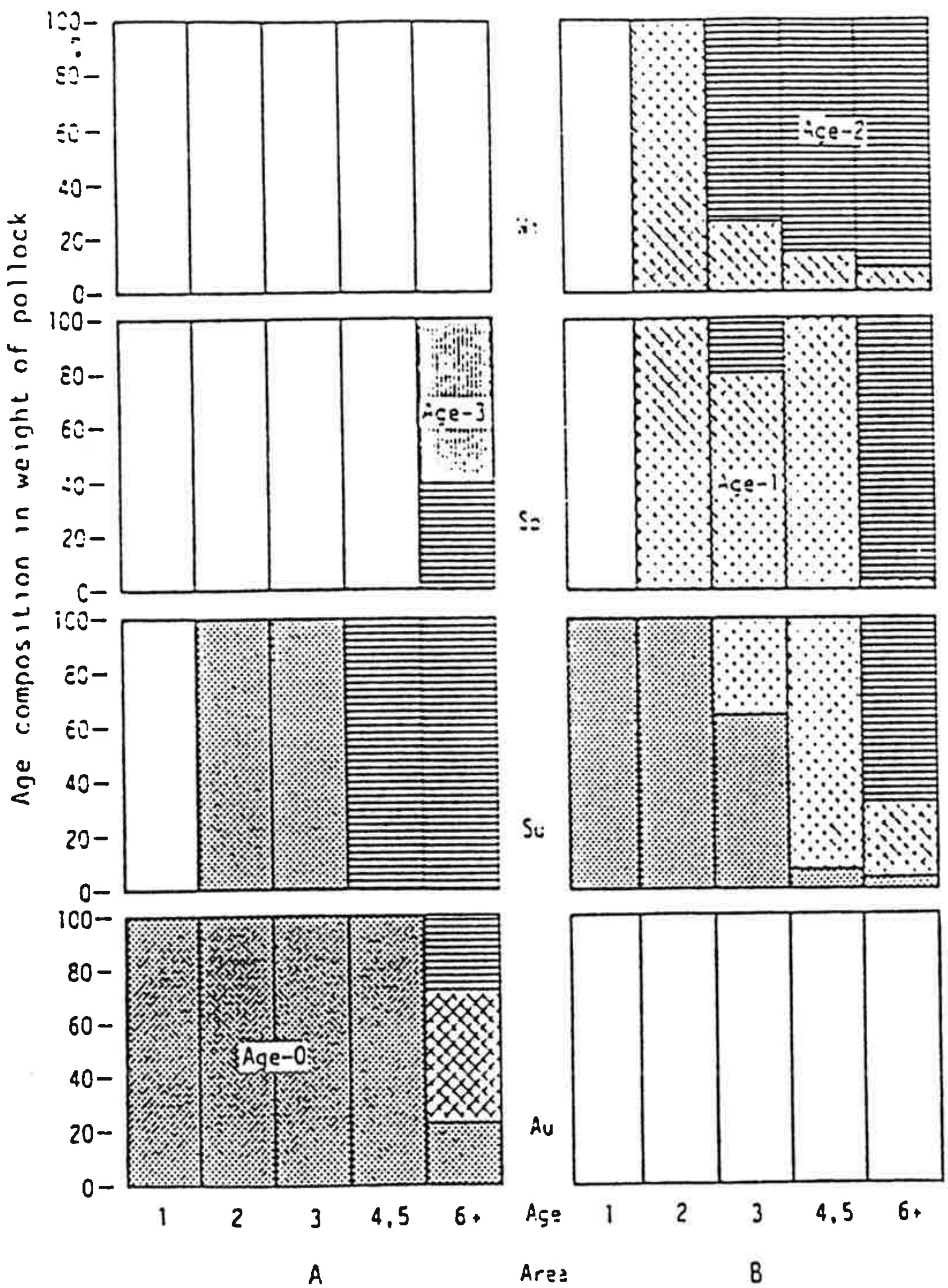

Figure 14. Age composition of pollock in weight consumed by pollock by area, season and age of pollock in the Bering Sea. From Mito (1990).

MODULE D

Module D: Age and Growth

Facilitator: Dan Kimura

The facilitator reviewed the "Report from the workshop on ageing methodology of walleye pollock (Theragra chalcogramma) held at the Sea Fisheries Institute in Gdynia, Poland, September 10-14, 1990." (Supplement D.1) This workshop was held at the direct request of the participants at the Khabarovsk Symposium held April 2-5, 1990, in the Soviet Union. The participating countries at this workshop, Canada, Japan, P.R.C., Poland, and the U.S. were able to agree on two substantive matters:

1. Considering both the time preparing structures, and the quality of resulting age data, the participants unanimously agreed that under our present knowledge that the break and burn method provides the best method for ageing walleye pollock.

2. The participants unanimously agreed that scale ages seriously underage walleye pollock.

Two areas of needed research were also identified:

1. The identification of the first annulus appears to be a problem. For example, were the dominant year-classes 1972 or 1973, and 1977 or 1978, or both?

2. The break and burn method for walleye pollock needs to be validated.

Dr. Fadeev raised several questions concerning the break and burn otolith method of ageing walleye pollock. He asked if there were any differences in the left and right otoliths, and when ring formation occurred. B. Goetz responded that usually both otoliths were examined before one is selected for ageing. She also noted that there is no known differences in the two structures for the purposes of ageing. J. Lyons indicated that the timing of annulus formation is dependent on the age of the fish, and forms from March to July. It was also asked if the existence of strong year-classes did not contradict older ages. The facilitator commented that this might have been so at one time, but probably now most fisheries biologists can accept the possibility of the existence of strong year-classes and older ages.

It was pointed out that we used to think pollock lived to be 15-16yr old, and few fish live beyond 10-11yr, but now we have doubts. Dr. Fadeev then summarized the results of several ageing method studies performed in the Soviet Union, at TINRO. These studies showed scales age ranges were consistently lower than otolith age ranges. Size at age differed greatly by ageing method and even by reader. It was thought that growth increment analysis did not completely support either the scale or otolith method of ageing.

Dr. Fadeev went on to summarize his thoughts on this matter. First, he concluded that there is no consistency in counting or eliminating rings (i.e. ageing criteria) for either the scale or otolith method of ageing. There have been descrepancies in the dominant year-classes when otoliths have been used (this was also noted at the workshop in Poland). He felt that the growth increment data suggested that the scale method undercounted the annular rings, while the otolith method added additional rings that were not annular. Finally, Dr. Fadeev suggested that age structure cannot be used to delineate stocks, and he suggested that the current ages must be used cautiously in any stock assessments.

Dr. Horbowy raised a question as to the validity of using growth increments in length frequencies to validate an ageing method. He pointed out that a length category will generally consist of several ages. A suggestion was made that an analysis using distribution mixtures would be more valid, but still very approximate.

Dr. Sasaki noted that age-length keys were available for the Bogoslof, Shelf, and Doughnut Hole areas, but what about the Western Bering Sea?

Because scale data appears to be available from the Western Bering Sea, Dr. Methot described how the Stock Synthesis Model can be used to interpret scale ages ages in a way that is consistent with otolith ages.

Dr. Lee noted that the Republic of Korea has been ageing eastern Bering Sea pollock since 1977 using scales. Since 1985, both scales and otoliths have been collected from the Doughnut Hole. Korea plans to age the Doughnut Hole pollock using the methods recommended by the ageing workshop.

The facilitator noted that the AFSC had changed ageing criteria immediately before the workshop on ageing held in Poland. The criteria change was to count ages on the "foot" area of the otolith (See McFarlane and Beamish 1990, p50). This will provide older ages for some of the fish over 10yr of age. The correctness of this procedure is under some debate in the literature (Gauldie and Nelson 1990), but this is AFSC's current ageing method.

References:

McFarlane, G.A., and R.J. Beamish. 1990. An examination of age determination structures of walleye pollock (Theragra chalcogramma) from five stocks in the northeast Pacific Ocean. I.N.P.F.C Bulletin Number 50.

Gauldie, R.W., and D.G.A. Nelson. 1990. Otolith growth in fishes. Comp. Biochem. Physiol. Vol 97A, No. 2, p119-135.

SUPPLEMENT D.1

Supplement D.1 includes the complete "Report from the Workshop on Ageing Methodology of Walleye Pollock (*Theragra chalcogramma*)" held in Gdynia, Poland in September of 1990. This document consists of:

1. Report text pages 1-11.
2. Appendix 1 which contains 3 working papers.
3. Appendix 2-A map showing the location of walleye pollock reference samples.
4. Appendix 3-A list of workshop participants.

Report From The Workshop On Ageing Methodology Of Walleye Pollock (*Theragra chalcogramma*)

Held at the Sea Fisheries Institute
Gdynia, Poland
September 10-14, 1990

At the Khabarovsk Symposium, held April 2-5, 1990, a research plan for Donut Hole pollock in the Bering Sea was adopted. The first item in this plan was that a workshop on ageing methodology be convened in Poland during 1990 to standardize age determination techniques for walleye pollock. Such a meeting was held from Sept. 10-14, 1990, at the Sea Fisheries Institute, Gdynia, Poland. The participants were:

1. Canada, Dr. Richard J. Beamish, Pacific Biological Station.

2. Japan, Dr. Akira Nishimura, Mr. Taku Yoshimura, Institute For Far Seas Fisheries, Shimizu.

3. Peoples Republic of China, Mr. Ren Shengmin, Yellow Sea Fisheries Institute, Qingdao.

4. Poland, Dr. Tomasz B. Linkowski, Dr. Jerzy Janusz, Ms. Magdalena Kowalewska-Pahlke, Ms. Barbara Szostakiewicz, Sea Fisheries Institute, Gdynia.

5. United States, Dr. Daniel K. Kimura, Ms. Julie Lyons, Alaska Fisheries Science Center, Seattle.

Dr. R.J. Beamish presented preliminary data to show that accurate estimates of strong year classes are important in the understanding of the effects of climate changes on recruitment. Mr. R. Shengmin presented a paper titled: Age determinations of walleye pollock based on otoliths in the eastern Bering Sea. The Japanese participants gave a presentation titled: Scanning electron microscope observations of the polished surface of the otolith of adult walleye pollock in the Aleutian Basin. And the U.S. participants presented three working papers (Appendix 1). In addition, ageing criteria for walleye pollock were discussed using photographic prints and slides provided by the Sea Fisheries Institute.

Two otolith reference samples were prepared for this meeting:

1. The Alaska Fisheries Science Center (AFSC) prepared a sample of 125 otolith pairs collected from 4 areas of the Bering Sea and the Gulf of Alaska. These were either whole otoliths or break and burn otoliths.

2. The Sea Fisheries Institute (SFI) prepared a sample of 144 otolith thin sections, collected from areas of the Bering Sea, and the north Pacific.

The AFSC reference sample was aged prior to the meeting by age readers from Canada, Poland, and the U.S. prior to the meeting. This sample was aged during the meeting by the P.R.C. reader during the meeting. The SFI reference sample was aged prior to the meeting by three Polish age readers, and were aged during the meeting by age readers from the other participating countries. In addition, the Donut Hole subsample from the SFI reference sample was also aged using the break and burn method.

The results from the AFSC reference samples were very encouraging (Table 1). These results were judged to be very good considering that age readers came from distant countries and generally have not had opportunities to work together.

The results from ageing the SFI reference sample was also thought to be good (Table 2). Again, considering that readers were from distant countries and did not have the opportunity to work together, reader agreement was thought to be quite good. The Donut Hole subsample of the SFI reference sample was also aged using the break and burn method (Table 3). The comparison of thin section and break and burn ages from this sample showed that ages compared quite well, but with the thin section method, on average, providing ages slightly older than the break and burn method.

Considering both the time preparing structures, and the quality of resulting age data, the participants at this workshop unanimously agreed that under our present knowledge that the break and burn method provides the best method for ageing walleye pollock. The participants also unanimously agreed that scale ageing seriously underage walleye pollock.

It was noted that pollock ageing methodology in the participating countries could be made more similar by exchanging reference samples on an annual basis. Canada, Poland, P.R.C., and the U.S. agreed to begin this exchange during the first half of 1991, with an exchange of 125 otolith pairs that would be aged using the break and burn method. It was agreed that Poland would initiate the sample, with the sample being subsequently passed to the U.S., Canada, and P.R.C., in that order. Japan declined to be involved in the exchange at this time because no production ageing of walleye pollock is currently being planned.

Several research issues surfaced during the workshop:

1. It was felt that identification of the first annulus in walleye pollock should be investigated. Identification of the first annulus might be a major factor causing uncertainty in the exact timing of two dominant year classes (1972 or 1973, and 1977 or 1978). Exact timing of year classes is critical when attempts are being made to correlate year class strength with environmental events.

2. The break and burn method for ageing walleye pollock has never been properly validated. Validation is a difficult problem, but without validation, pollock age data will depend on our working hypotheses concerning what annuli are in this species, and may in fact be incorrect.

3. Participants at this workshop agreed that an interchange of scientific information and manuscripts concerning the age determination for walleye pollock would be mutually beneficial. The AFSC agreed to be the clearing house for passing information on to workshop participants.

Table 1. Results from ageing the Alaska Fisheries Science Center reference sample using the break and burn method. Reader 1=Julie Lyons, 2=Betty Goetz, 3=Shayne MacLellan, 4=Barbara Szostakiewicz, 5=Magdalena Kowalewska-Pahlke, 6=Jerzy Janusz, 7=Ren Shengmin.

specimen	sex 1=m 2=f	length mm	U.S.		Can	Poland			P.R.C.
			1	2	1	1	2	3	1
SHELIKOF AREA									
1	2	410	4	5	4	5	5	4	5
2	1	390	5	5	4	5	4	4	5
3	2	430	5	5	5	6	6	4	5
4	2	260	2	2	2	2	2	2	3
5	1	510	11	12	10	11	12	9	11
6	1	470	5	5	5	6	9	5	6
7	2	470	6	6	6	6	8	5	6
8	2	440	6	6	7	6	6	5	6
9	1	530	13	11	12	13	13	9	10
10	2	410	5	5	4	5	5	4	5
11	2	620	11	11	10	11	11	10	13
12	1	440	5	5	4	5	6	4	5
13	2	460	11	9	5	8	7	7	6
14	2	380	4	5	4	4	4	4	5
15	1	380	4	4	4	4	4	4	5
16	2	370	5	5	4	4	4	4	5
17	2	530	11	12	13	13	13	12	11
18	2	410	5	5	5	5	5	5	5
19	2	340	3	4	3	3	3	3	4
20	1	230	2	2	2	2	2	2	3
21	2	420	4	5	4	5	4	4	5
22	1	470	9	7	6	6	6	6	6
23	2	540	9	9	9	10	10	8	10
24	2	640	17	16	11	13	12	12	14
25	2	230	2	2	2	2	2	2	3

CONTINUED

SOUTHEAST SHELF AREA

26	1	470	8	9	8	7	8	7	6
27	1	460	7	7	7	8	7	7	6
28	2	530	11	15	13	15	15	14	11
29	1	510	11	9	8	9	9	8	9
30	1	460	7	10	8	8	8	8	6
31	2	560	10	9	9	9	9	9	9
32	1	440	5	5	5	6	6	5	6
33	1	530	9	9	9	9	9	9	9
34	1	560	9	8	6	7	7	7	9
35	2	400	6	5	5	5	5	5	5
36	1	430	11	11	9	10	10	8	8
37	2	550	7	7	8	8	7	7	8
38	1	590	14	12	11	11	12	11	14
39	1	460	8	7	7	8	7	7	8
40	2	460	5	5	5	6	5	6	6
41	2	480	5	5	5	5	6	5	5
42	1	450	7	7	7	8	7	7	8
43	1	430	6	6	6	7	6	6	6
44	2	430	7	7	8	8	7	7	8
45	1	460	6	7	7	7	6	6	7
46	1	400	6	7	8	8	7	6	6
47	1	470	7	7	7	7	9	7	7
48	1	440	7	7	7	8	8	7	7
49	1	380	8	9	8	8	8	8	5
50	1	460	7	7	7	8	8	7	8

NORTHWEST SHELF AREA

51	1	370	5	5	5	6	5	5	6
52	2	400	6	6	5	6	5	5	6
53	1	460	7	7	7	8	7	7	7
54	2	440	5	6	5	5	5	6	6
55	2	390	5	5	5	6	5	5	6
56	2	420	7	7	7	7	7	6	6
57	2	380	5	5	5	6	5	5	6
58	2	370	6	5	5	6	5	5	5
59	1	420	5	5	5	6	6	6	6
60	1	440	7	7	7	8	7	6	7
61	2	430	5	5	5	5	6	5	5
62	1	450	7	7	7	8	7	7	6
63	2	470	7	7	8	7	8	6	6
64	1	450	7	7	7	8	8	7	7
65	2	390	5	5	5	6	5	5	6
66	2	370	5	5	5	6	5	4	5
67	1	360	5	5	5	6	5	5	5
68	2	410	5	5	5	6	6	5	6
69	2	450	7	7	7	8	7	7	8
70	2	430	6	6	5	6	6	6	6
71	1	380	5	5	5	6	5	5	6
72	1	350	4	4	4	5	4	5	5
73	1	390	6	5	5	6	5	5	6
74	1	400	5	5	5	6	5	5	6
75	2	400	5	5	5	5	5	5	6

CONTINUED

DONUT HOLE AREA

76	1	480	10	11	10	10	10	11	8
77	1	470	10	10	10	12	11	11	9
78	1	490	10	10	11	10	11	10	8
79	1	470	10	9	9	10	10	9	10
80	1	500	24	23	23	21	21	21	10
81	2	460	5	5	5	6	6	6	5
82	2	480	8	8	8	7	9	9	9
83	2	450	10	9	9	9	9	9	6
84	2	490	10	10	10	10	11	11	8
85	2	460	7	7	7	8	8	6	7
86	2	510	10	12	10	12	12	11	11
87	2	470	10	10	11	10	12	9	10
88	2	470	10	10	8	10	10	11	9
89	2	550	16	16	13	16	16	16	18
90	1	460	10	10	10	11	11	11	5
91	1	500	16	14	14	14	15	13	10
92	1	500	13	12	11	13	12	12	10
93	1	490	16	10	10	10	10	12	10
94	2	520	12	12	11	10	12	11	13
95	2	520	16	15	15	15	15	13	14
96	1	480	7	7	5	6	7	6	5
97	1	450	10	10	9	10	11	10	8
98	2	490	10	10	9	10	10	10	9
99	2	480	6	6	5	7	7	7	7
100	2	470	9	9	9	9	9	8	7

BOGOSLOF AREA

101	2	430	6	6	5	7	7	6	6
102	2	530	11	11	11	11	11	10	11
103	2	520	11	11	11	11	12	10	11
104	2	480	11	11	11	11	11	12	11
105	1	490	8	8	8	9	8	7	9
106	1	470	7	7	8	8	7	7	9
107	1	490	11	10	10	11	11	10	10
108	2	490	8	7	7	8	8	7	9
109	1	490	17	12	11	12	12	9	11
110	1	470	11	11	11	11	12	10	10
111	1	460	17	16	14	17	16	15	9
112	2	510	11	11	11	11	11	10	11
113	2	470	7	7	7	8	7	7	8
114	1	470	11	12	11	11	12	11	10
115	2	530	8	9	8	8	8	9	9
116	1	480	11	12	10	10	12	12	9
117	1	440	9	9	9	10	9	9	9
118	2	440	4	5	4	5	7	5	6
119	2	440	4	5	4	5	7	5	5
120	2	520	11	12	10	12	11	11	11
121	1	470	13	13	11	13	12	13	14
122	1	460	11	10	9	10	9	9	10
123	1	460	11	11	9	10	9	11	19
124	1	500	17	16	15	17	16	13	16
125	1	460	17	16	16	15	15	15	10

Table 2. Results from ageing the Sea Fisheries Institute reference sample using thin sections. Reader 1-Barbara Szostakiewicz, 2-Magdalena Kowalewska-Pahlke, 3-Jerzy Janusz, 4-Richard Beamish, 5-Julie Lyons, 6-Akira Nishimura, 7-Taku Yoshimura, 8-Ren Shengmin.

No.	Length cm	1	2	3	4	5	6	7	8
	Sample No. 1		DONUT HOLE						
1	40.0	7	7	7	6	6	5	6	7
2	43.0	8	8	9	8	6	6	6	8
3	45.0	12	12	13	--	11	9	9	8
4	47.0	13	13	13	12	12	11	12	9
5	49.0	13	13	13	--	13	11	10	12
6	51.0	13	13	13	12	13	11	13	12
7	52.0	19	20	19	13	19	19	21	--
8	54.0	19	19	18	--	17	18	17	10
9	38.0	6	6	6	6	4	4	5	5
10	41.0	8	8	8	6	8	6	6	7
11	42.0	7	8	7	--	5	5	6	5
12	44.0	8	9	9	--	7	6	6	8
13	46.0	9	9	10	6	8	7	7	7
14	48.0	11	11	11	11	11	10	10	7
15	49.0	13	13	14	--	12	11	13	7
16	50.0	12	12	13	11	11	11	9	9
17	51.0	13	13	13	11	11	11	10	9
18	52.0	12	12	14	12	11	11	11	8
19	53.0	13	13	13	12	11	12	10	11
20	54.0	22	21	21	22	21	21	20	11
21	55.0	15	14	15	--	13	13	11	13
22	56.0	12	11	12	11	10	10	12	11
23	57.0	18	17	18	16	18	16	16	--
24	58.0	14	14	13	11	11	14	10	14

CONTINUED

Sample No. 2 EASTERN BERING SEA

1	36.0	5	5	4	5	4	4	4	5
2	37.0	5	5	4	--	4	4	4	5
3	38.0	6	6	6	4	5	5	4	6
4	39.0	6	6	6	4	5	5	4	6
5	40.0	5	5	5	4	4	5	4	5
6	49.0	19	18	18	--	17	--	--	6
7	41.0	5	5	4	4	4	4	4	5
8	42.0	6	5	5	4	5	4	5	6
9	43.0	5	5	4	4	4	4	4	5
10	44.0	6	6	6	--	5	5	6	6
11	45.0	7	7	7	--	7	6	7	8
12	46.0	7	7	7	6	7	5	6	7
13	47.0	7	7	7	5	6	6	6	7
14	48.0	8	7	8	5	7	8	6	7
15	49.0	7	7	8	6	6	6	7	7
16	50.0	7	8	7	7	7	8	7	8
17	50.0	9	9	9	5	7	7	7	8
18	51.0	7	7	7	6	6	6	6	8
19	51.0	7	7	6	6	7	6	6	7
20	52.0	7	8	7	6	7	6	6	7
21	53.0	19	19	18	17	14	15	17	--
22	56.0	9	9	8	8	10	10	11	9
23	57.0	12	12	12	10	10	12	11	12
24	58.0	13	14	12	12	12	12	12	12

Sample No. 3 ALEUTIAN

1	37.0	4	4	4	--	4	4	4	4
2	40.0	4	4	4	4	4	3	3	4
3	42.0	6	6	5	--	5	5	5	6
4	44.0	7	6	6	--	6	4	6	6
5	46.0	8	8	7	--	--	5	6	7
6	48.0	7	7	6	3	6	4	6	7
7	50.0	7	7	6	--	7	6	6	8
8	51.0	13	13	13	--	12	12	10	12
9	52.0	9	10	9	--	8	10	8	10
10	43.0	6	6	5	--	6	5	7	6
11	45.0	8	8	7	--	8	7	7	8
12	47.0	6	6	6	4	7	5	6	6
13	49.0	9	9	9	--	9	11	11	12
14	53.0	12	12	11	11	11	12	11	12
15	54.0	7	7	6	4	7	6	9	10
16	55.0	13	13	12	--	13	12	13	13
17	56.0	13	13	12	11	11	12	12	13
18	57.0	7	7	6	6	8	5	--	12
19	58.0	17	17	17	15	18	17	18	14
20	59.0	10	11	10	8	9	--	13	13
21	61.0	12	12	12	12	13	12	12	13
22	62.0	11	11	11	12	11	11	12	13
23	64.0	12	12	12	--	12	12	13	13
24	65.0	12	13	13	12	12	12	13	14

CONTINUED

Sample No. 4 CHIRIKOF

1	35.0	3	2	2	2	2	2	3	3
2	36.0	3	3	3	--	3	3	3	4
3	37.0	3	3	3	3	3	3	4	4
4	40.0	3	3	3	3	3	3	4	4
5	42.0	3	3	3	3	3	3	3	4
6	44.0	3	3	3	--	5	3	4	4
7	45.0	5	5	5	--	6	3	6	6
8	47.0	7	7	7	7	7	6	6	8
9	48.0	6	6	6	5	6	5	6	8
10	49.0	7	7	7	--	9	8	7	10
11	50.0	6	6	6	5	5	5	6	8
12	52.0	9	10	10	8	10	8	10	10
13	53.0	8	8	8	7	8	8	8	10
14	53.0	9	8	8	--	9	8	10	10
15	54.0	9	10	9	7	9	9	14	11
16	50.0	5	5	4	--	6	5	6	--
17	51.0	7	7	7	6	6	9	8	--
18	51.0	9	9	8	8	7	8	8	9
19	52.0	7	7	8	6	6	6	9	9
20	52.0	7	7	7	6	6	5	7	--
21	52.0	6	6	6	--	6	5	5	9
22	53.0	10	10	10	8	9	9	10	11
23	54.0	9	8	8	7	8	8	8	10
24	54.0	5	5	5	4	--	4	5	10

Sample No. 5 KODIAK

1	43.0	4	4	3	3	3	3	3	4
2	44.0	5	5	5	4	4	4	4	4
3	46.0	4	4	3	--	3	3	3	5
4	47.0	7	5	5	--	5	6	5	6
5	48.0	8	8	7	--	6	5	7	8
6	49.0	5	5	5	--	--	4	5	9
7	50.0	7	6	6	--	--	6	7	10
8	51.0	6	6	6	--	6	6	5	8
9	52.0	9	8	7	--	6	8	6	9
10	57.0	7	7	7	5	9	6	7	10
11	43.0	4	4	3	--	3	3	4	4
12	44.0	5	5	5	--	5	4	4	5
13	45.0	5	5	5	4	3	4	4	5
14	47.0	7	7	7	--	6	6	6	7
15	49.0	7	7	7	--	--	8	6	9
16	50.0	6	6	6	5	6	5	10	9
17	51.0	7	7	7	--	6	5	6	--
18	52.0	9	9	8	7	8	7	8	9
19	53.0	7	6	5	--	--	4	7	10
20	54.0	7	7	7	--	7	9	10	11
21	54.0	7	7	6	--	7	9	10	--
22	56.0	8	9	8	--	8	6	7	12
23	54.0	8	9	9	--	8	8	7	10
24	59.0	10	10	9	9	9	9	9	13

CONTINUED

Sample No. 6 VANCOUVER

1	36.0	2	2	2	2	2	2	3	3
2	37.0	2	2	2	2	2	2	4	3
3	38.0	2	2	2	--	2	2	3	3
4	40.0	2	2	2	2	2	2	3	3
5	43.0	4	4	4	3	4	3	4	5
6	44.0	5	5	5	3	4	4	6	5
7	45.0	6	4	4	--	7	3	6	5
8	46.0	7	7	7	6	11	7	7	7
9	47.0	4	4	4	4	4	4	4	--
10	42.0	2	2	2	2	2	4	3	3
11	45.0	5	5	4	--	4	4	5	5
12	46.0	4	4	4	4	4	4	4	4
13	47.0	5	4	4	4	--	4	4	5
14	48.0	5	5	5	--	6	4	6	5
15	49.0	8	8	8	7	9	8	9	8
16	50.0	8	8	8	6	8	5	8	9
17	50.0	5	5	5	--	5	7	7	--
18	51.0	7	8	9	--	11	8	7	10
19	52.0	6	5	5	--	5	5	6	6
20	52.0	7	6	6	6	8	6	7	9
21	53.0	7	8	7	6	9	9	10	10
22	53.0	7	7	7	7	10	12	12	10
23	54.0	7	7	7	7	8	--	8	9
24	58.0	9	9	9	8	--	13	11	--

Table 3. Results from ageing the Donut Hole subsample of the Sea Fisheries Institute reference sample using the break and burn method. These results can be compared with the results using thin sections in Table 2.

No.	Length cm	1	2	3	4	5	6	7	8
1	40.0	6	6	6	6	6	6	5	
2	43.0	6	6	6	6	8	6	6	
3	45.0	11	11	11	11	12	12	12	
4	47.0	12	12	14	12	14	11	12	
5	49.0	12	12	11	11	14	11	11	
6	51.0	12	12	12	12	13	12	11	
7	52.0	19	18	17	19	18	17	20	
8	54.0	17	18	18	17	19	20	16	
9	38.0	4	4	3	3	4	5	5	
10	41.0	7	6	7	7	7	7	8	
11	42.0	7	6	7	5	5	5	7	
12	44.0	7	7	7	7	6	7	10	
13	46.0	9	9	9	7	7	11	8	
14	48.0	10	10	10	12	11	10	8	
15	49.0	12	13	12	12	12	11	10	
16	50.0	11	11	11	12	10	11	11	
17	51.0	11	11	11	11	12	11	11	
18	52.0	11	12	11	--	10	11	11	
19	53.0	12	12	11	11	10	11	11	
20	54.0	21	22	22	22	21	21	21	
21	55.0	14	14	13	12	13	15	14	
22	56.0	12	12	12	13	12	13	14	
23	57.0	18	17	19	17	16	16	16	
24	58.0	13	13	15	11	13	16	12	

Appendix 1

Information Concerning the Reference Sample of Walleye Pollock Provided by the Alaska Fisheries Science Center and Some Additional Donut Hole Data

by

Daniel K. Kimura
and
Julaine J. Lyons

Prepared for the
Workshop on Ageing Methodology of Walleye Pollock
Held at the Sea Fisheries Institute
Gdynia, Poland
September 10-14, 1990

In accordance with agreements reached at the Khabarovsk Symposium (April 2-5, 1990), the Alaska Fisheries Science Center has prepared a reference sample of 125 specimens sampled from various areas of the Bering Sea and the Gulf of Alaska. Twenty-five otolith pairs are provided from each of five areas (Fig.1):

1. Shelikof, specimen 1-25, collected 3/15/89
2. Southeast Shelf, specimens 26-50, collected 2/28/89
3. Northwest Shelf, specimens 51-75, collected 2/17/89
4. Donut Hole, specimens 76-100, collected 12/22/88
5. Bogoslof, specimens 101-125, collected 2/23/89

An effort was made to provide samples from surveys made during nearly the same time period so that the structures and data would be most comparable. The samples from the Northwest Shelf, Southeast Shelf, Bogoslof, and Shelikof were collect by the R.V. Miller Freeman during the first quarter of 1989. And the Donut Hole samples were collected by the Japanese vessel Kaiyo Maru during December 1988 and sent to us for ageing.

Since the larger survey of which the reference collection is a part has been aged at the Alaska Fisheries Science Center, we provide age distributions and size at age distributions based on these broader samples (Table 1). For the Donut Hole samples, which were collected late in 1988, one year was added to the ages so that these ages would be directly comparable with ages from the other areas. Also, we did not plot the broader sample from the Northwest Shelf because only one haul was made in that area.

Fig. 2 (Table 1) shows the age distributions collected from four areas. This figure shows that age compositions were much younger in the Southeast Shelf Area of the Bering Sea compared with the deeper Bogoslof and Donut Hole areas. It is interesting to note that although the age ranges found in the Southeast Shelf area is similar to that found in the Shelikof area, the dominant year-class appeared to be different in the two areas.

Fig. 3 (Table 1) shows the average length at age distributions calculated from these samples. Evidently, the Shelikof length at age is greater than in the Bering Sea samples. In the Bering Sea, the greater length at age seen in the older fish collected from the Southeast Shelf compared to the Bogoslof and Donut Hole areas, may be partially due to the relatively small samples for fish 7yr-old and older.

Because only a very small sample was available from the survey of the Donut Hole, additional samples collected from 1985 through 1989 by U.S. Observers aboard fishing vessels were examined. Although sample sizes were small (Table 2), the 1978 year-class was clearly visible in these data. The length at age data from all of the years combined (Table 3) indicate the length at age in the Donut Hole is not dramatically different from other areas in the Central and Eastern Bering Sea.

Table 1. Length at age (cm) and sample size for walleye pollock sampled from four different areas.

Southeast Shelf

Age	Males		Females		Sexes Combined	
4	41.5	11	41.5	8	41.5	19
5	41.0	106	41.9	71	41.4	177
6	42.6	31	43.2	33	42.9	64
7	44.8	122	45.9	128	45.3	250
8	45.4	18	46.1	27	45.8	45
9	50.3	8	49.8	21	49.9	29
10	53.0	2	53.5	2	53.3	4
11	52.6	5	53.3	12	53.1	17
13	.0	0	57.0	1	57.0	1

Bogosloff

Age	Males		Females		Sexes Combined	
4	42.0	1	.0	0	42.0	1
5	40.7	3	44.0	2	42.0	5
6	45.3	6	46.8	10	46.3	16
7	44.8	32	46.6	65	46.0	97
8	47.0	14	48.4	21	47.9	35
9	47.6	27	49.0	20	48.1	47
10	47.0	10	48.8	12	48.0	22
11	47.6	104	49.7	157	48.9	261
12	47.8	19	50.3	33	49.4	52
13	49.9	16	50.0	32	50.0	48
14	49.1	7	50.8	12	50.2	19
15	48.6	9	51.8	11	50.3	20
16	48.8	5	50.0	2	49.1	7
17	47.6	5	51.1	8	49.8	13

Donut Hole

Age	Males		Females		Sexes Combined	
5	39.0	1	.0	0	39.0	1
6	.0	0	43.0	2	43.0	2
7	44.6	8	46.8	8	45.7	16
8	46.5	2	47.0	5	46.9	7
9	45.0	3	47.2	5	46.4	8
10	47.8	9	48.8	5	48.1	14
11	47.3	20	49.9	22	48.6	42
12	49.5	4	50.0	2	49.7	6
13	48.8	4	52.7	3	50.4	7
14	48.0	1	.0	0	48.0	1
15	48.2	5	53.2	6	50.9	11
16	.0	0	54.0	2	54.0	2

Age	Males		Shelikof Females		Sexes Combined	
2	23.5	31	23.8	35	23.7	66
3	31.5	60	32.2	50	31.8	110
4	38.3	194	39.1	171	38.7	365
5	39.3	231	41.4	232	40.4	463
6	44.8	68	47.0	70	45.9	138
7	48.4	35	50.6	55	49.7	90
8	51.6	19	52.8	16	52.1	35
9	50.2	9	54.7	11	52.7	20
10	53.3	3	54.8	6	54.3	9
11	51.7	29	55.8	56	54.4	85
12	52.5	2	54.5	6	54.0	8
13	.0	0	55.0	1	55.0	1

Table 2. Age distributions from commercial catches of fish caught in the Donut Hole and sampled by U.S. Observers.

Age	Years 85	86	87	88	89
4	4	0	4	0	6
5	9	4	17	1	23
6	35	2	11	12	17
7	126	4	6	24	45
8	64	4	7	23	36
9	65	11	44	33	23
10	62	3	7	130	20
11	55	2	8	25	157
12	47	1	6	30	9
13	25	1	14	10	6
14	17	2	5	16	3
15	15	0	2	9	6
16	4	0	0	1	0
17	4	0	1	0	2
18	2	0	0	2	0
19	1	0	0	0	0
20	0	0	0	0	0
21	0	0	0	0	0
22	0	0	0	1	0

Table 3. Length at age (cm) and sample size for walleye pollock sampled from the Donut Hole during 1985-1989.

	Donut Hole					
Age	Males		Females		Sexes Combined	
4	40.2	5	41.1	9	40.8	14
5	40.5	28	42.7	26	41.6	54
6	42.0	32	43.2	45	42.7	77
7	43.8	100	44.7	105	44.2	205
8	45.5	57	46.5	77	46.1	134
9	47.0	87	48.3	89	47.6	176
10	47.4	101	49.3	121	48.4	222
11	48.8	107	50.2	140	49.6	247
12	50.2	43	52.1	50	51.2	93
13	50.4	25	52.3	31	51.5	56
14	51.5	16	52.9	27	52.4	43
15	51.3	10	52.5	22	52.2	32
16	50.7	3	53.5	2	51.8	5
17	51.8	4	55.0	3	53.1	7
18	54.0	1	52.7	3	53.0	4
19	.0	0	53.0	1	53.0	1
22	.0	0	51.0	1	51.0	1

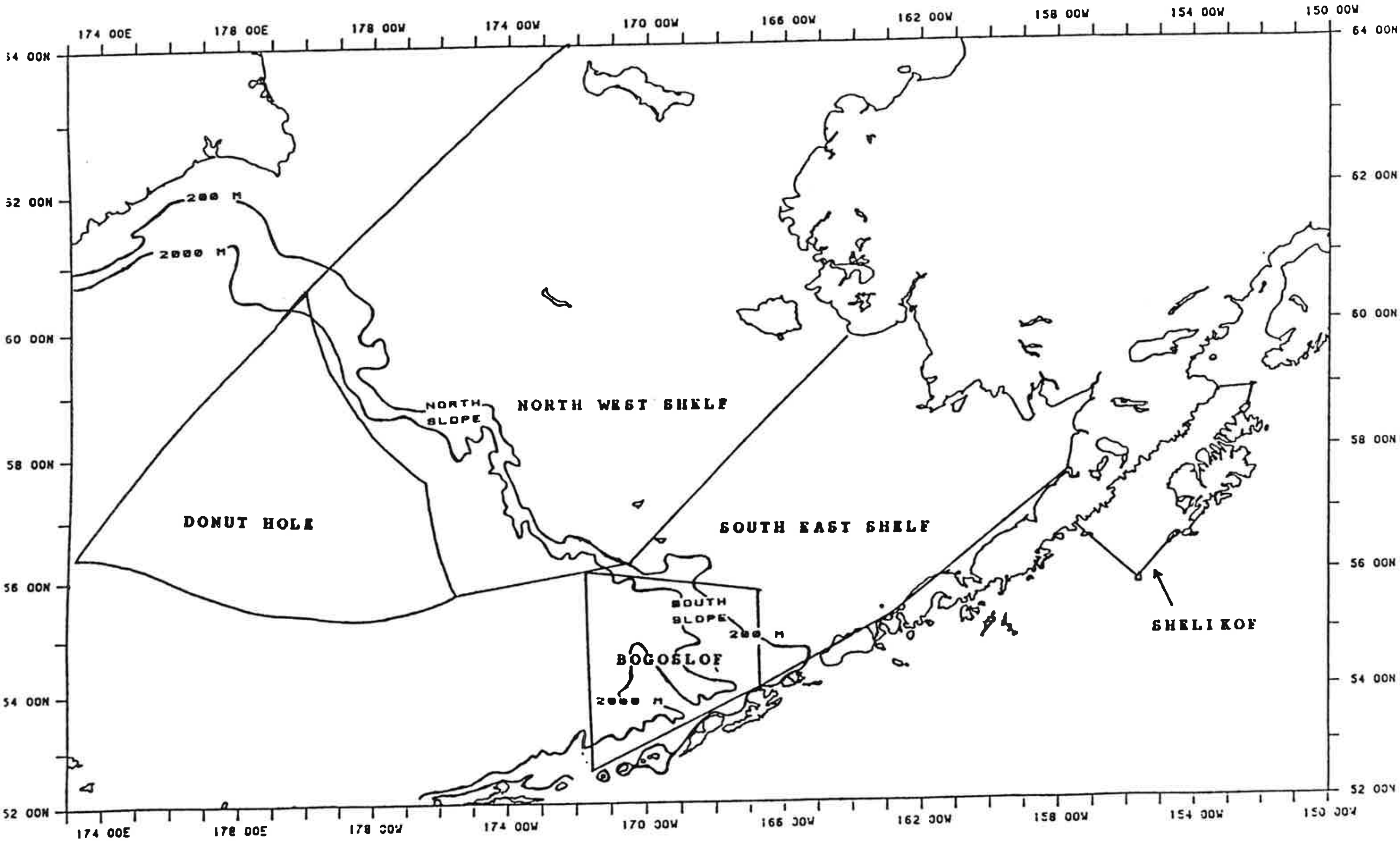

Figure 1. Map showing the five areas of the Bering Sea and the Gulf of Alaska from which reference samples were collected.

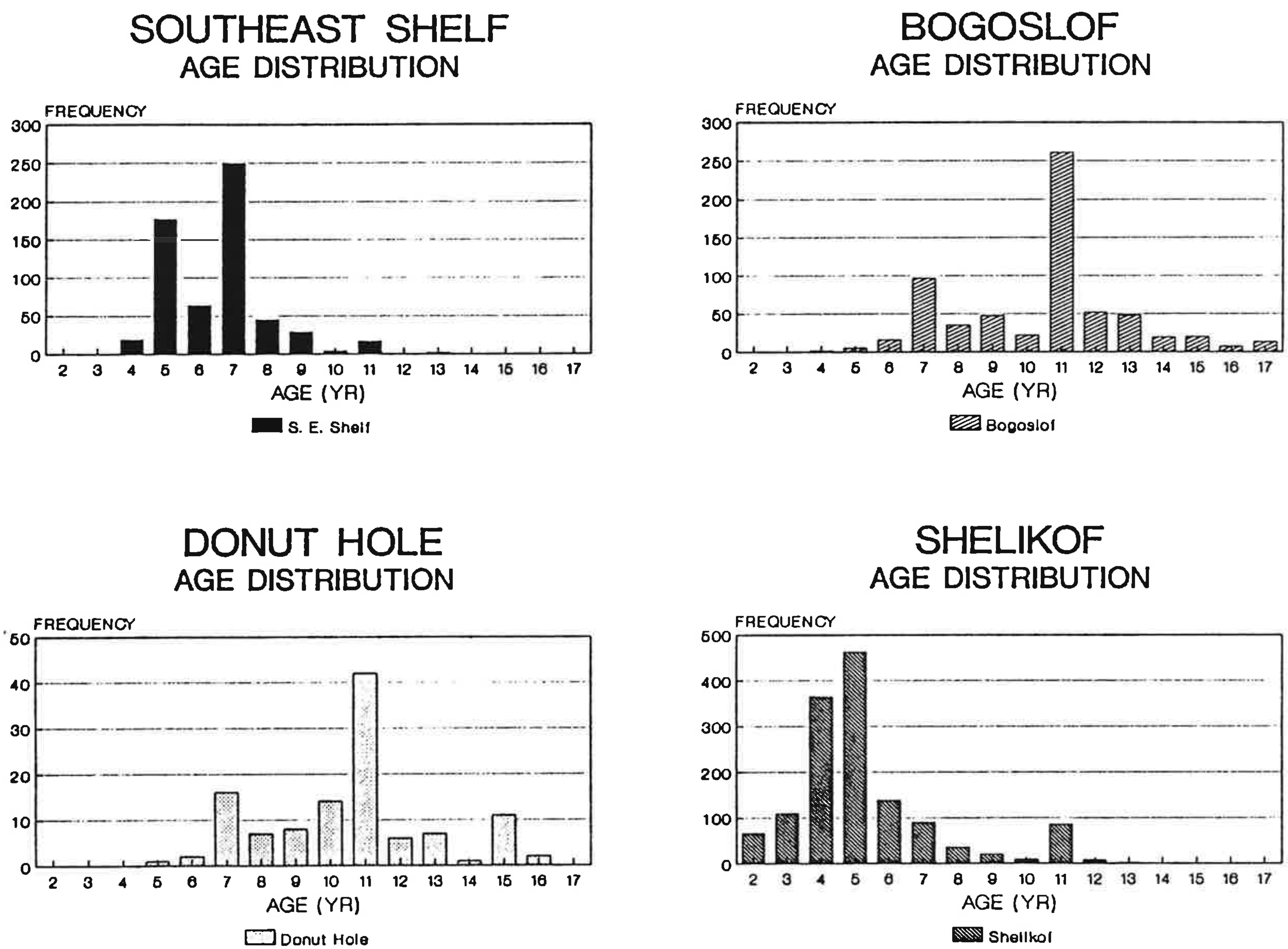

Figure 2. Age distributions calculated from the broader surveys from which reference samples were collected.

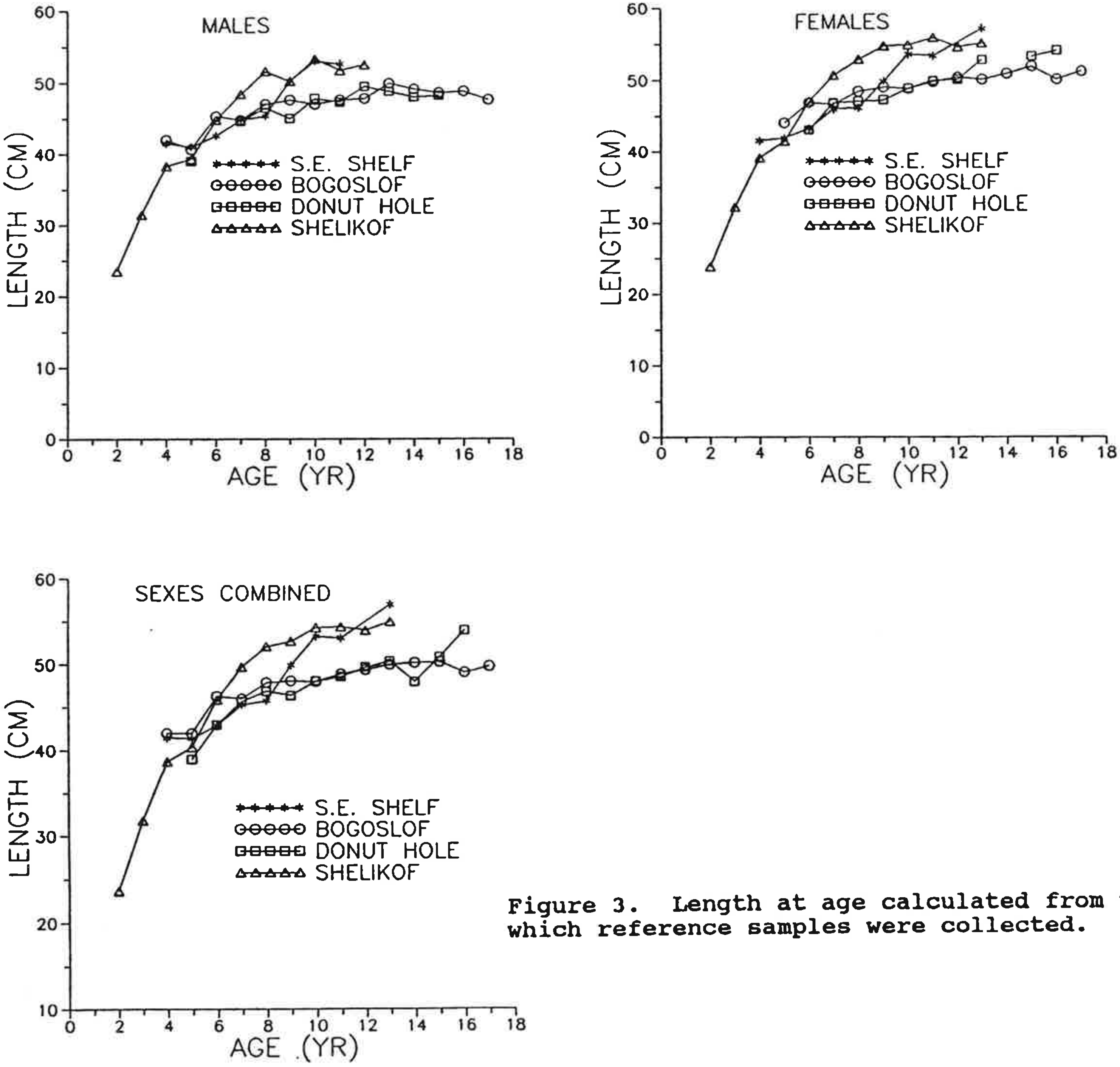

Figure 3. Length at age calculated from the broader surveys from which reference samples were collected.

Comparisons of Scale and Otolith Ages For Walleye Pollock

by

Daniel K. Kimura
and
Julaine J. Lyons

Prepared for the
Workshop on Ageing Methodology of Walleye Pollock
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Gdynia, Poland
September 10-14, 1990

Scales and otoliths have long been the favorite structures for the ageing of fishes. Walleye pollock (Theragra chalcogramma) from the North Pacific appear to have been first aged using scales (Ogata 1956). Sometime later (LaLanne 1975, 1977), proposed using otoliths. For some unknown reason pollock otoliths collected from Alaskan waters during the 1970's appeared clearer than those collected today, so LaLanne proposed surface readings. LaLanne examined transverse cuts of the otolith for the purpose of validating the surface readings. Beamish (1981) and McFarlane and Beamish (1990) found pectoral and dorsal fin-ray sections useful in the ageing of slow growing pollock from the Strait of Georgia.

The discrepancy between scale ages and otolith ages has long been a concern at Alaska Fisheries Science Center. In 1977 a study was performed comparing scale ages read at the Japanese Far Seas Fisheries Research Laboratory, with otolith surface ages read at the U.S. Alaska Fisheries Science Center on the same fish. The results of this study (Bakkala et al. 1985) are summarized in Fig. 1. Clearly scale ages differed greatly from otolith surface ages at ages 6yr and older.

During June and July, 1990, we had the good fortune of having Ms. Marina Raklistova and Dr. Valery Paschenko of the Pacific Scientific Research Institute of Fisheries and Oceanography (TINRO) visit the Alaska Fisheries Science Center. They were particularly interested in comparing their scale ages with the otolith ageing method we currently use. Their sample consisted of fish for which both scales and otoliths had been collected. Since 1981, the Alaska Fisheries Science Center's method of ageing walleye pollock has been to read a surface age if the fish is young and the otolith relatively clear, and use the break and burn method (Beamish and Chilton 1982) if the otolith is unclear and/or old. As the sampled otoliths became more difficult to age (i.e. more unclear and older), we have progressively used the break and burn method (generally using an isomet saw for the transverse cut) on a greater percentage of otoliths. A comparison of the age distribution of ages read by Marina Raklistova and Julie Lyons is presented in Fig. 2.

It is apparent that by age 7yr there were serious discrepancies between scale and otolith ages. In addition, a plot was prepared showing the deviation of the average scale age for all fish of a given otolith age (Fig. 3). It is apparent from this figure that the deviation between scale and otolith ages increase with otolith age.

Because of studies such as these there is little doubt that scale and otolith ages can differ significantly for walleye pollock. However, to say that one is wrong and one is right is more difficult. From 1980-1989 we have aged over 173,000 pollock otoliths, so it should be apparent which structure we favor.

Other researchers (Janusz 1986, Lai and Yeh 1986, McFarlane and Beamish, 1990) appear also to favor otoliths. They appear to do so on the basis of precision and the probable correctness of the older ages than on actual validation data. McFarlane and

Beamish (1990) concluded that the geographic location and age structure of a population will affect the choice of ageing structure and preferred method of ageing walleye pollock. This would imply that the older population structure which has been observed in the international Donut Hole should be aged using the break and burn method.

From our point of view, we favor otolith ages because they allow us to follow strong year-classes to older ages. Fig. 4 shows how the strong 1978 year-class appeared in catch at age data from 1980 through 1987. From Fig. 4, it can be seen that at every age, compared with other year-classes, the 1978 year-class made up the largest percentage of the annual catch of that age. Also, by generalization, the older ages attributed to some rockfish species using the otolith break and burn method (Beamish 1979), appear to have been validated using radioisotopes (Bennett et al. 1987, Campana 1990). Therefore, we expect the older break and burn otolith ages for pollock to prove to be correct.

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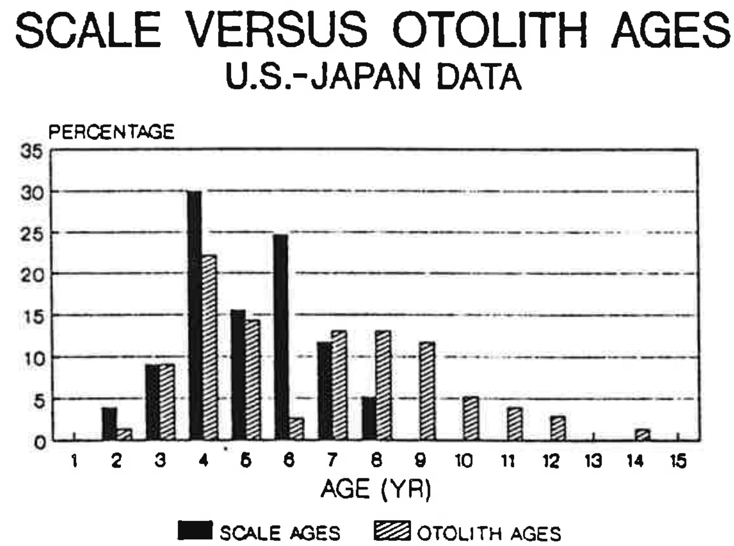


Figure 1. A comparison of age distributions when the same fish are aged using scales and otoliths. Scale ages were read by the Japanese Far Seas Fisheries Research Laboratory and surface otolith ages were read by the U.S. Alaska Fisheries Science Center.

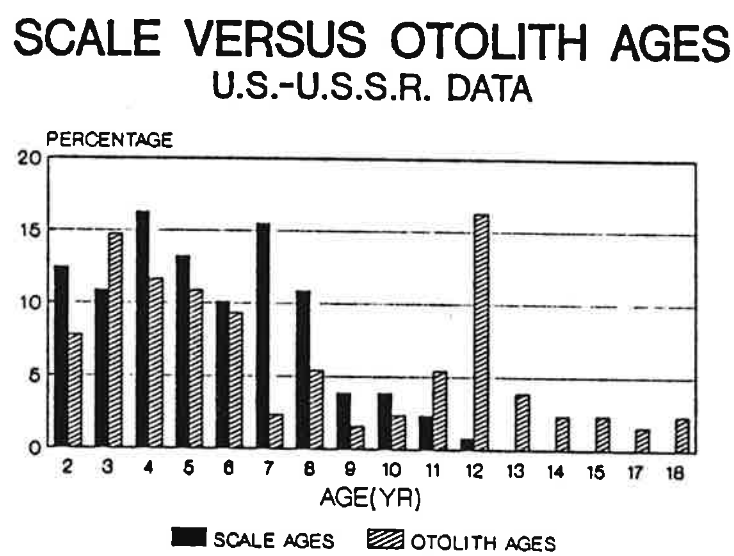


Figure 2. A comparison of age distributions when the same fish are aged using scales and otoliths. Scale ages were read by the Soviet Pacific Scientific Research Institute of Fisheries (TINRO) and otolith ages were read by the U.S. Alaska Fisheries Science Center using surface or break and burn methods as required.

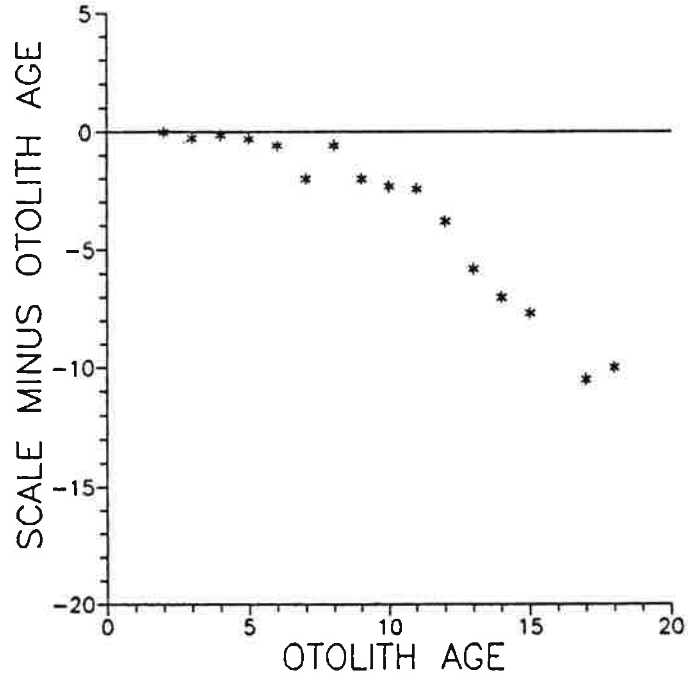


Figure 3. A graph of deviations between scale and otolith ages at nominal otolith ages. The deviation shown is the difference between the average scale age and the nominal otolith age using U.S.-U.S.S.R. data.

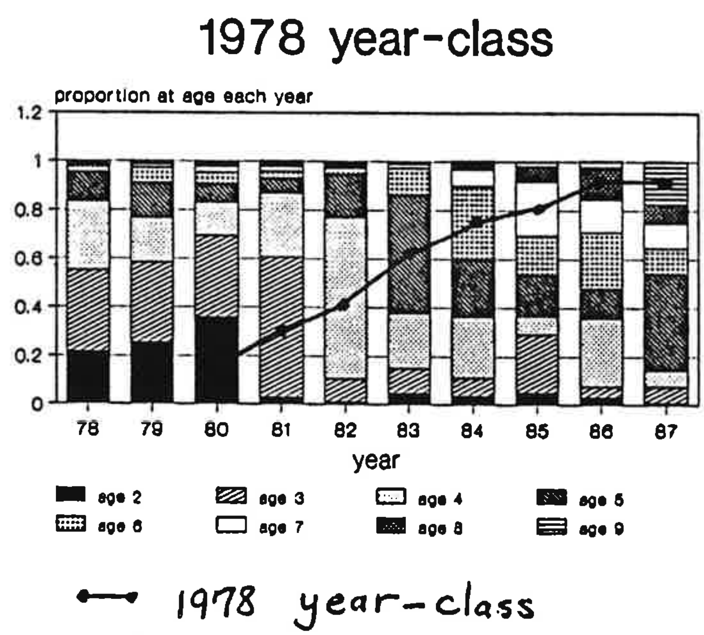


Figure 4. Graph of the age composition of catches taken from the Eastern Bering Sea during 1978-1987, using otolith ages, showing the dominance of the 1978 year-class.

Comparison of Break and Burn and Otolith Thin section Ages From Walleye Pollock

by

Daniel K. Kimura
and
Julaine J. Lyons

Prepared for the
Workshop on Ageing Methodology of Walleye Pollock
Held at the Sea Fisheries Institute
Gdynia, Poland
September 10-14, 1990

Following the I.N.P.F.C. Meeting held in Seattle during 1989, Dr. Jerzy Janusz of the Sea Fisheries Institute visited the Alaska Fisheries Science Center. During this visit he met with Ms. Julie Lyons and discussed the ageing of Walleye Pollock through the use of otolith thin sections. During this meeting Dr. Janusz and Ms. Lyons examined a sample of several thin sectioned otoliths that Dr. Janusz had prepared. The clarity of these thin sections were impressive to us, and we felt that we should further examine thin sections, particularly to see whether ages obtained from thin sections compared well with ages obtained using our standard break and burn or whole otolith methods.

For this study, we prepared 42 otoliths collected by U.S. Observers aboard commercial fishing vessels. The otoliths that were selected were from previously aged samples for which we already had production ages. The selected otoliths were collected from the Donut Hole and the Southeast Shelf areas in the first quarter of 1989:

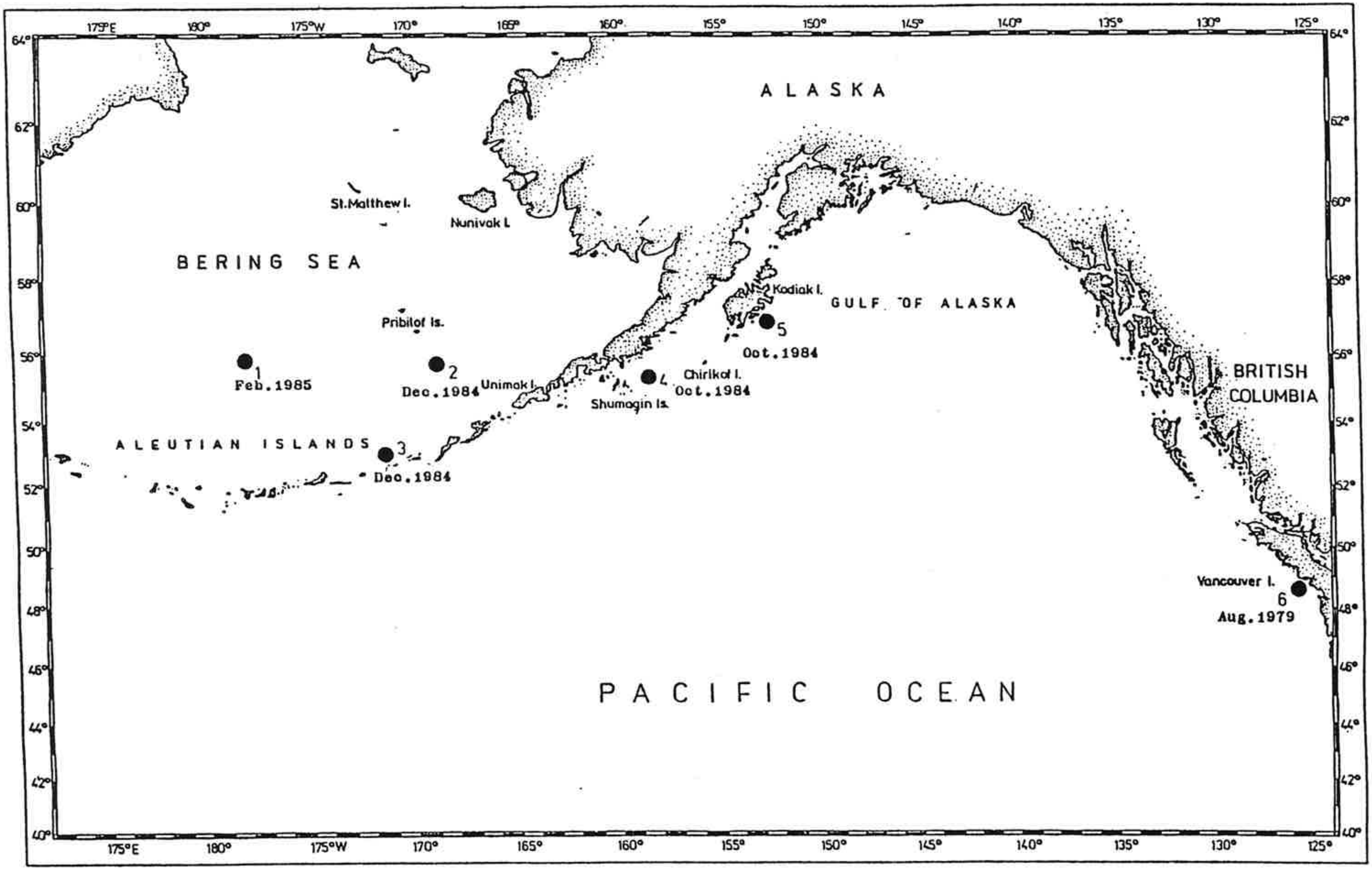
Break & burn Age	Donut Hole (number)	S. E. Shelf (number)	
6	0	2	
7	8	6	1982 year-class
8	0	1	
9	3	0	
11	11	8	1978 year-class
13	0	1	
14	1	0	
17	1	0	

Results from ageing these specimens using thin sections are shown below.

break & burn age	Section Ages (yr)									
	5	6	7	8	9	10	11	12	13	14
6	1	.	.	.	.	.	1	.	.	.
7	1	1	3	8	.	.	1	.	.	.
8	.	.	.	1	.	.	.	.	.	.
9	.	.	.	1	1	.	1	.	.	.
10	.	.	.	.	.	.	.	.	.	.
11	.	.	.	.	1	.	13	1	1	3
12	.	.	.	.	.	.	.	.	.	.
13	.	.	.	.	.	.	1	.	.	.
14	.	.	.	.	.	.	1	.	.	.
15	.	.	.	.	.	.	.	.	.	.
16	.	.	.	.	.	.	.	.	.	.
17	.	.	.	.	.	.	.	.	.	1

Results comparing the thin section ages with break and burn ages were disappointing. Otoliths sections were overaged compared to break and burn ages. Also, the 1982 year-class (i.e. 7 yr-olds), which was thought to be strong from break and burn ages, was entirely missed by the otolith thin sections. Therefore, based on this very limited study, we have some doubts concerning the usefulness of otolith thin sections.

Appendix 2



LOCATION OF WALLEYE POLLOCK REFERENCE SAMPLES

Appendix 3

WORKSHOP ON AGEING METHODOLOGY OF WALLEYE POLLOCK
GDYNIA, 10-14 SEPTEMBER 1990

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END OF SUPPLEMENT D.1 AND MODULE D

MODULE E

Module E: Distribution, Migration and Stock Structure

Facilitator: Pierre Dawson

Tagging

Tagging of pollock carried out in the Bering Sea in the 1960's and 70's yielded relatively few returns (Yoshida 1979 Figure 1). Two pollock tagged on the western Bering Sea shelf were recovered on the eastern Bering Sea shelf, approximately 600 miles away. Another 2 pollock from the western shelf were recaptured in the Aleutian Basin, one of them after 7.5 years. One pollock tagged off Hokkaido Island, Japan was also recovered in the Aleutian Basin. Apparently the vessel that reported that tag had just been fishing off Hokkaido (Sasaki 1987 personal communication) so it is possible that the tagged fish might actually have been caught in the Hokkaido area.

Fleet movement

There is a general movement of the fishing fleet in the donut hole from the western portion in the fall to the southeastern quadrant by February and March when catches are at their minimum (Sasaki 1989, Sasaki and Yoshimura 1987). The fleet typically again encounters concentrations of pollock in the southeastern corner in March and April and moves generally northwestward (Figure 2). During February and March pollock are found spawning in large concentrations in the Bogoslof Island area, 240 miles to the southeast of the donut hole.

This movement of the fleet and the change in catch levels suggest that pollock are migrating across the donut hole and continuing to the southeast to spawn in the Bogoslof Island area and then dispersing back throughout the donut hole after spawning is completed.

Distribution

The distribution of spawning grounds in the Bering Sea is portrayed in figure 3 (Bulatov 1989). The distribution of eggs is shown in figure 4 (Fadeev 1990). Large concentrations were found in the southeastern Basin in the Bogoslof Island area, over the southeastern Bering Sea shelf, and in the Gulf of Olyutorski in the western Bering Sea. The distribution of larvae is shown in figure 5. Major concentrations were reported over the eastern Bering Sea shelf and in the Olyutorski-Karaginskiy area in the west. In September and October, 1987, young of the year were distributed broadly over the eastern shelf and in Korfa-Karaginskiy area in the west (Figure 6). In the same time period, one year old pollock were found over the northeastern and northern shelves and the Olyutorski region in the west (Figure 7). The distribution of juvenile pollock in the US EEZ is shown in Figure 8. Concentrations end at the shelf edge with just traces found in the deep water of the Aleutian Basin.

Age Composition

Comparisons of age composition data from commercial fisheries and research surveys in the central and eastern Aleutian Basin and on the eastern Bering Sea shelf have shown that the population of fish in the Basin is much older than that sampled on the eastern Bering Sea shelf, with few fish younger than 5 found in the Basin (Figure 9) . The 1978 year class was a dominant year class on the eastern shelf and has been the dominant year class in the basin since 1984. Within different areas in the basin and between summer and winter within a year, the age composition in the Basin has varied little (Figure 10 and 11). On the eastern Bering Sea shelf, the region to the north of the Pribilof Islands typically has a greater percentage of younger ages than the shelf to the south (Traynor et al. 1990, Figure 12). In 1989 the abundance of each age class north and south of the Pribilof Islands as measured by the annual bottom trawl survey is shown in figure 13. In addition to the larger percentage of younger ages in the north, the overall biomass is greater in the north. With the strata shown in figure 14, figure 15 shows the biomass by subarea on the eastern Bering Sea shelf measured by the annual bottom trawl survey. A continually growing percentage of the biomass has been found in the subarea 6, the outer shelf northwest of the Pribilof Islands until that subarea has come to contain the largest fraction of the measured biomass.
The age composition in the basin and shelf sampled in 1989 is shown in figure 16. The abundance of each age class for the Bogoslof Island area in the winter and the eastern Bering Sea shelf in the summer is shown in figure 17. The shelf abundance at age only represents the portion of the population sampled by the bottom trawl survey and so does not include midwater pollock.

In 1990 an age sample was collected on a cooperative Soviet-US bottom trawl survey that sampled strata 140,150 and 160 in the western Bering Sea shown in figure 18. The age composition shows the same basic yearclasses that are important in the eastern shelf, namely the 1978, 1982, and 1984. The 1985 yearclass shown as important in the western Bering Sea sample also showed up significantly in portions of the eastern Bering Sea.

Size at Age

The typical size at age of pollock on the eastern Bering Sea shelf and in the Bogoslof area is shown in figure 19. The data presented in the figure comes from a summer 1988 combined bottom trawl and acoustic/midwater surveys on the eastern shelf and from an acoustic/midwater survey in the Bogoslof area in the winter of 1988 but the results are similar to that reported by other researchers (Lynde et al. 1986, Dawson 1989). The northern shelf pollock are typically smaller at age than fish from the southern shelf. Pollock from the basin at age 5 or 6 have a similar size at age to pollock on the shelf but at older ages their size at age does not increase at the rate that it does on the shelf. Consequently, by age 10 in 1988 the size at age of basin pollock was less than that of the shelf pollock from either area.

The size at age sample from the western Bering Sea in 1990 was similar to that from the eastern Bering Sea shelf in 1989 (Figure 20, Honkalehto 1990, for winter Bogoslof and shelf size-at-age). The size at age of eastern shelf pollock was stable between the winter and summer of 1989 (Figure 20).

Typically the size at age of samples from the basin shows little difference between areas and seasons. 1989 data is shown in figure 20. In 1988, however, there was a strong seasonal difference in size at age between winter and summer in the basin (Figure 21). The age composition between these samples in 1988 in the basin did not change.

Length Composition

The length composition of the northern and southern portions of the eastern Bering Sea shelf and the basin in 1988 is shown in figures 10, 11 and 12. The length composition is markedly different between the north and south shelf with the size distribution extending to smaller lengths in the north than in the south. The basin sample however represents a very narrow size range in comparison to the shelf samples. In the basin the vast majority of the pollock are between 40 and 55 cm in fork length while fish on the shelf are found between 20 and 60 cm from the 1988 data. Data from the commercial fishery in the donut hole has shown a similar size distribution each year with a steady increase in mean size of approximately .5 to 1 cm per year (Figure 22).

Dr. Fadeev reported that there was a similar difference in length composition between pollock on the western Bering Sea shelf and western basin areas, with a broader size range found over the shelf and a very narrow size range over the western basin. The size distribution in the western basin was very similar to that found to the east (Figure 23).

Length-weight

The length-weight relationship is not very different between the shelf and the basin (Hinckley 1987, Figure 24).

Fecundity

Hinckley (1987) found a different fecundity-weight relationship for pollock from the basin than pollock on the shelf (Figure 25) although a study by Teshima et al. (1989) found a more similar relationship between the shelf and basin pollock (Figure 25).

Genetic Studies

A recent genetic study looking at mitochondrial DNA by Mulligan et al. (In press) found Bogoslof Island pollock to be similar to pollock sampled in the donut hole with small differences seen between that grouping and Shelikof Strait in the Gulf of Alaska. A much larger genetic difference was found between the Aleutian Basin samples and the sample from the Aleutian Islands area (Figure 26). Unfortunately no samples from either shelf were included in this study.

Egg and Larval drift

Satellite-tracked drifter buoys placed in the Bogoslof Island area either drifted up onto the shelf or along the shelf break (Reed et al. 1988, Reed and Stabeno 1989, Figures 27 and 28). The drift pattern suggests that larvae from the Bogoslof Island may drift up onto the eastern Bering shelf or drift along it possibly ending up on the northern Bering Sea shelf.

Larval hatch dates

Dr. Sasaki presented results of a study that found a similar distribution of larval hatch dates for samples from the central and eastern Bering Sea (Table 1). The hatch date distribution more closely matched the period of shelf spawning which is approximately one month later than spawning in the basin.

Conclusions

After discussing the above data the group reached a consensus on a working hypothesis to describe the stock structure of Bering Sea pollock. Three stocks were described, one on the western Bering Sea shelf, another over the eastern Bering Sea shelf and a third in the Aleutian Basin. The recruits to the basin population are hypothesized to come from the eastern and western Bering Sea shelves. Spawning occurs in all three areas but the spawning in the Aleutian Basin may contribute to the biomass on the shelves. One possible implementation of this hypothesis was presented by Dr. Mito in figure 29. All of the details need to be filled in by further research, of which it was agreed a basin-wide tagging study was an important part.

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Table 1.--Collecting data and results of birth date estimation of juvenile walleye pollock in the eastern Bering Sea, 1989 summer survey.

Area	Station no.	Collecting date	Fish no.	Fork length Range	Fork length Mean	Increment no. Range	Increment no. Mean	Estimated hatching date Range	Estimated hatching date Mean
Southern shelf	A06	7, Aug.	17	45.8-74.6	60.0	71-104	87.6	24, Apr.-28, May	11, May
	L03	3, Aug.	17	33.2-67.1	48.2	60-98	78.7	29, Apr.- 4, June	16, May
	A13	18, Aug.	16	43.8-70.5	63.7	72-114	94.4	25, Apr.- 6, June	15, May
	L17	22, Aug.	24	55.6-75.3	63.8	70-105	89.8	9, May -13, June	24, May
	L18	23, Aug.	22	40.1-77.2	67.2	76-104	91.9	11, May - 8, June	23, May
Northern shelf	L22	14, Sep.	23	68.1-94.5	83.6	97-135	117.6	2, May - 9, June	19, May
	L24	15, Sep.	20	74.6-92.1	83.8	80-139	118.1	29, Apr.-26, June	19, May
Basin	L16	21, Aug.	20	55.2-78.1	67.1	77-115	97.7	28, Apr.- 5, June	15, May

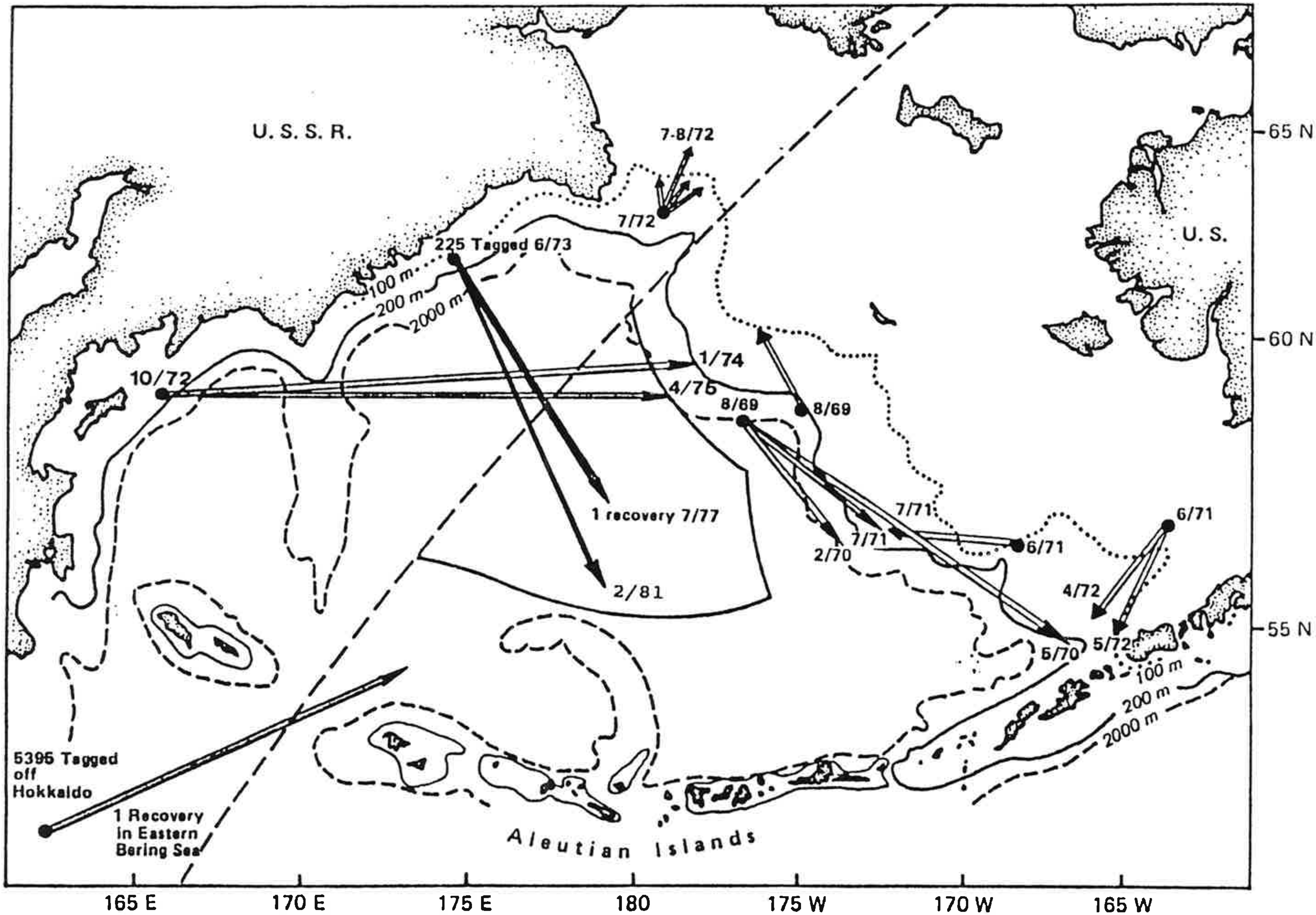


Figure 1.--Movement of Japanese-tagged pollock in the Bering Sea (from Yoshida 1979, Sasaki 1987 pers. commun.).

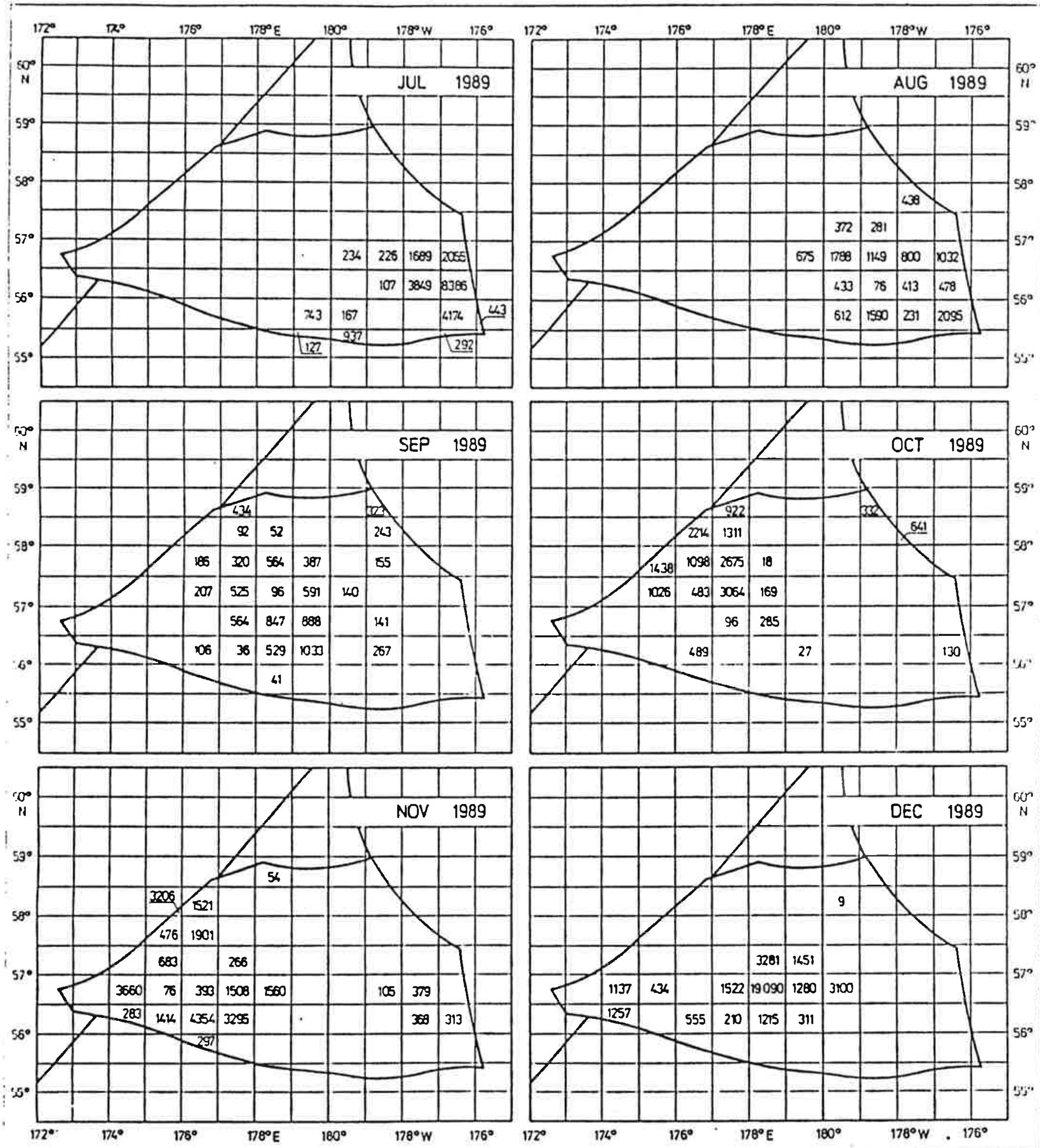


Figure 2.--Polish commercial catches in last half of 1989 and first half of 1990 by months and 1/2 degree lat. by 1 degree long. areas (Provisional data).

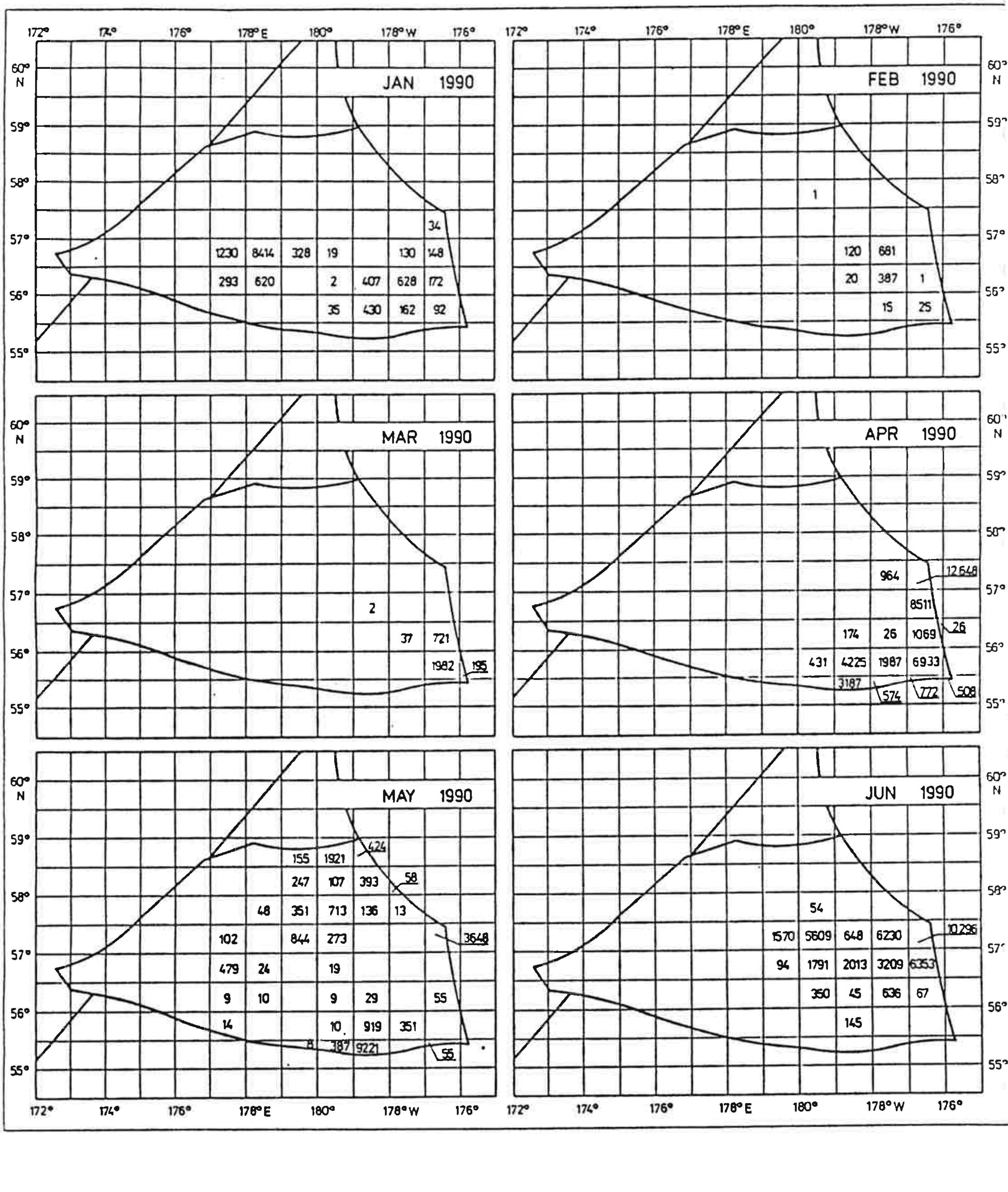


Figure 2.--Continued.

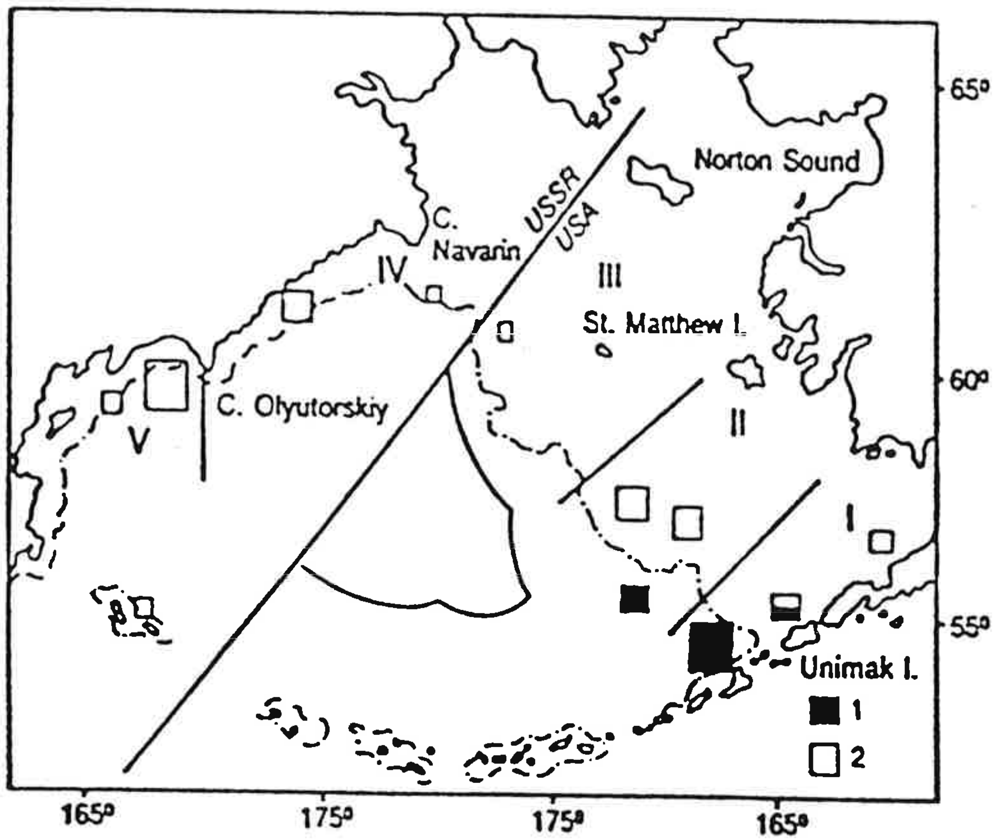


Figure 3.--The main spawning grounds of walleye pollock in the Bering Sea (generalized).

Legend: I = Unimak grounds, II = Pribilof grounds, III = St. Matthew grounds, IV = Olyutorskiy-Navarin grounds, V = Korfa-Karagin grounds. 1 = winter spawning, 2 = spring spawning.

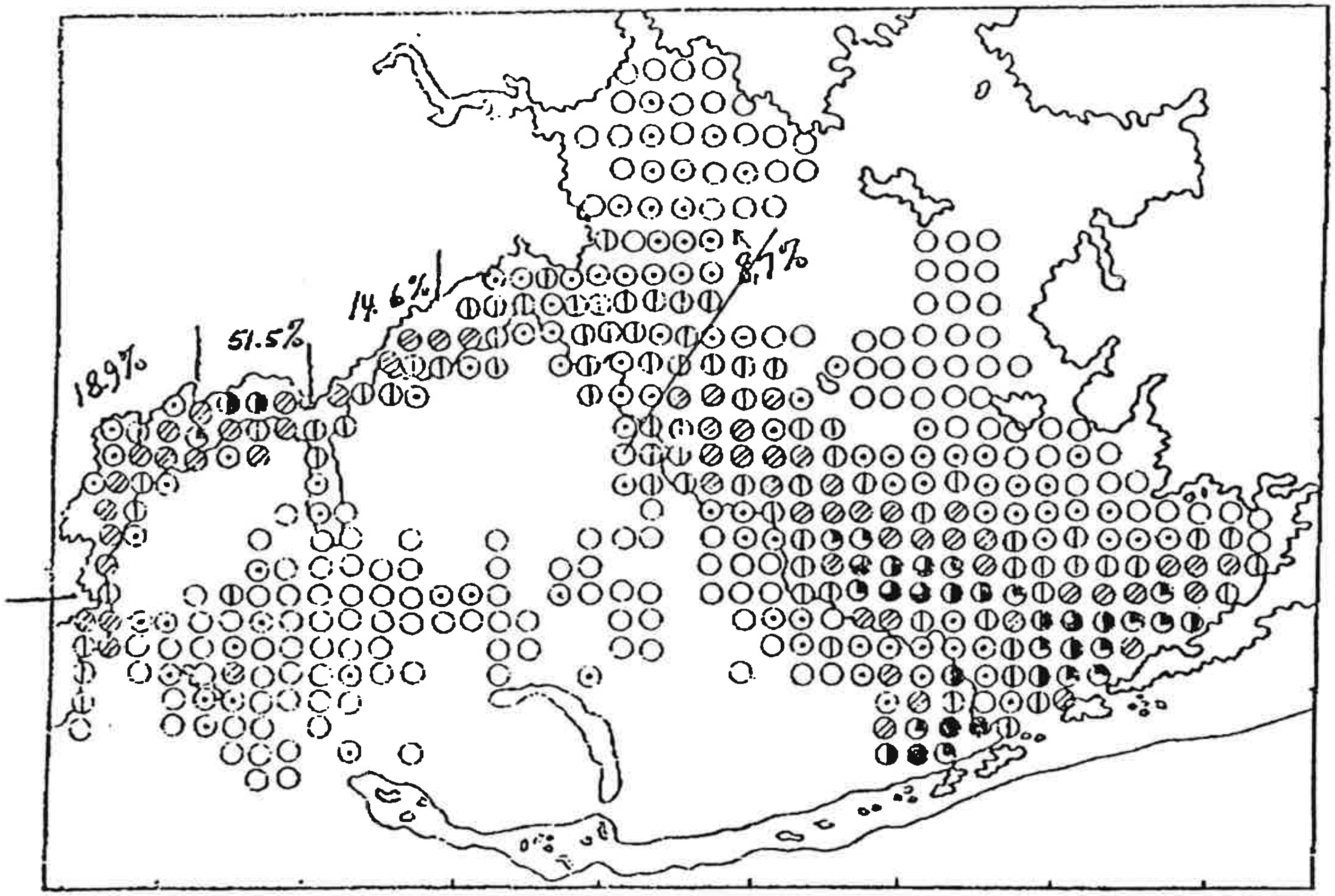


Figure 4.--Distribution of pollock eggs in the Bering Sea based on Soviet research.

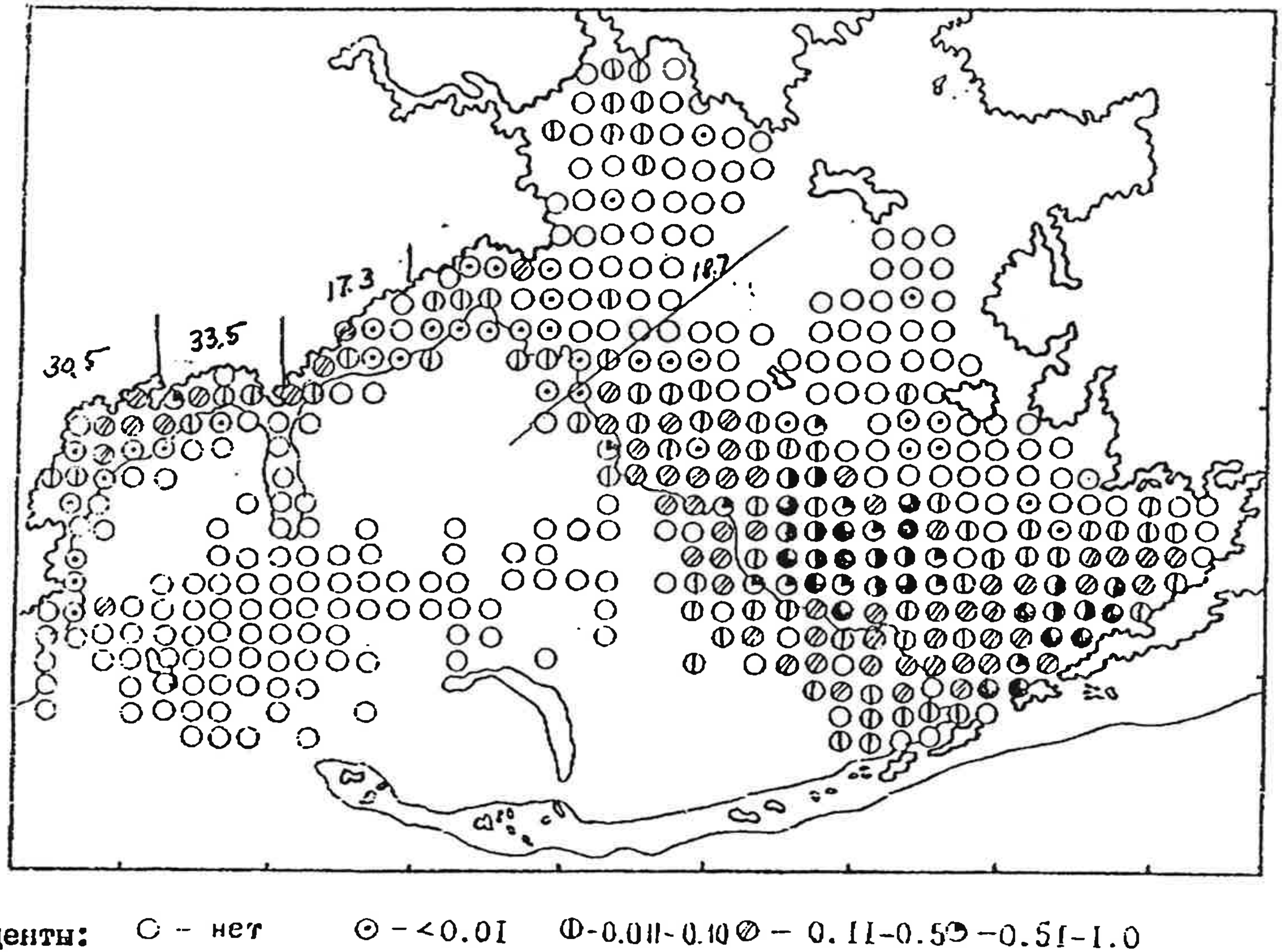


Figure 5.--Distribution of pollock larvae in the Bering Sea based on Soviet research.

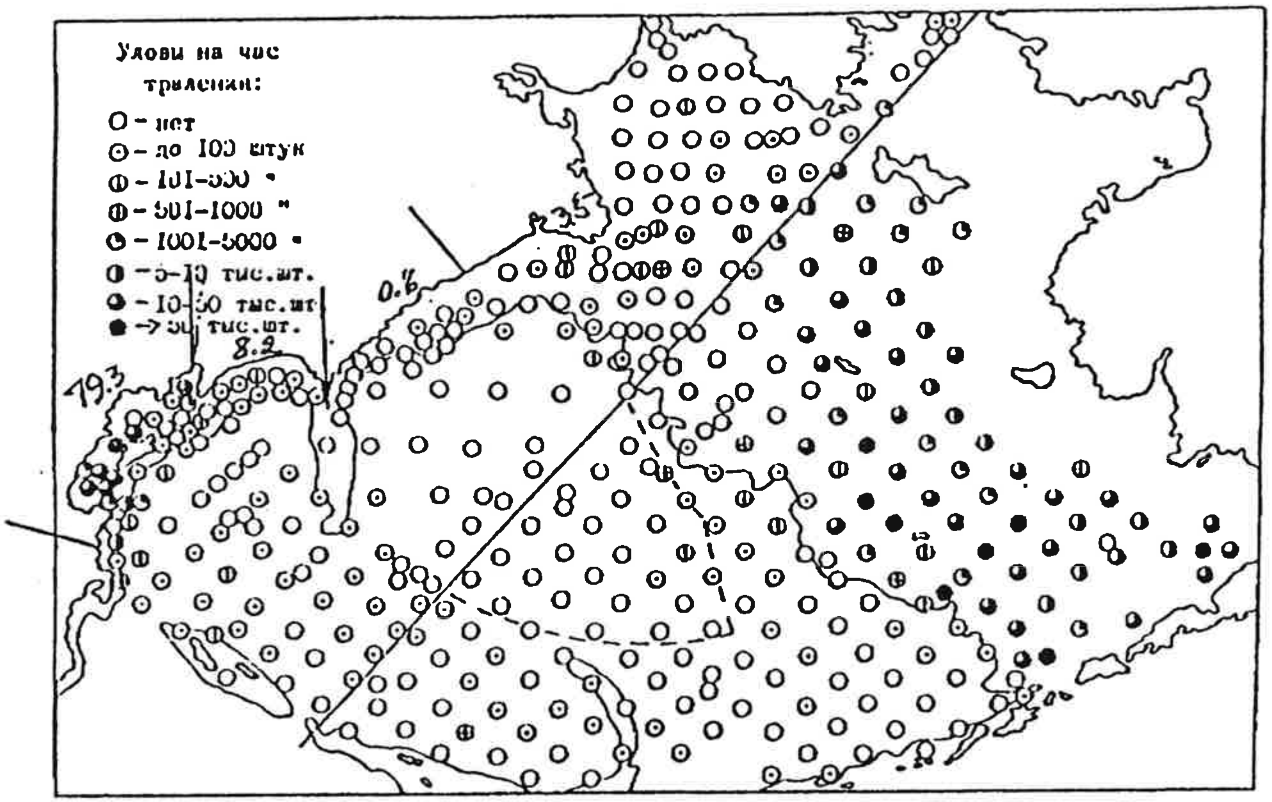


Figure 6.--Distribution of young of the year pollock in September to October 1987, from Soviet research.

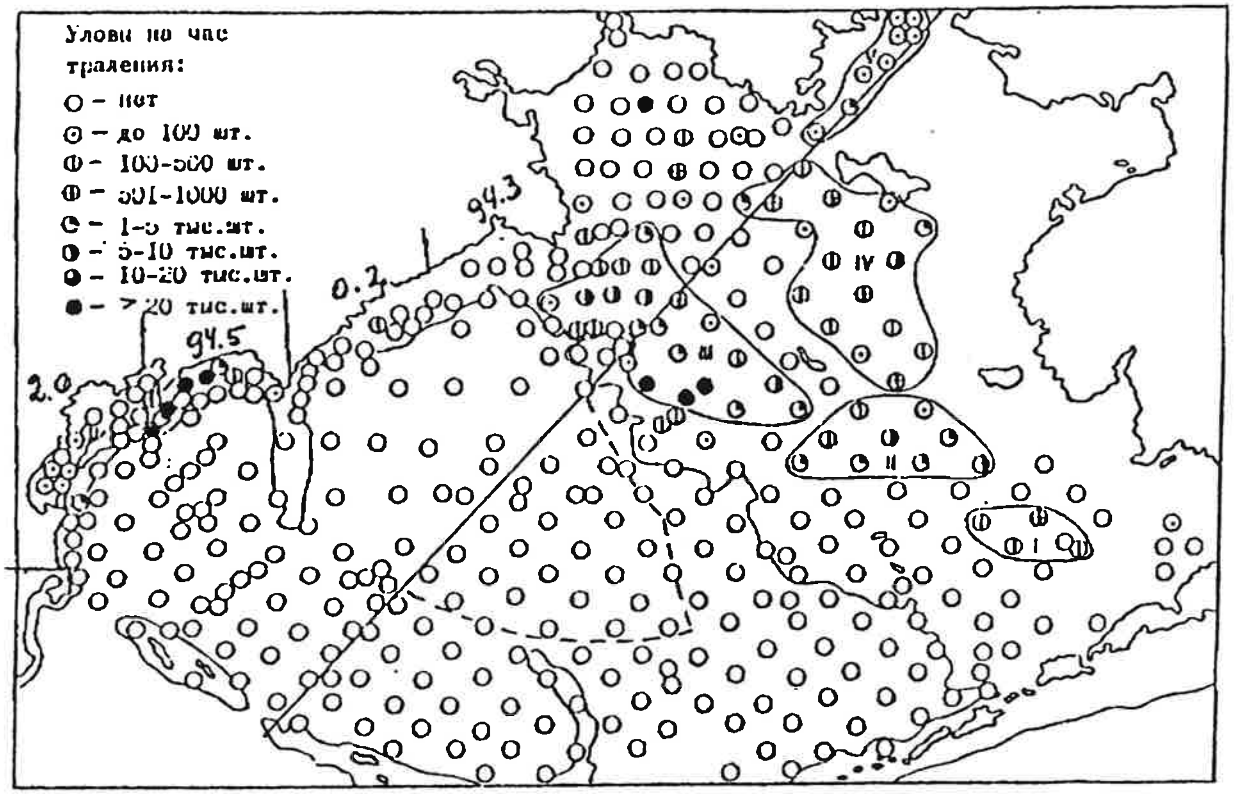


Figure 7.--Distribution of one year old pollock in September to October 1987, from Soviet research.

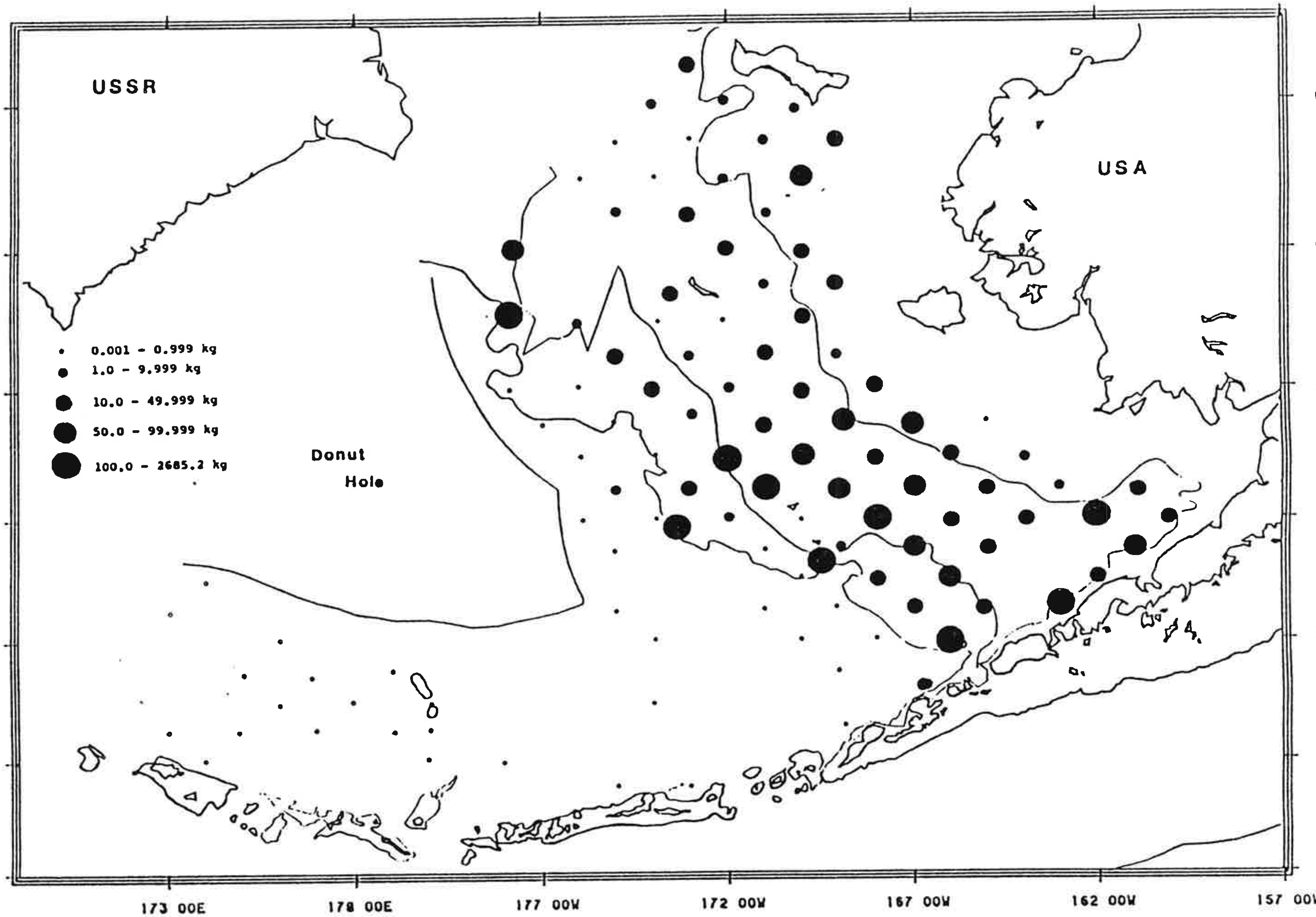


Figure 8.--Relative juvenile pollock abundance from RV Darvin, 22 Aug-08 Oct 1987.

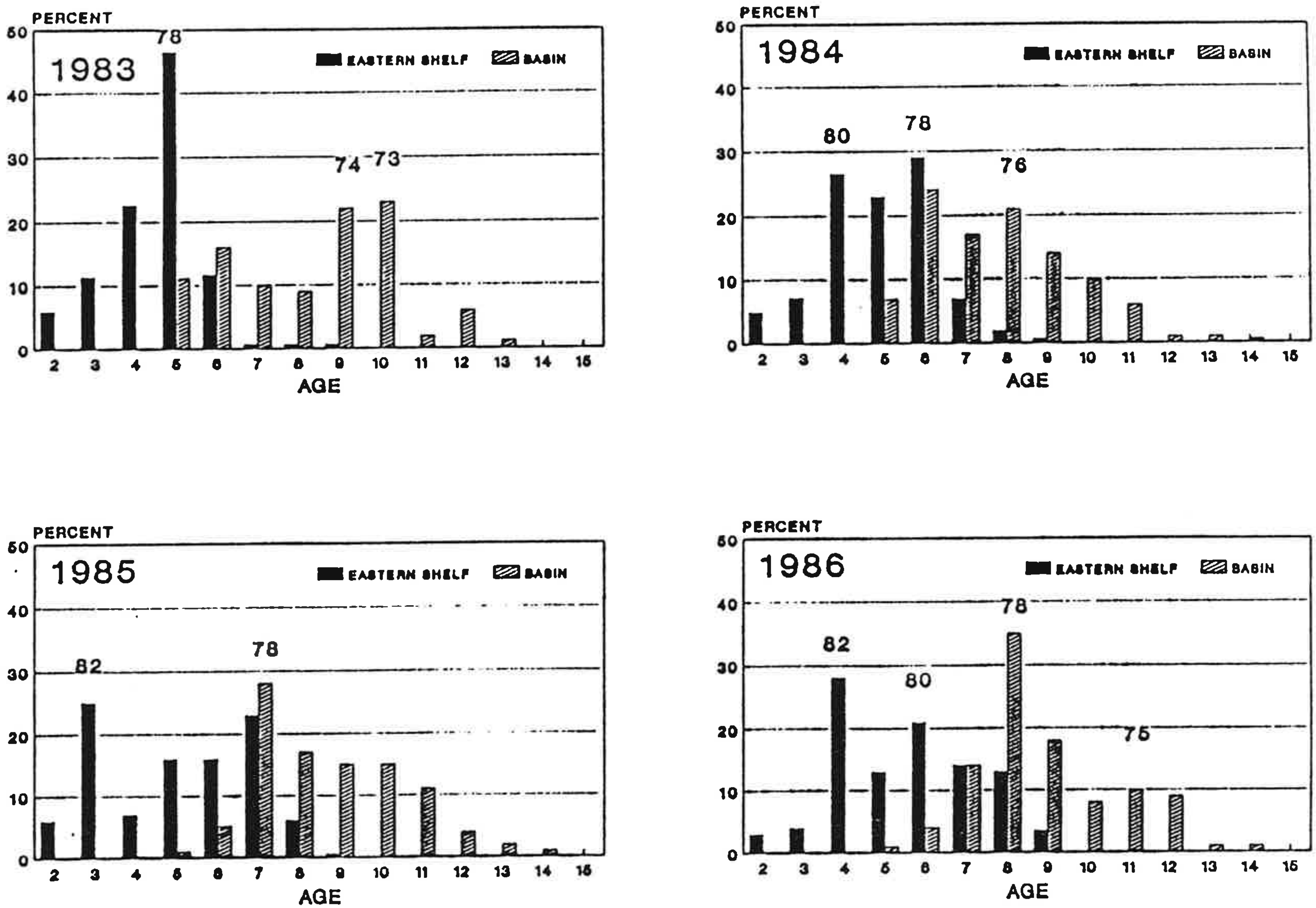
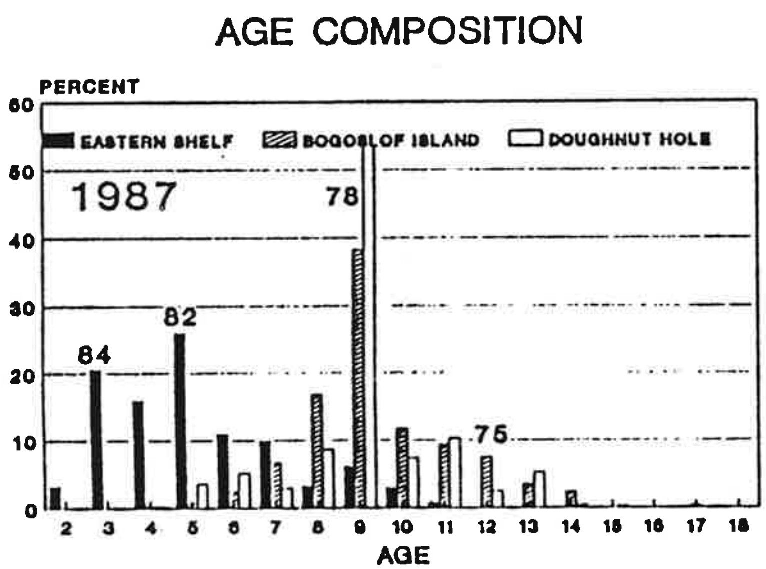


Figure 9.--Age distribution for pollock in 1983-1988 on the eastern shelf and Basin.



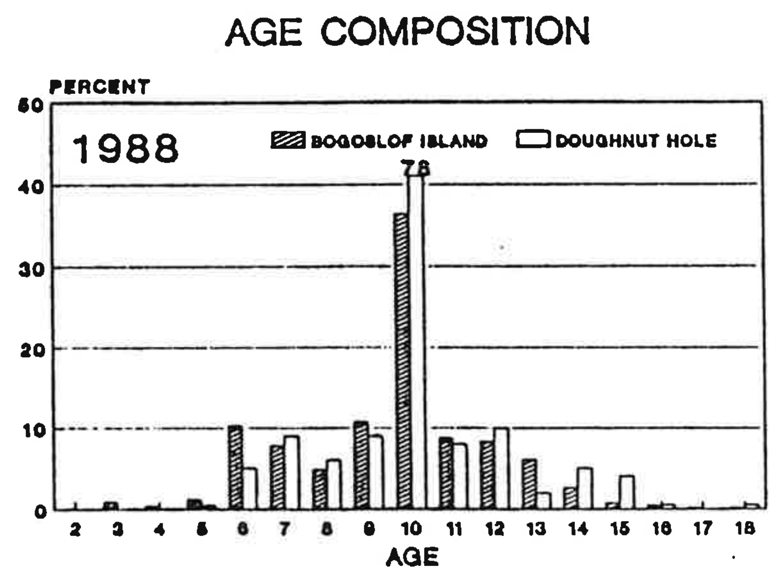


Figure 9.--Continued.

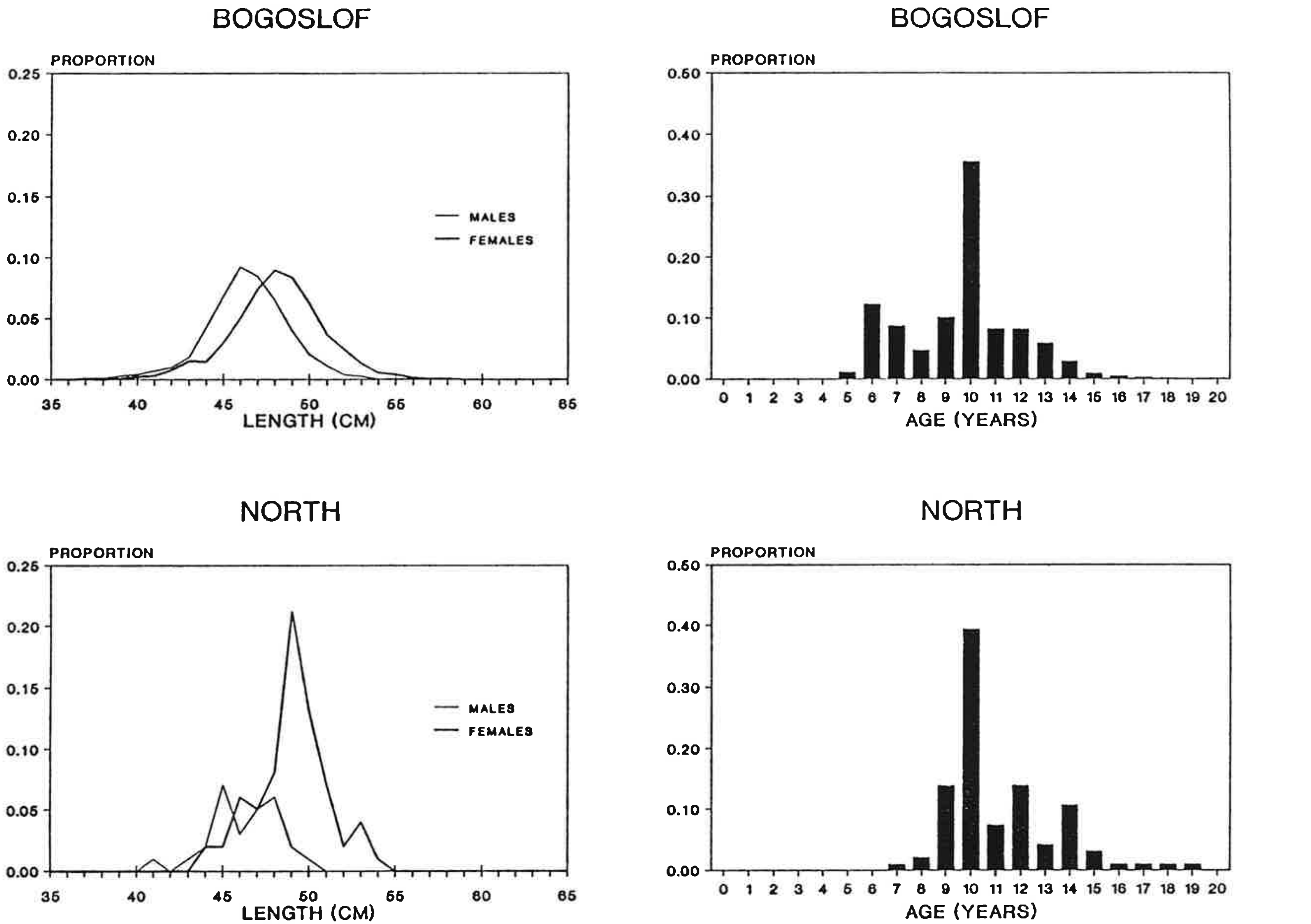


Figure 10.--Age composition and length composition in winter 1988 U.S. survey of central and eastern Aleutian Basin.

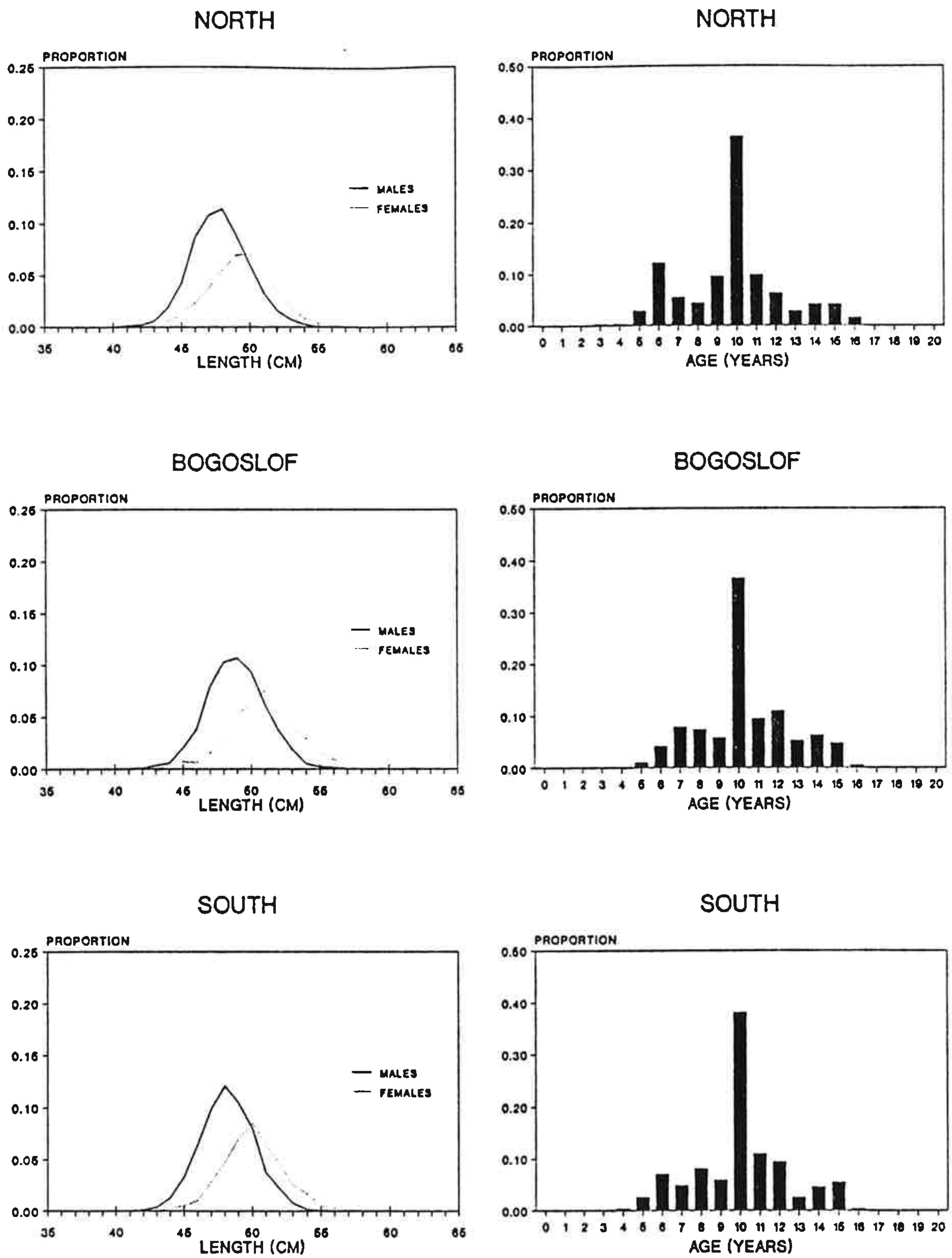


Figure 11.--Age and length distribution of pollock sampled in summer 1988 during cooperative U.S.-Japan central and eastern Aleutian Basin survey.

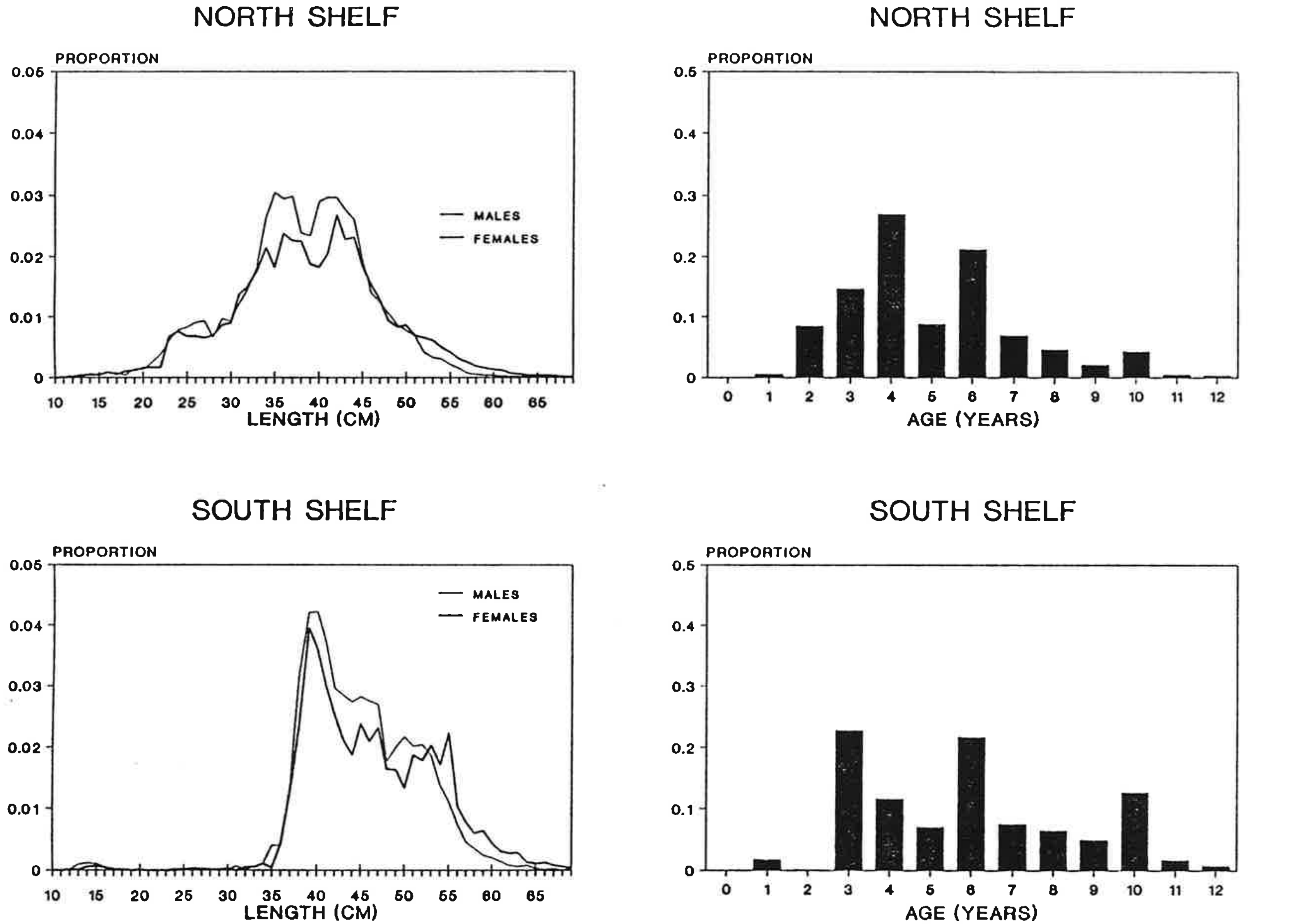


Figure 12.--Age and length distribution of pollock sampled on eastern Bering Sea shelf during 1988 combined bottom trawl and acoustic/midwater trawl survey.

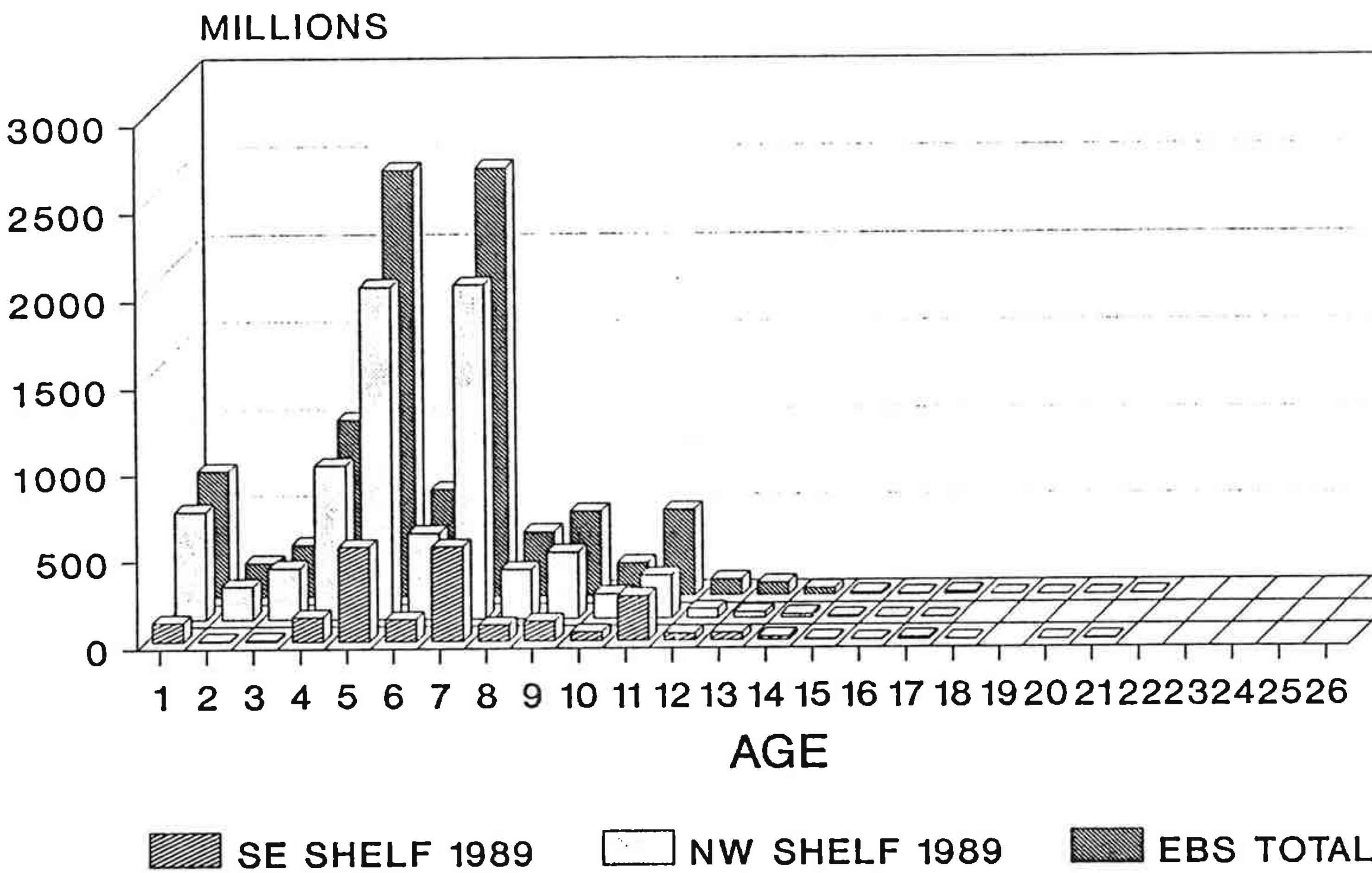


Figure 13.--Abundance at age of pollock north and south of Pribilof Islands as measured by 1989 summer bottom trawl survey.

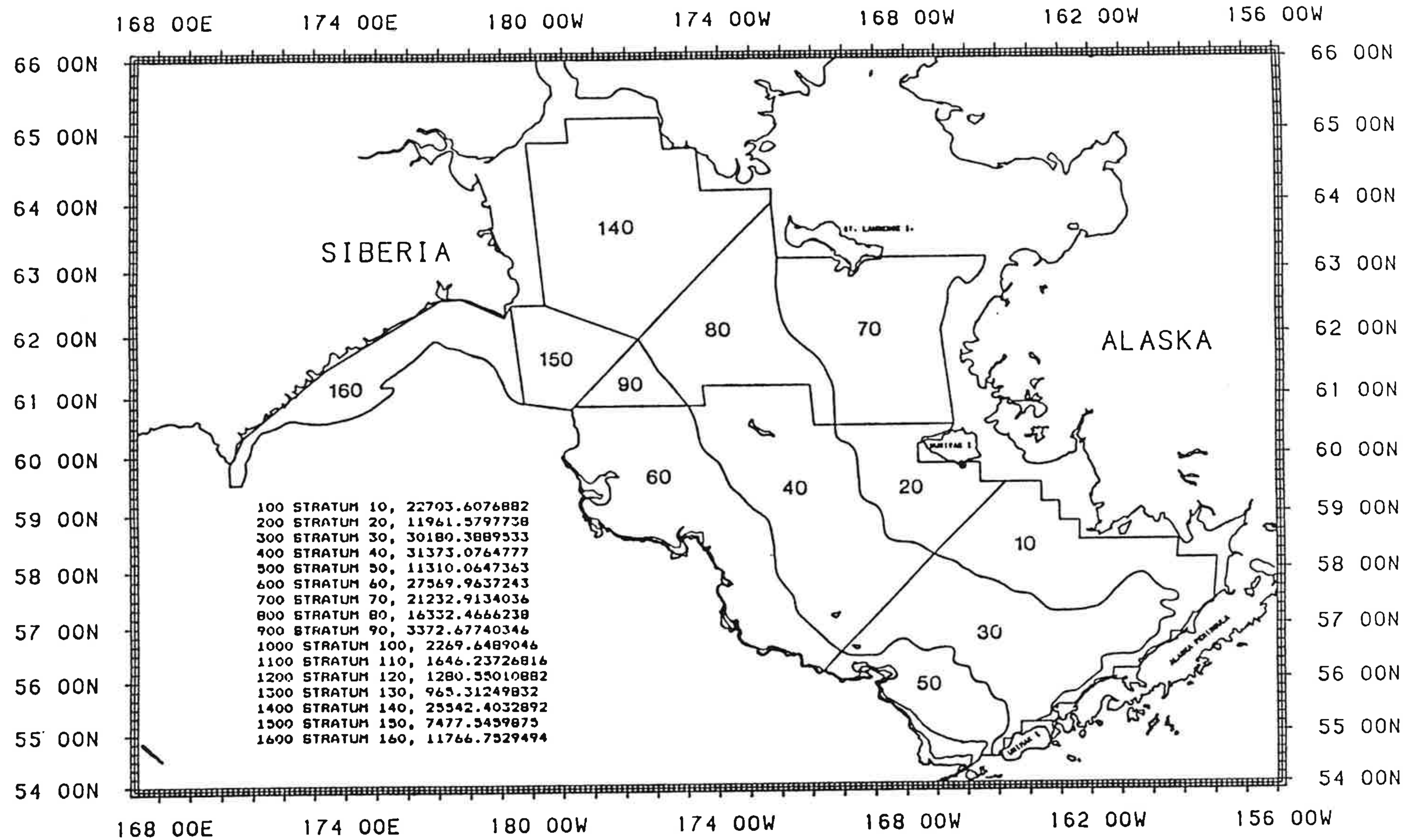


Figure 14.--Survey strata used in Bering Sea pollock surveys by AFSC.

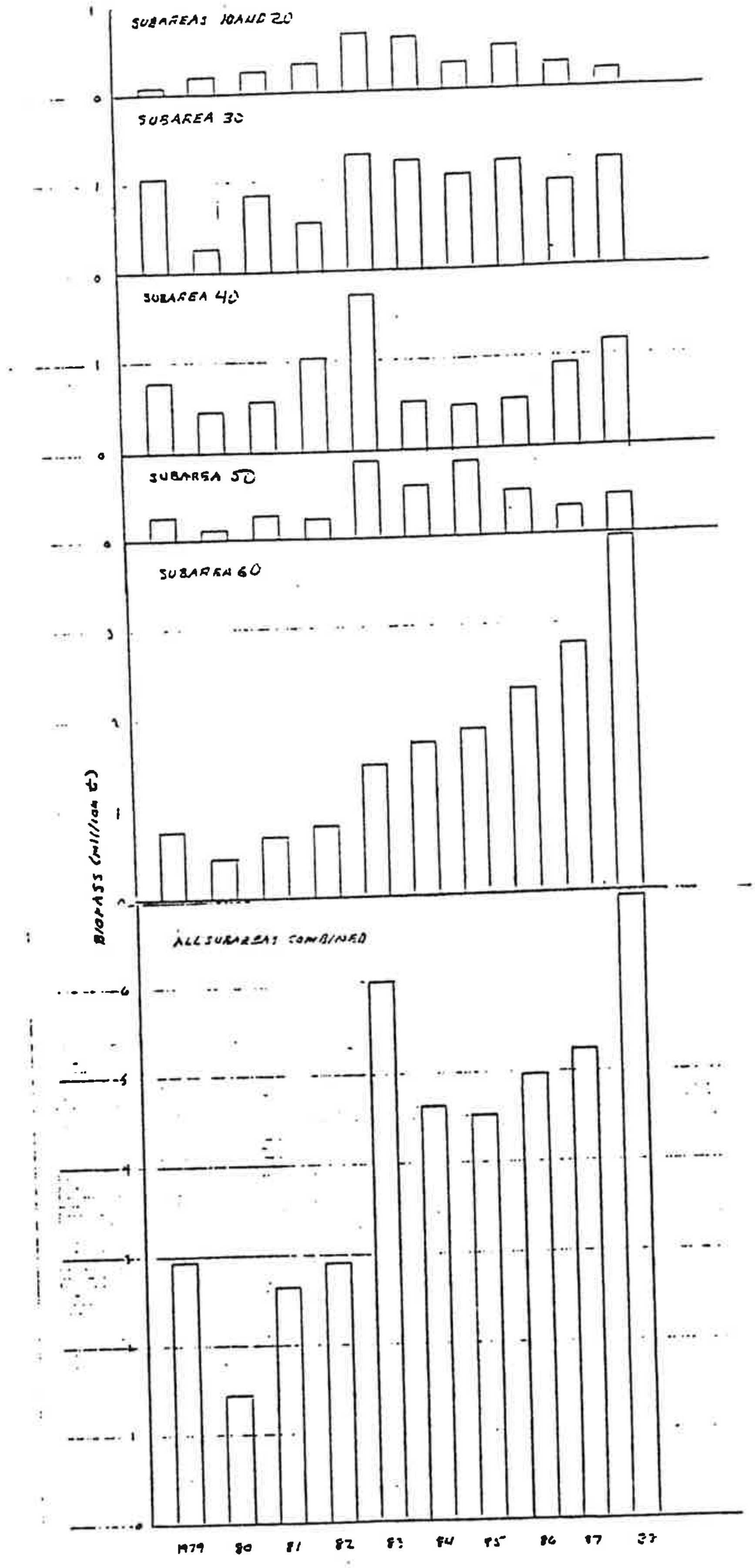


Figure 15.--Biomass of pollock in the eastern Bering Sea by subarea and for all subareas combined from bottom trawl survey data.

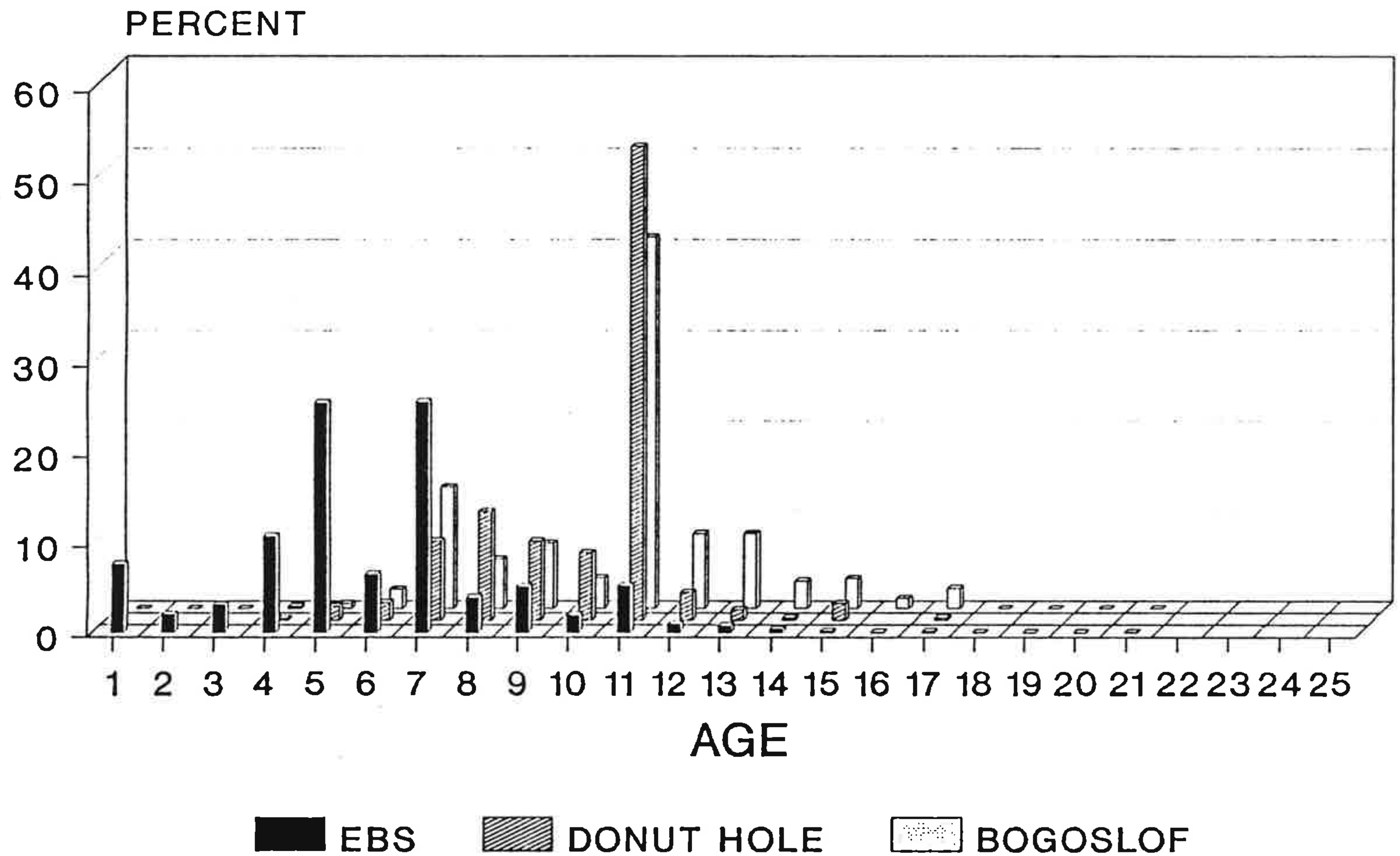


Figure 16.--Age composition of pollock sampled from research surveys and commercial fishing operations in the eastern Bering Sea, Bogoslof Island area and the donut hole in 1989.

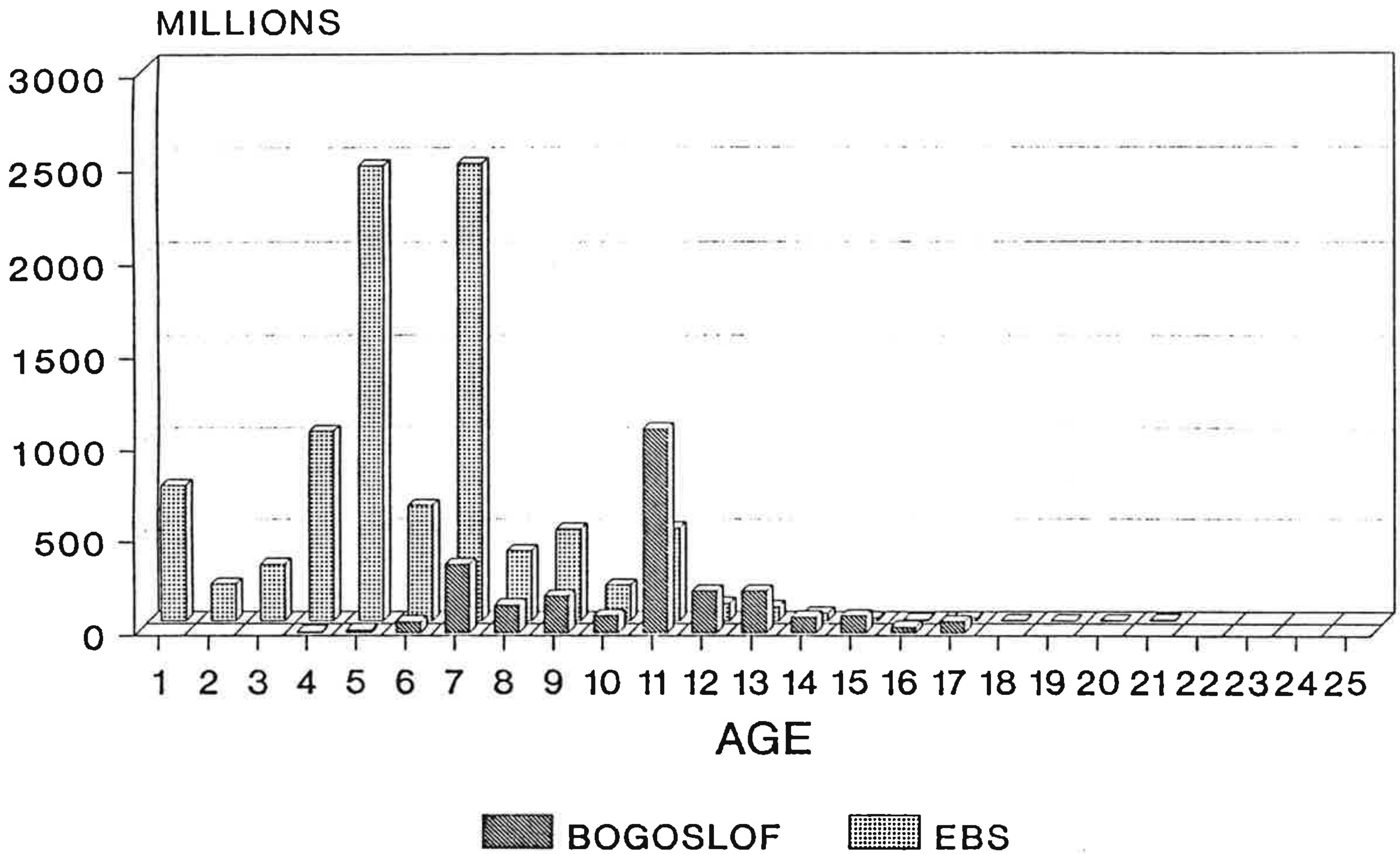


Figure 17.--Abundance at age for pollock in Bogoslof Island area and on eastern Bering Sea shelf from survey data in 1989.

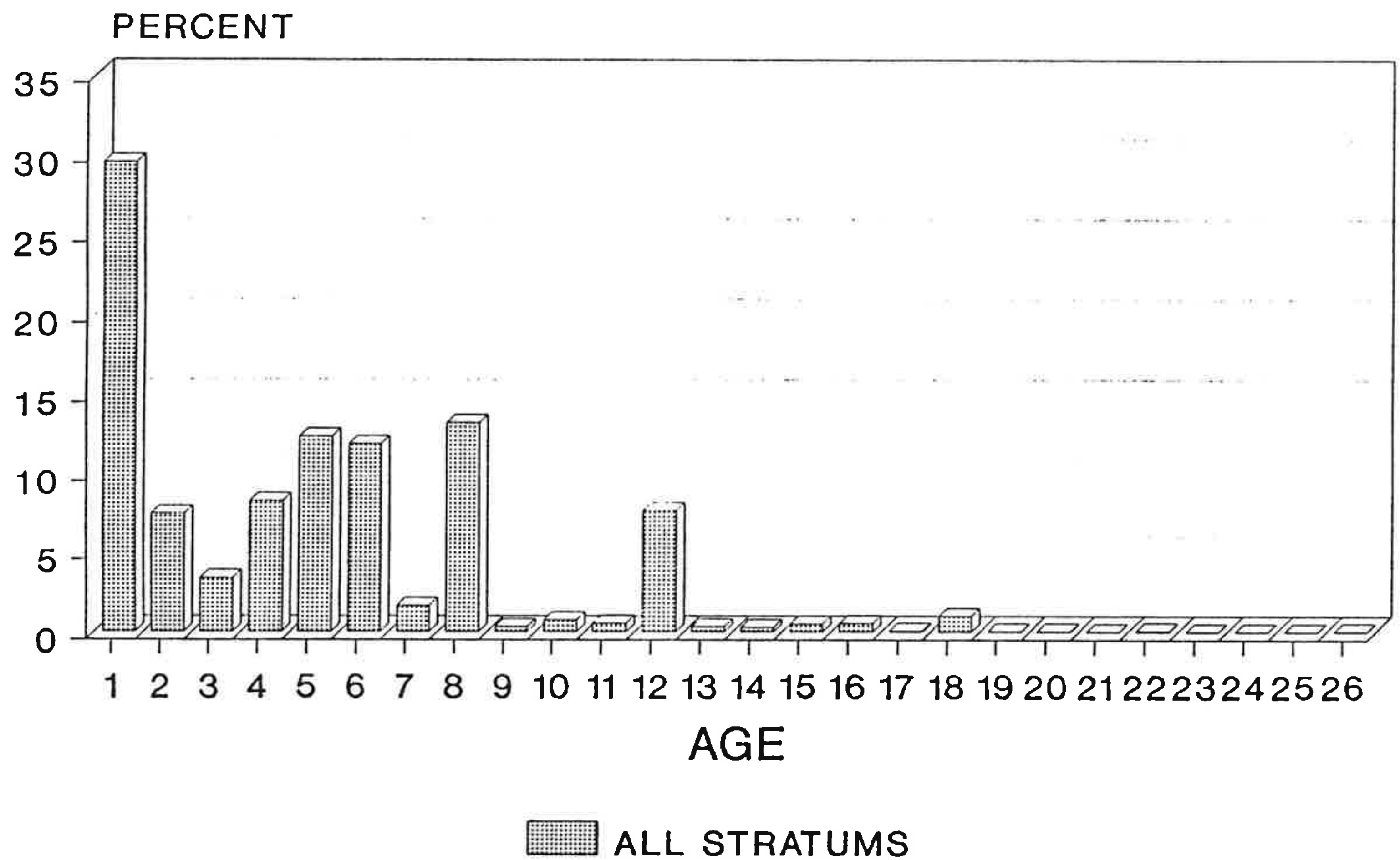


Figure 18.--Age composition of pollock sampled in strata 140, 150, and 160 of the western Bering Sea in Fig. 14 during summer 1990.

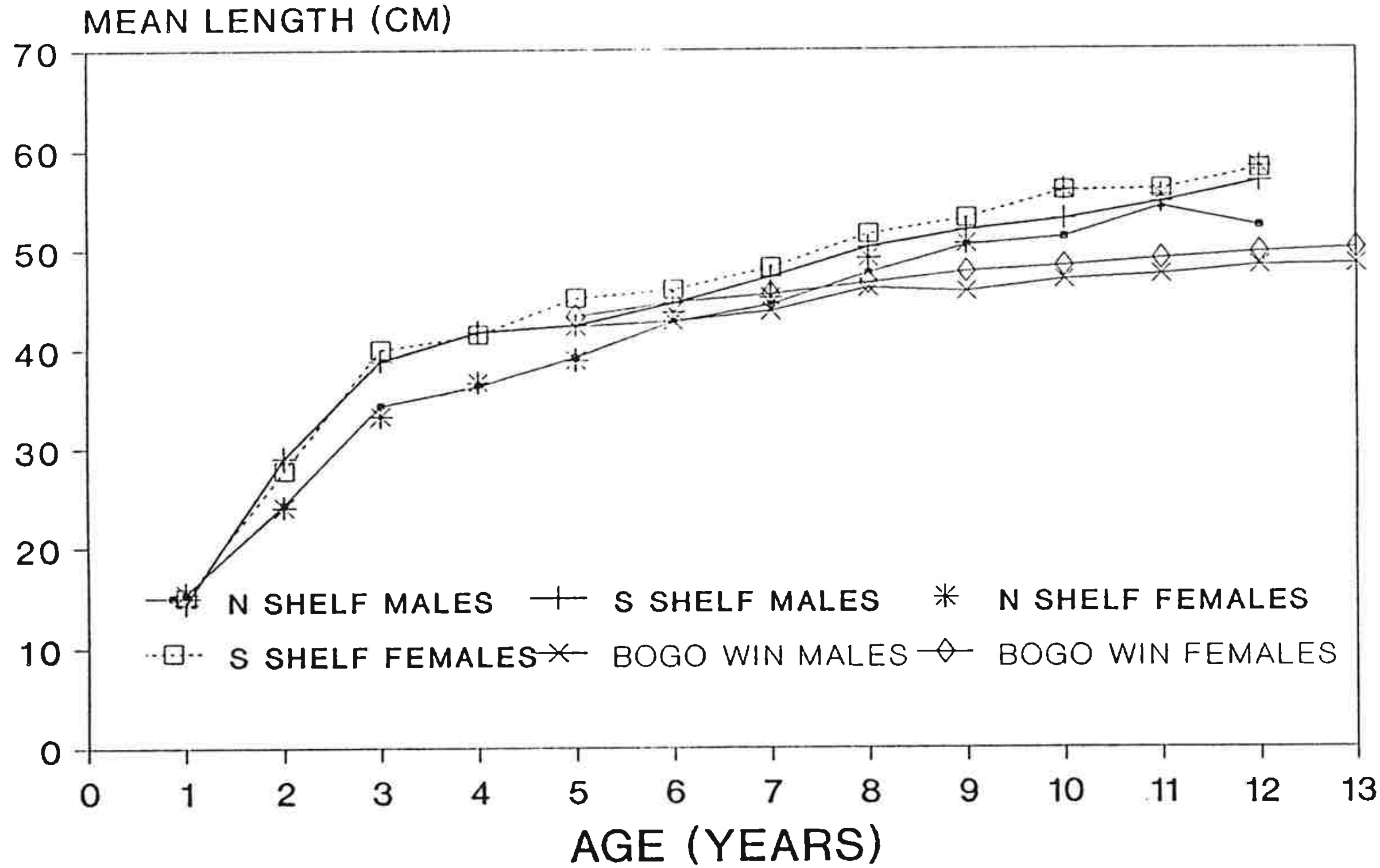


Figure 19.--Size at age of pollock from the northern and southern parts of the eastern Bering Sea shelf and the Bogoslof Island area from research survey data in 1988.

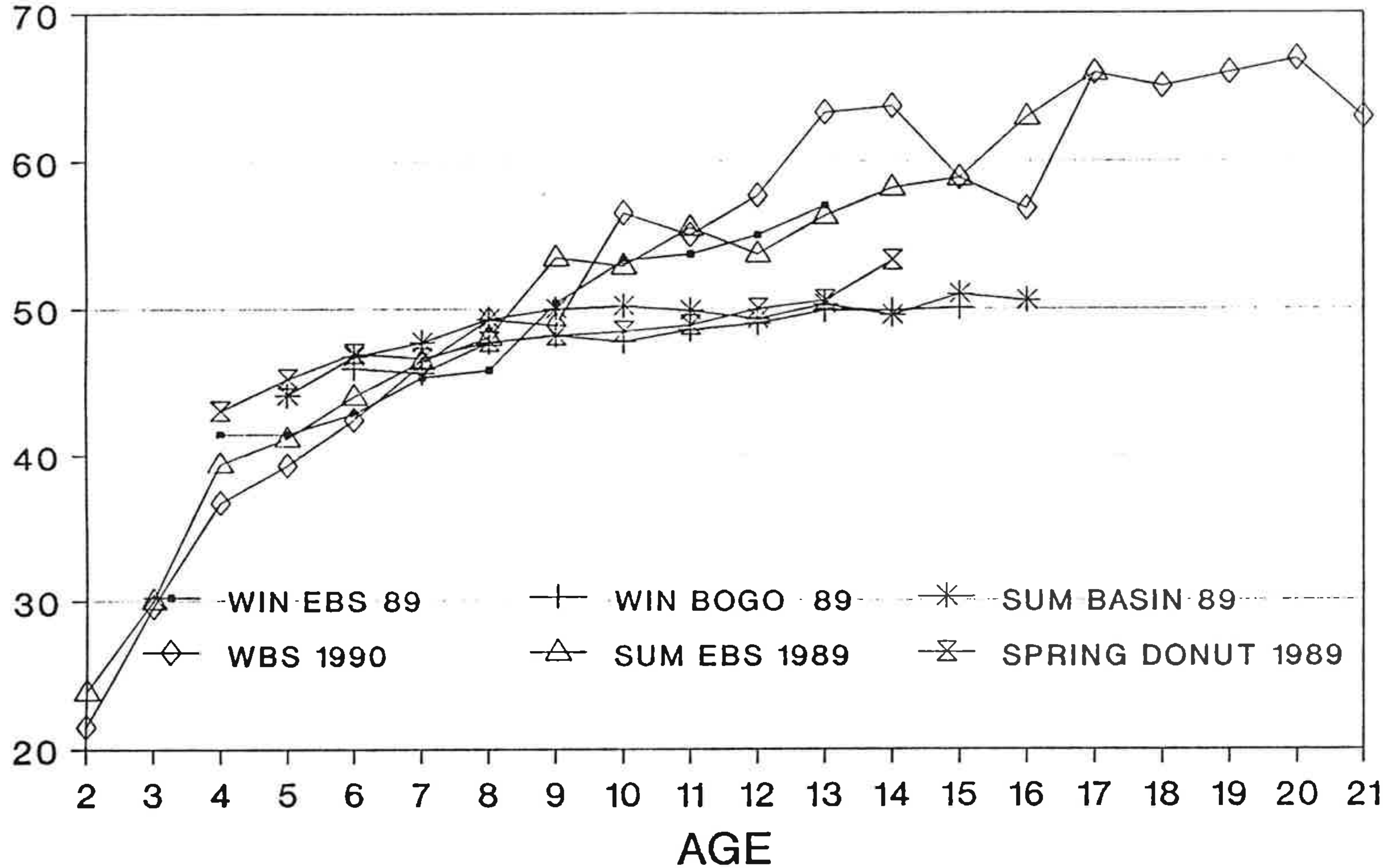


Figure 20.--Size at age of pollock from the western Bering Sea shelf in 1990 and from the eastern Bering Sea shelf in the summer and winter, 1989 and from the winter, spring, and summer of basin locations in 1989 from research survey data.

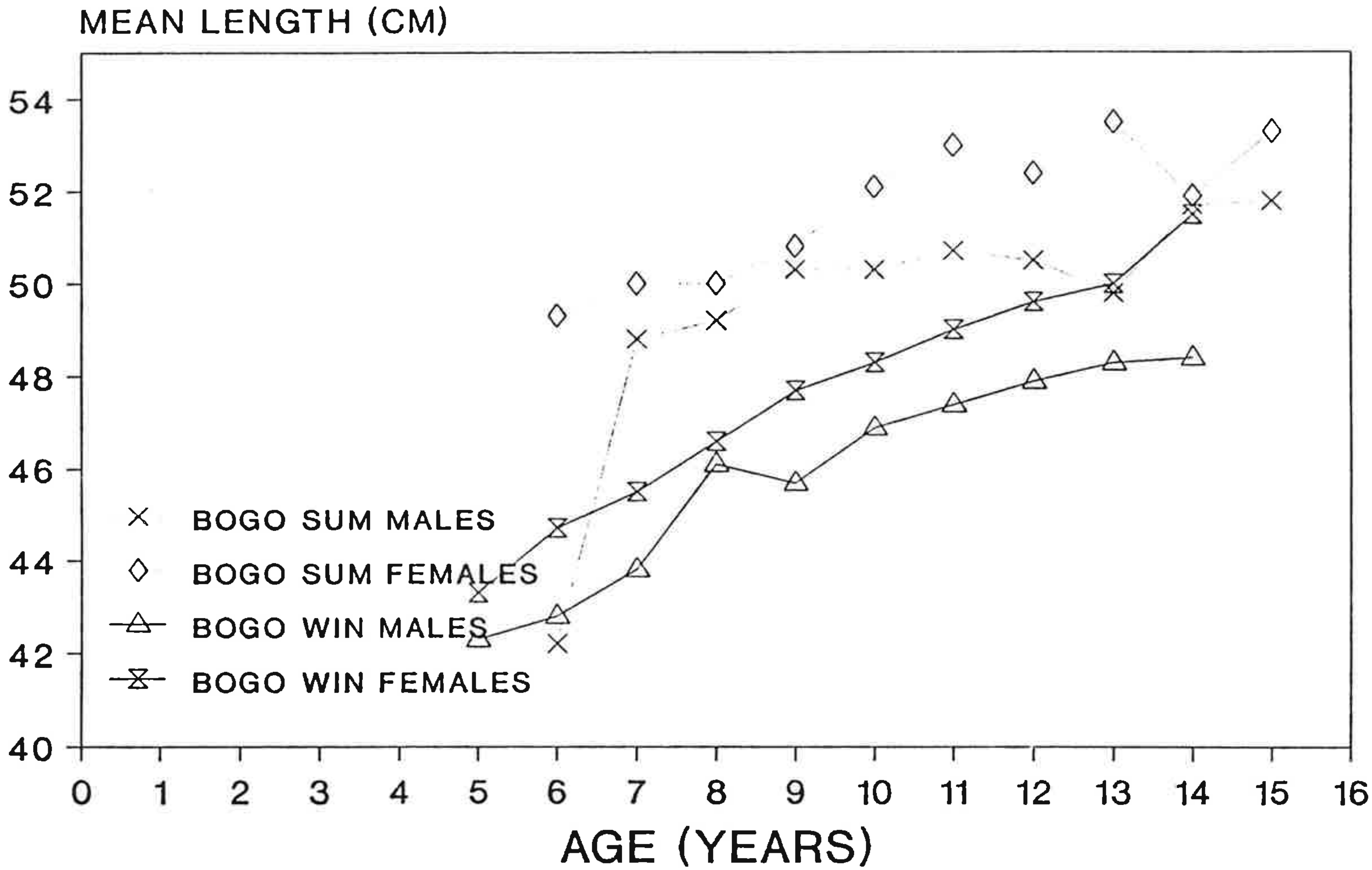


Figure 21.--Size at age of pollock from the Bogoslof Island area from research survey data in 1988 in the winter and summer.

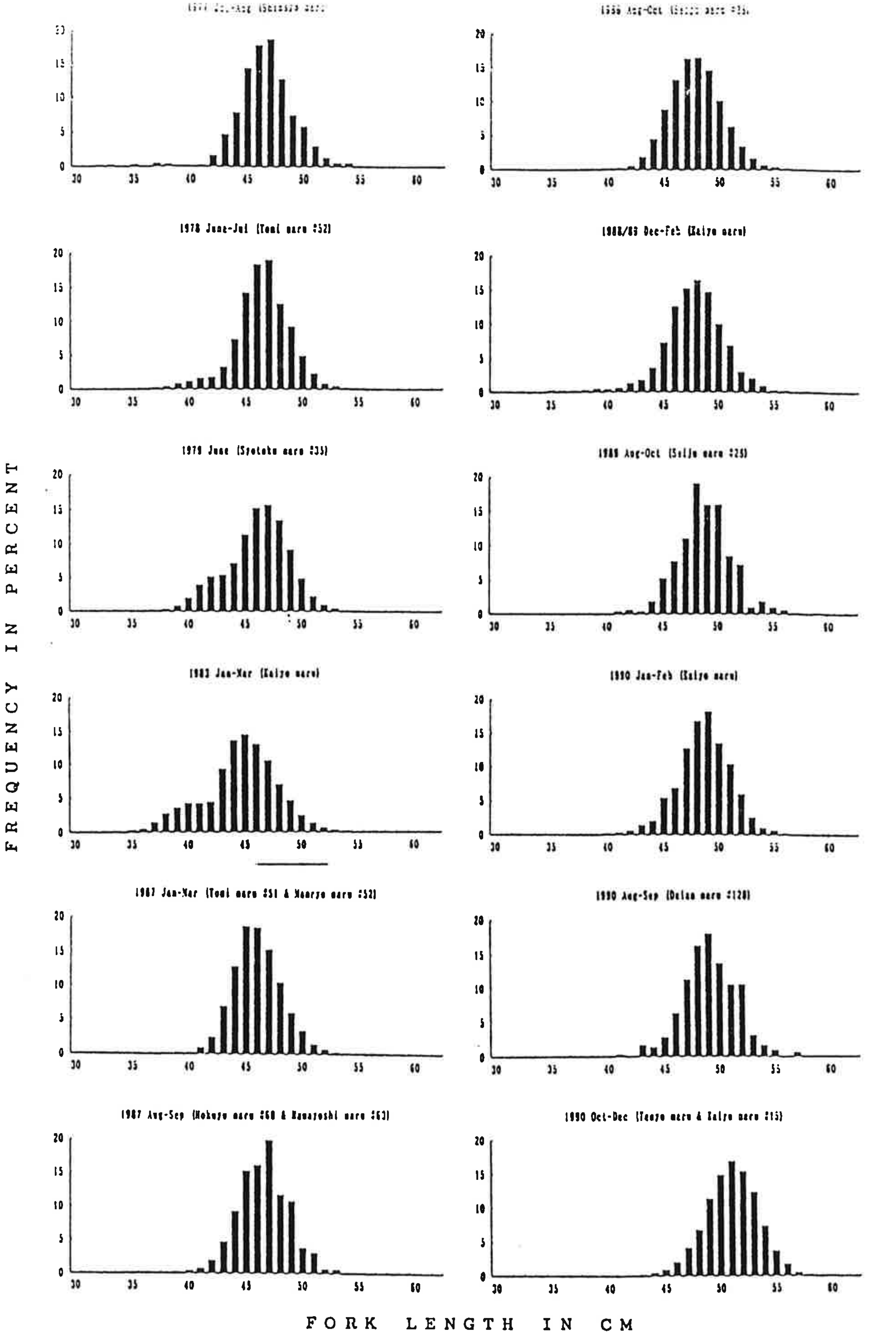


Figure 22.--Japanese survey size composition data of pollock in the Aleutian Basin.

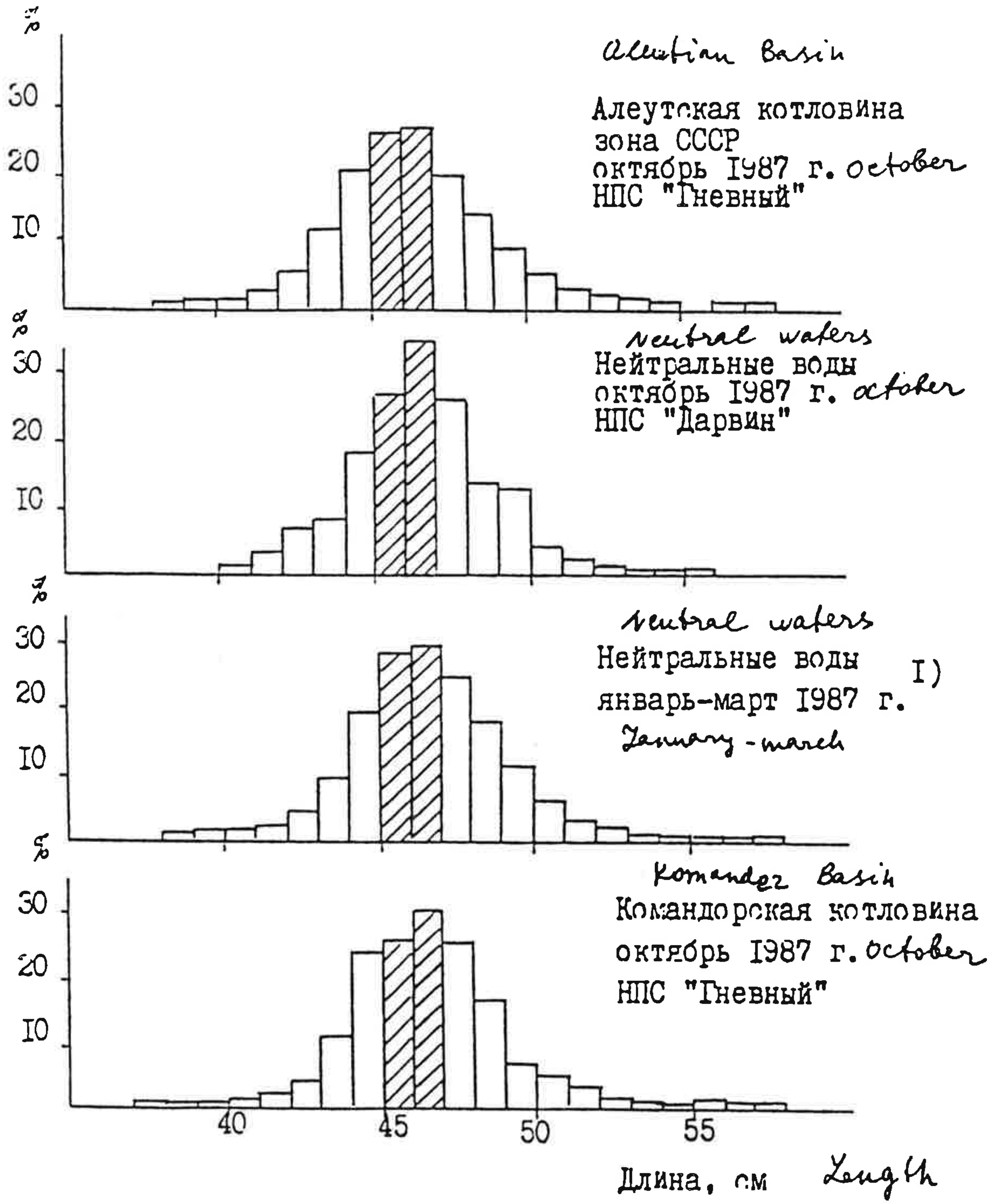


Figure 23.--Size composition of pollock in the basins of the Bering Sea.

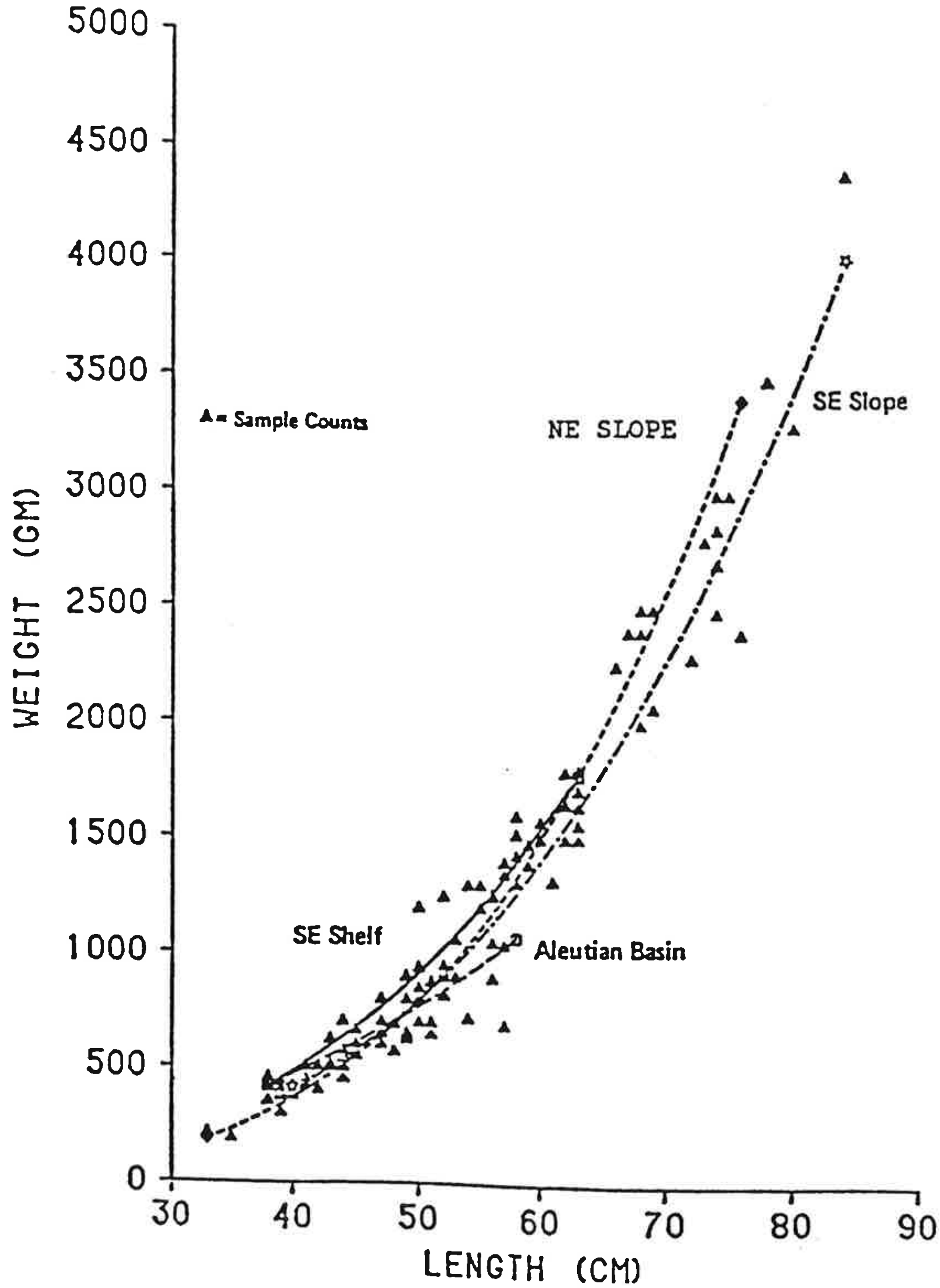


Figure 24.--Length-weight relationship between pollock from 4 areas of the Bering Sea.

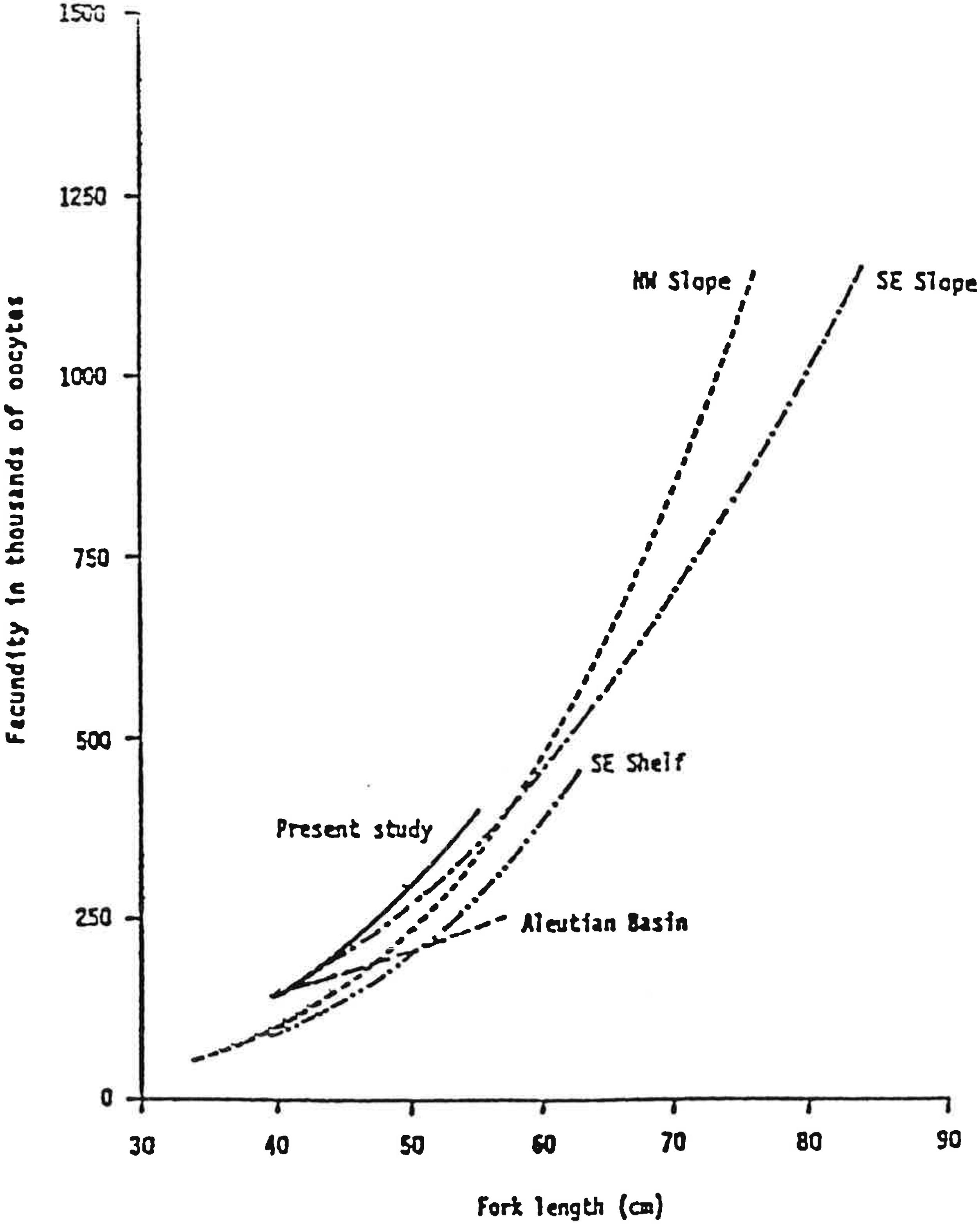


Figure 25.--Fecundity-fork length relationships of pollock in the five different seas areas (Teshima et al., 1989). Present study in the figure was obtained from pelagic pollock in the international waters of the Bering Sea by Teshima et al. (1989) and NW and SE slopes, SE shelf in the eastern Bering Sea, and Aleutian Basin are from Hinckley (1987).

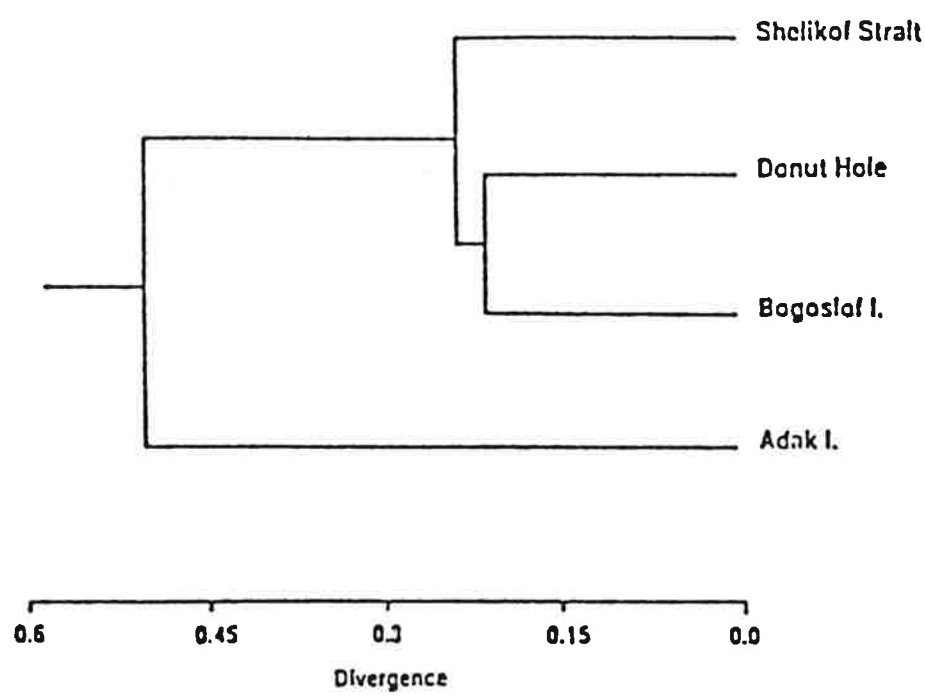


Figure 26.--UPGMA clustering of genetic distances among Theragra chalcogramma populations in the eastern Bering Sea and Shelikof Strait, Gulf of Alaska.

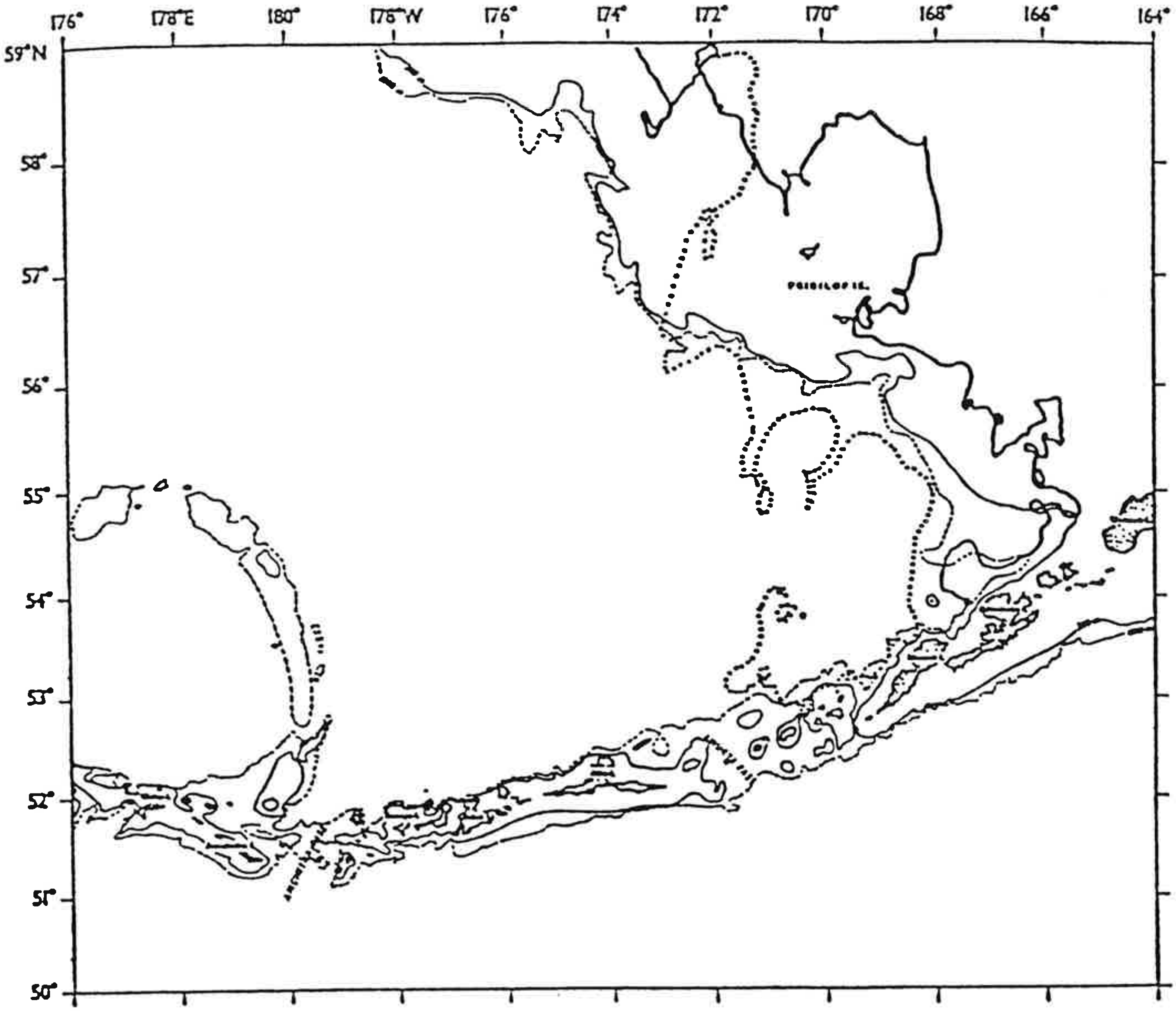


Figure 27.--Trajectories of satellite tracked buoys deployed in February 1986.

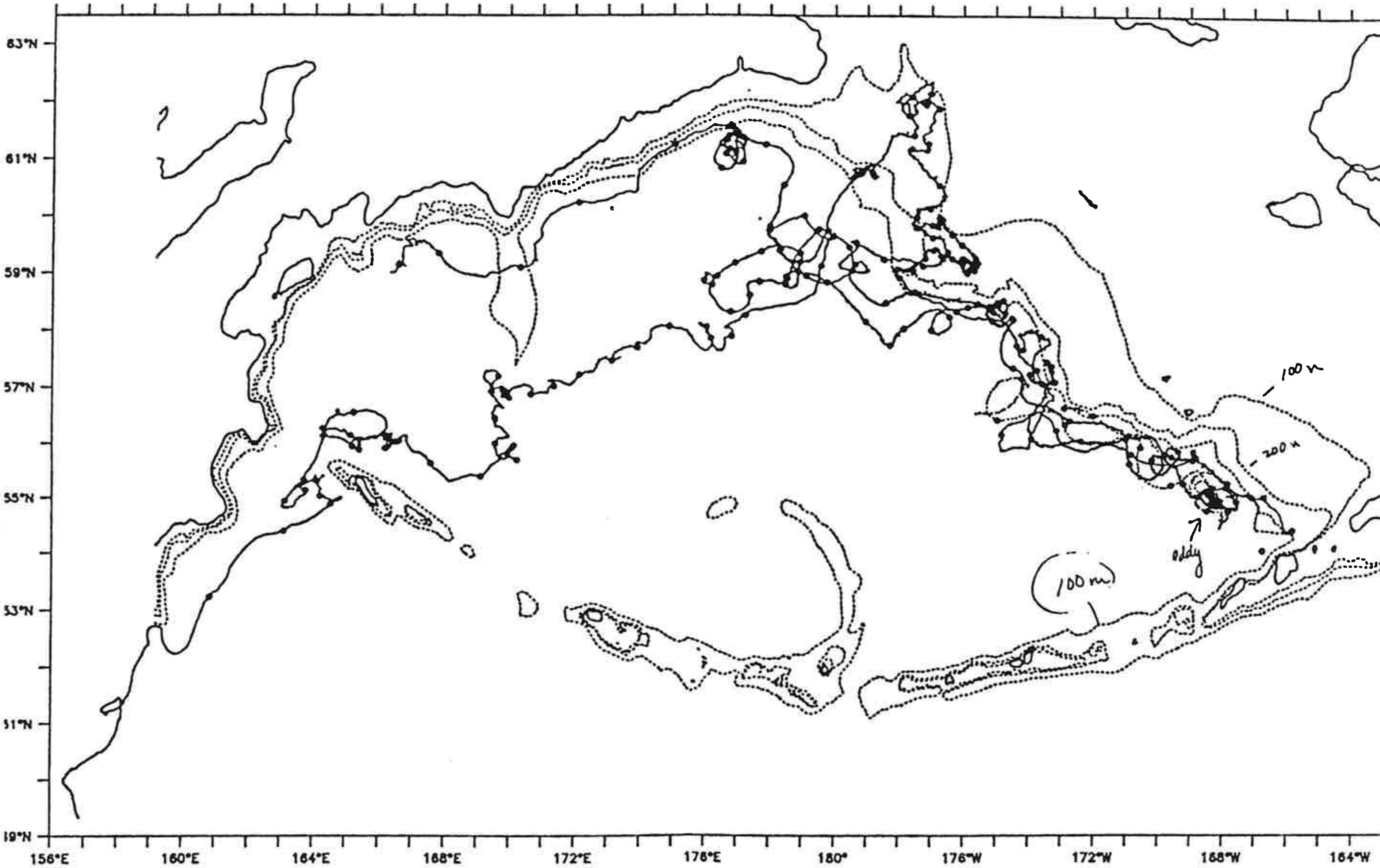


Figure 28.--Drifters deployed mid-March to mid-April 1988.

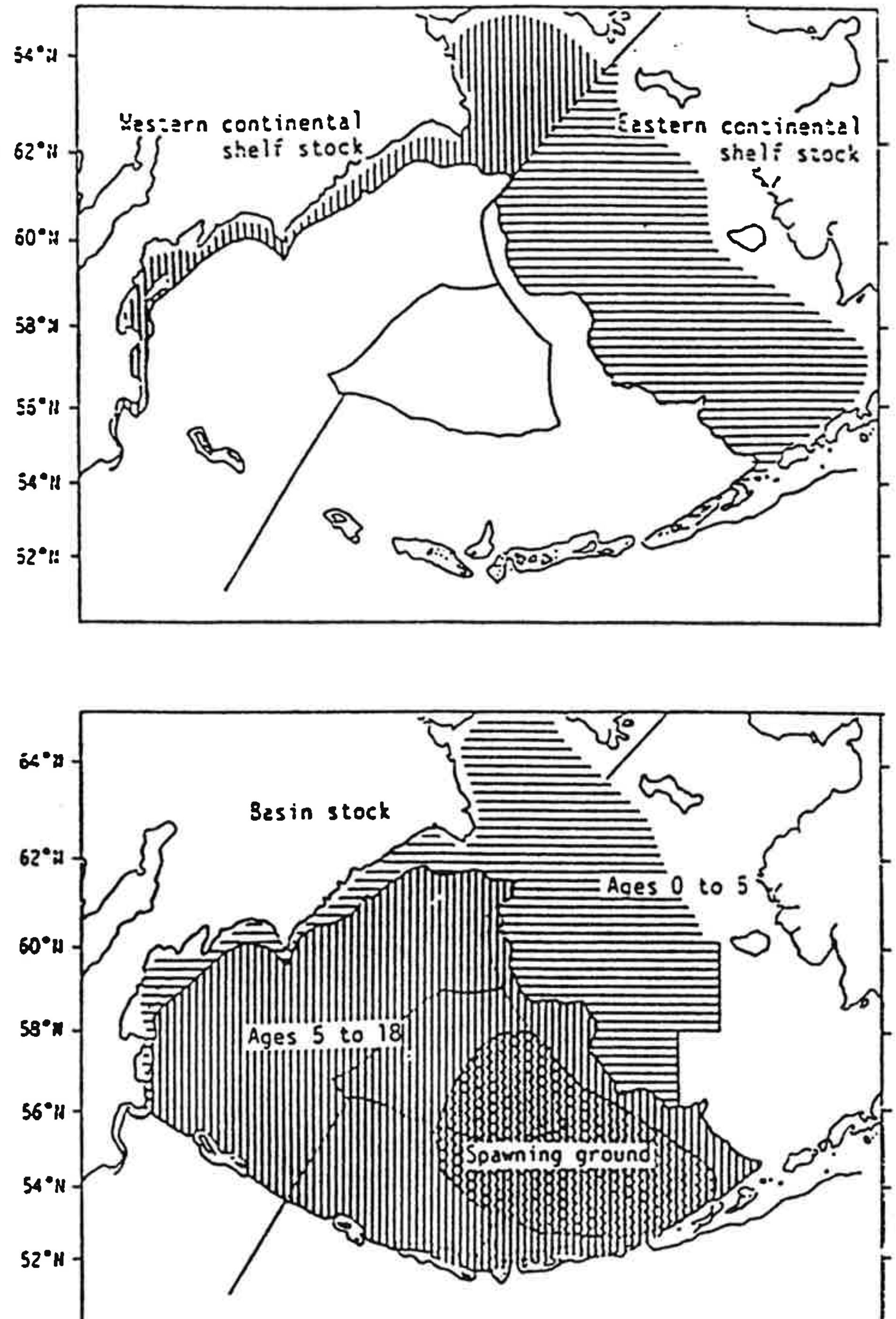


Figure 29.--One possible schematic distribution of the assumed three stocks of pollock in the Bering Sea.

MODULE F

Module F: Survey Abundance Estimates

Facilitator: Jim Traynor

SURVEY DATA AND SCHEDULES

Discussions regarding historical survey data and survey plans were discussed in the morning of February 7. Surveys that have been carried out by Japan, the USSR, and the USA were presented (Table 1). It was agreed that each nation with historical survey information would provide the survey information presented in Table 2. The information will be forwarded to the Alaska Fisheries Science Center by February 1, 1992. It was mentioned that the needs for some of this information by the modeling group may be more immediate and some information may be required earlier.

Plans for the 1991 international survey by the USSR, Japan, and the USA were presented by each nation (Table 3). The need for close cooperation between the nations to ensure that all data will be comparable and present the best possible information regarding summer distribution of pollock in the Bering Sea was stressed. The need for intercalibration of bottom trawl vessels as well as the acoustic systems on the midwater vessels that will be conducting echo integration surveys was emphasized. It was tentatively decided that the intercalibration exercises should take place in August 1991, but details must be worked out between now and the time of the survey this summer.

Preliminary plans for a cooperative survey of spawning pollock throughout the Bering Sea in the winter of 1993 was discussed. Japan indicated that a Japanese vessel would probably be available for about three months and the US also indicated that a US vessel would be available for about three months to participate in this survey. The USSR indicated that they would probably be able to provide vessel time for such a survey. Other nations expressed interest but were not sure about the availability of vessels at this time.

Table 1. Summary of surveys in Bering Sea.

HISTORICAL SURVEYS, BERING SEA

USSR

WESTERN BERING SEA

1980-1990 BOTTOM TRAWL SURVEYS
MIDWATER TRAWL SURVEYS
1980-1990 ICHTHYOPLANKTON SURVEYS

ALEUTIAN BASIN

1987 MIDWATER TRAWL SURVEY

EASTERN BERING SEA

1980-1990 BOTTOM TRAWL/MIDWATER TRAWL
1980-1990 ICHTHYOPLANKTON

JAPAN

ALEUTIAN BASIN

1977 HANDLINE
1978-1979 MIDWATER TRAWL
1983,1985 MIDWATER TRAWL
1987 ECHO INTEGRATION/ MIDWATER TRAWL
1988-1990 ECHO INTEGRATION/ MIDWATER TRAWL

EASTERN BERING SEA

1967-1978, 1981 BOTTOM TRAWL
1979, 1982, 1985, 1982 PARTICIPATE IN EBS TRIENNIAL SURVEY
1979-1984 MULTI-VESSEL DANISH SEINE SURVEY
1989-1990 ECHO INTEGRATION/ MIDWATER TRAWL

USA

ALEUTIAN BASIN

1988, 1989 ECHO INTEGRATION/ MIDWATER TRAWL

EASTERN BERING SEA

1979-1990 BOTTOM TRAWL
1979, 1982, 1985, 1988 ECHO INTEGRATION/ MIDWATER TRAWL
(TRIENNIAL)

Table 2. Summary of requested information for Bering Sea Surveys.

1) METHODS, INCLUDING PARAMETERS USED IN ABUNDANCE ESTIMATION PROCEDURES, AREA SURVEYED

2) DISTRIBUTION OF POLLOCK

3) SURVEYS FOR POLLOCK GREATER THAN AGE ZERO:

BIOMASS POPULATION ESTIMATES BY LENGTH POPULATION ESTIMATES BY AGE	SUMMARIZED BY REASONABLE AREAS (E.G. NORTH/SOUTH OF PRIBILOFS IN EBS)

4) ICHTHYOPLANKTON SURVEYS

DISTRIBUTION/ ABUNDANCE OF EGGS/LARVAE
BIOMASS EST. FOR ADULTS (INCLUDING METHODS) - WITH SAME INFORMATION AS FOR BIOMASS ESTIMATION ABOVE

US WILL ACT AS CLEARING HOUSE WITH DATA TO BE DISCUSSED AT A FUTURE WORKSHOP.

REQUEST INFORMATION BE PROVIDED BY FEBRUARY 1, 1992.

Table 3. Survey plans for 1991 Bering Sea surveys.

COUNTRY	VESSEL	LOCATION	SURVEY TYPE	TIME
JAPAN	HOKUTEN TRAWLER	ALEUTIAN BASIN E. OF CONVENTION LINE	ECHO INTEGRATION MIDWATER TRAWL	JULY-SEPT
USSR		WBS SHELF	ICHTHYOPLANKTON/ MIDWATER TRAWL	APRIL-MAY
		EBS SHELF	ICTHYOPLANKTON/ BOTTOM TRAWL	APRIL-MAY MAY-JUNE
		WBS SHELF	BOTTOM/MIDWATER TRAWL	JUNE-JULY
		WBS SHELF	ECHO INTEGRATION/ MIDWATER TRAWL	JULY-AUGUST
		W. ALEUTIANS	BOTTOM/MIDWATER TRAWL	AUTUMN/ WINTER
USA	MILLER FREEMAN	EBS SHELF/ BOGOSLOF	ECHO INTEGRATION/ MIDWATER TRAWL	FEB-MARCH
	CHARTER1	EBS SHELF	ECHO INTEGRATION/ MIDWATER TRAWL	JUNE-AUGUST
	CHARTER2	EBS SHELF	BOTTOM TRAWL	JUNE-AUGUST
	CHARTER3	EBS SHELF	BOTTOM TRAWL	JUNE-AUGUST
	MILLER FREEMAN	EBS SLOPE	BOTTOM TRAWL MIDWATER TRAWL	SEPTEMBER
	CHARTER3	ALEUTIAN SHELF/ SLOPE	BOTTOM TRAWL	JULY-AUGUST

SYNTHESIS AND MODEL FORMULATION

Synthesis and Model Formulation

Catch-age models have been performed on portions of the Bering Sea pollock resource by several researchers (Figure 1.). The greatest attention has been on the eastern Bering Sea where several different models have been used. Two analyses have been done for the Aleutian Basin, and one for the western Bering Sea.

Estimates for the eastern Bering Sea by different models are in general agreement and are in line with estimates from resource surveys (Figure 1.). The western Bering Sea estimate does not exhibit any trend. The two estimates for the Aleutian Basin show a strong increase in abundance in the 1980's to a high biomass level and then a sharp downward trend in recent years (Figure 1.). The Aleutian Basin catch-age model estimates are higher than resource survey estimates in the area, but survey estimates vary over a broad range.

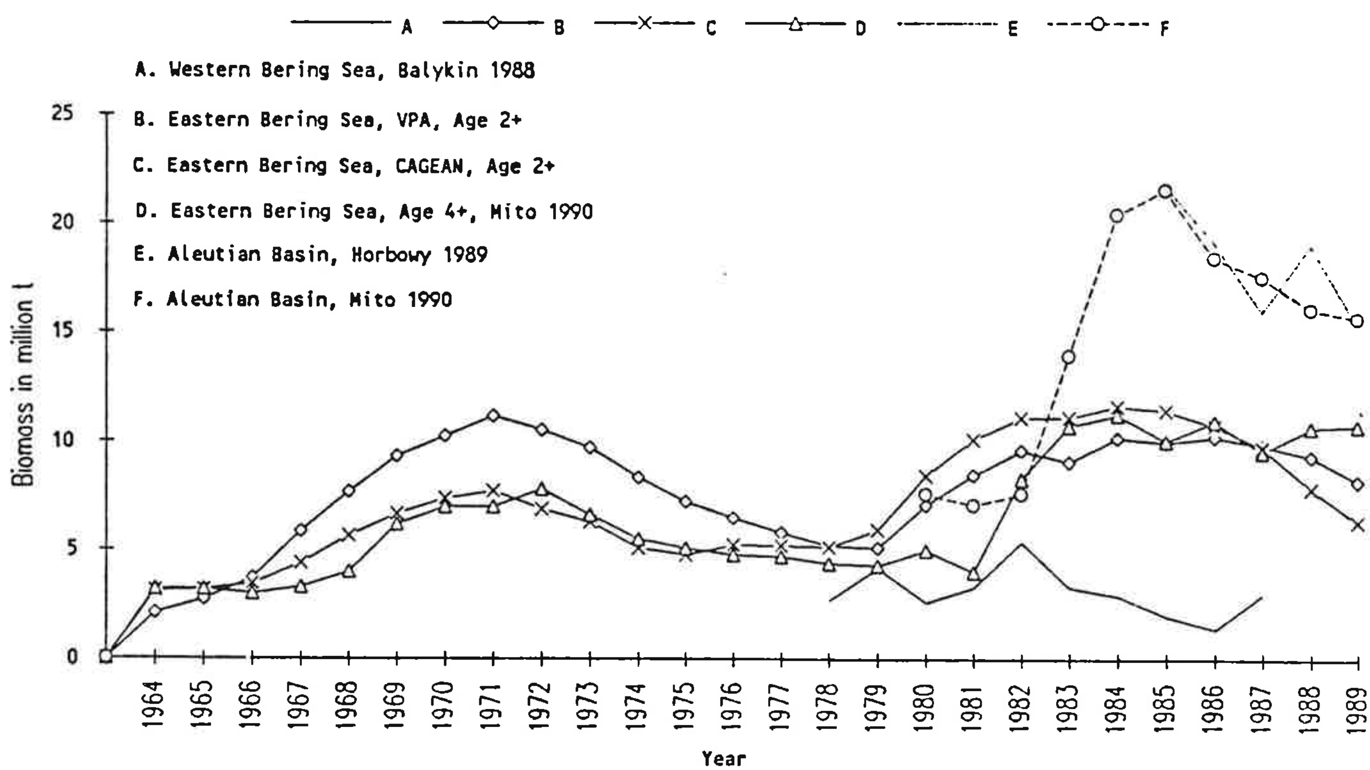
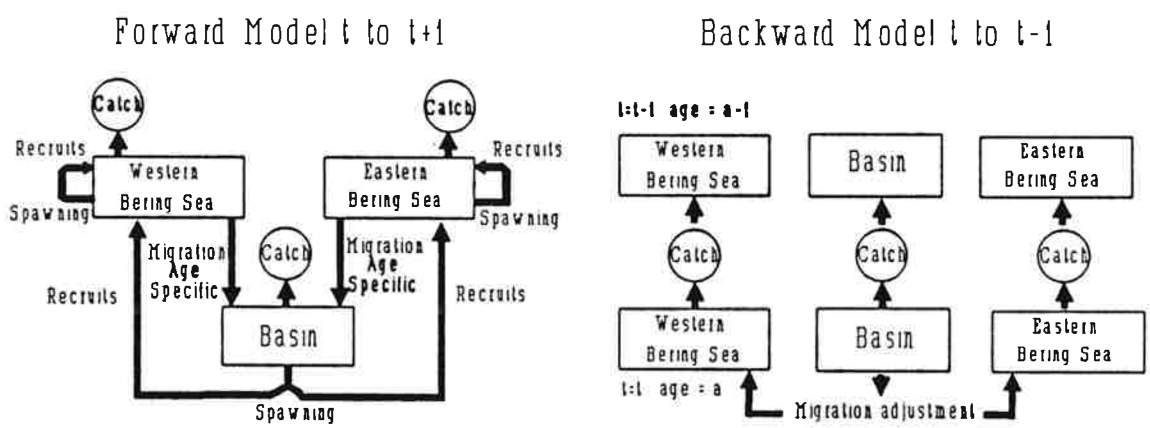


Figure 1. Catch-Age model estimates of Bering Sea pollock biomass

Due to differences in methods, assumptions, and auxiliary "tuning" information, it was difficult to reach a consensus among researchers as to the "right" estimate of pollock abundance in the Bering Sea. Following the review of available data it was concluded that a simple catch age model incorporating migration be developed to estimate the stock of pollock in the Bering Sea.

A schematic representation of the model developed in the workshop is shown in Figure 2. Three major areas: western Bering Sea shelf, eastern Bering Sea shelf and Aleutian Basin are included in the model. The models are constructed on the findings that fish in the Aleutian Basin primarily move to the basin from the adjoining shelf areas. The origin and manner of pollock recruitment to the Aleutian Basin is not fully understood; therefore a broad range of age specific migration rates and area of origin mixtures will be examined. The models will use data for age 4 and older pollock using natural mortality rates (M) = 0.2-0.3

Figure 2. Bering Sea Pollock Migration Models



<u>Migratory Cohort Analysis Model</u>

Quinn, T. J., R. B. Deriso, and P. R. Neal. 1990. Migratory Catch-Age Analysis. Can. J. Fish. Aquat. Sci. 47:2315-2327.

A comprehensive model for the Bering Sea pollock populations was conceptually outlined at the workshop. Most of the previous analyses for the Bering Sea populations did not consider interchange among the Western Bering Sea (WBS), the Aleutian Basin (Basin), and the eastern Bering Sea (EBS). One exception was the work of Dr. Mito, who considered a model similar to the one presented below. A suitable model for the Bering Sea has to consider the interchange among the areas.

A general framework for analysis of migratory populations is migratory cohort analysis. The basic cohort analysis procedure is readily generalized to include migration information (Quinn et al. 1990). A schematic presentation of the basic migration equations are:

$$a.)\ N_{a+1} = \Theta_a [N_a e^{-M_a} - C_a e^{\frac{-M_a}{2}}]$$

$$b.)\ N_a = \Theta_a^{-1} N_{a+1} e^{M_a} + C_a e^{\frac{M_a}{2}}$$

where :

Θ_a = *Migration* : (θ_{ij}) *area* $j \Rightarrow$ *area* i
a = *age*
N_a = *abundance by age by region*
C_a = *catch by age by area*
M_a = *Natural mortality*

Both a forward equation (a.) from age a to age a+1 and a backward equation (b.) from age a+1 to age a are given. The information needed for performing the analysis is catch-at-age, natural mortality-at-age, terminal fishing mortalities, and migration rates among areas. The migratory cohort analysis procedure can also be generalized to migratory catch-age analysis, which uses least squares estimation and the assumption of separability of age and year effects in fishing mortality, which avoids the problem of determining terminal fishing mortalities (Quinn et al. 1990).

Using the migratory cohort analysis framework, a forward and a backward representation of the comprehensive model for the Bering Sea are shown in Figure 2. Both representations are based on three populations for the Bering Sea (WBS, Basin, and EBS), with migration from the WBS and EBS (shelf) populations to the Basin and recruitment from spawning in the Basin occurring in the two shelf areas. Spawning from the EBS and WBS populations also results in recruitment to those areas, as shown. In the forward model, which could be used as a forecasting model, the linkages among the areas are shown from year t to year t+1 in the upper part of Figure 2.

The backward model shown in the bottom part of Figure 2 is conceptually simpler, proceeding backward in time from time t to time t-1. Starting with a particular age a, fish at age a in year t in the WBS or the EBS were also in the same area at age a-1 and year t-1. To find abundance one age earlier, one adds in removals due to catch and natural mortality. However, in the Basin, fish at age a in year t could have been in any of the three areas at age a-1 in year t-1. To properly account for these fish, some of them are allocated to each area based on the rates of migration, as shown in the lower part of Figure 2.

In either model, rates of migration must either be determined before doing the analysis or be estimated with the model. The success of estimating the rates is dependent on the utility of the survey data. The split of the Basin fish into WBS, EBS, and Basin recruitment must also be modeled or estimated. Finally, natural mortality must be redetermined, because many prior estimates include migration as well as mortality.

Stock Synthesis Model

Methot, Richard D. 1990. Synthesis model: an adaptable framework for analysis of diverse stock assessment data. INPFC Bull. 50: 259-277.

The Stock Synthesis model was presented as another type of catch-at-age analysis. This model is most accurately described as a forward simulation of the stock's dynamics, and of the processes which influence our observations of the stock. Synthesis is a complex tool that forces us to be very explicit about many assumptions, but its output is equally explicit with regard to the consequences of these assumptions for the fit to a wide variety of data.

Synthesis is designed to exactly match the observed catch biomass but, like CAGEAN, it produces only a statistical "best fit" to the catch age composition and CPUE. In addition, synthesis can directly examine the fit to survey abundance and survey age composition data. While one can force the model to assume that the surveys have knife-edge selectivity at a particular age or that the surveys measure only fishable biomass, the advantage of synthesis is that it can use the information in the survey age composition data to estimate the pattern of selectivity for the survey. Because synthesis is a forward simulation, it can adjust its estimates of sampled numbers at age to account for the effects of ageing imprecision and for the bias associated with ages determined from scales. Thus, the range of recruitments estimated by synthesis is likely to be greater than the range estimated by other models because synthesis can account for some of the apparent contribution of weak cohorts by leakage from adjacent strong cohorts.

Synthesis can be structured with one area (stock) and several competing fisheries within this area, or it can have multiple areas each with one or more fisheries and surveys. Some aspects of the two-area Pacific whiting synthesis model were described. This model differs from the proposed Bering Sea migration model in that it re-mixes the stock each year then partitions the fish into two areas according to an estimated age-specific function. However, the capability for a three-area model with only migration between the areas is already built into synthesis. When the Pacific hake model is run with only one area, then the estimated selectivity pattern for the U.S. fishery is dome-shaped with a peak near age 7 and the estimated selectivity pattern for the Canadian fishery is dome-shaped with a peak near age 10-11. When the model is run with two areas, then the model estimates a three parameter function that places none of the recruits and about 35% of the older fish in Canadian waters during the fishing period. In this two area model, the estimated selectivity patterns for the two fisheries converge because each is now estimated relative to the fish found within the defined area. A similar pattern for shelf versus basin fisheries could emerge in the Bering Sea as we explore the consequences of one versus three area models.

The data requirements for synthesis are:

For each fishery:

A. time series of aggregate catch biomass
B. body weight-at-age for harvested fish
C. catch age composition for ages 2 through the maximum observed age. The upper tail of this distribution will be accumulated down to an appropriate age (probably 10 to 15 years old). The catch age composition can be expressed in terms of expanded catch numbers at age for compatibility with other models, but synthesis will convert these data into catch proportions at age.
D. estimated discarded catch, if available.
E. CPUE data, if available. Discontinuous time series are acceptable.

For each survey:

A. estimated biomass or total numbers
B. body weight-at-age (if abundance is in terms of biomass)
C. survey age composition.

Note: Seasonal patterns in fishery age composition should be examined. If the winter fisheries on spawning aggregations differ much from the traditional summer fisheries, then the fishery data should be segregated into these time periods. Synthesis can accomodate up to four time periods and can be made sex-specific if the male patterns are found to differ substantially from the female patterns.

The following parameters must be supplied, although in some circumstances these can be estimated by the model:

A. natural mortality, may be age-specific. 1-3 parameters.

B. Ageing precision, entered as age-specific values for percentage reader agreement.

The following parameters will be estimated by the model:

A. Selectivity function for each fishery and survey. 4 parameters per function.

B. Time series of recruitment for each area. The number of parameters will be N years times N areas, but in some scenarios the basin area may be defined to have zero recruitment because all its fish come from immigration.

C. Age composition in each area at the beginning of the time series. This can take only 3 parameters if we assume an equilibrium age composition at the beginning (same assumption as in the catch curve analysis).

D. For each CPUE time series, the scaling factor that relates CPUE to fishable biomass (or equivalently, relates effort to fishing mortality).

DATA AVAILABILITY

Each nation fishing in the Bering Sea was asked to provide fishery and research data for use in modeling from 1980 to the present. The workshop assessed the quantity and quality of data available from the three regions to be modeled. A summary of the data is shown in Table 1. Table 1 divides the Aleutian Basin into two parts, west and east. The west encompasses the portion of the Aleutian Basin west of the US-USSR Convention line and the east that portion of the Basin east of the line. The workshop participants found the data to be sufficient to accomplish a catch-age analysis of Bering Sea pollock.

For the eastern Bering Sea detailed data of sufficient quality exist from 1978 to present. Detailed data of sufficient quality was found to exist for the Aleutian Basin from 1985 to present, and possibly back to 1980. For the western Bering Sea, basic data exists but additional data are needed to facilitate full model development.

Table 1. BERING SEA POLLOCK ASSESSMENT INFORMATION SUMMARY

		Western Bering Sea	Aleutian West	Basin East	Eastern Bering Sea
CATCH DATA					
	Aged Catch	1978-90	1986-90	1985-90	1964-90
Distribution					
	Annual ½x1 block	1986-90	1986-90	1985-90	1977-90
	Monthly ½x1 block	1986-90	1986-90	1985-90	1977-90
	Sub-Areas	1964-90	1985-90	1985-90	1964-90
Biological Data					
	Age-length keys	1978-90		1986-90	1978-90
	Length Frequency	1970-90		R-77 F-85	1964-90
	Age-comp data	1978-90		1985-90	1964-90
	Length-weight data	R-70		R-77 F-85	R-79 F-78
	by area	Yes	Yes	Yes	Yes
	by sex	Yes	Yes	Yes	Yes
	by period	month		quarter	month
CPUE	by area	1978- by day		1980- by hour	1978- by hour
	by block	1986 by block	1986 by block		
NATURAL MORTALITY		0.2 - 0.3	0.2 - 0.3	0.2 - 0.3	0.2 - 0.3
AUXILLIARY INFO					
Survey Biomass					
	Trawl Survey	1985-90		78 to present	1979-90
	Egg Larvae	1985-90	1988-90 *	1988-90 *	1976-90
	Hydroacoustic	No	No	1988-90 *	1979,82,85,88
SPAWNER-RECRUIT	Maturity Data	Yes	Yes	Yes	Yes
	Fecundity Data	Yes	Yes	Yes	Yes

* not every year R-research F-fisheries

WORKSHOP CONCLUSIONS

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1. Bering Sea Pollock resources shall be modelled by three major areas: western Bering Sea shelf, eastern Bering Sea shelf and Aleutian Basin.

2. Fish in the Aleutian Basin primarily move to the basin from the shelves.
   a.) Source and manner of recruitment of Basin pollock not fully understood.
      i. Emigration from shelf
      ii. Return of fish spawned in Basin
   b.) Further studies of recruitment and migration are needed.

3. Models will use data for age 4 and older.
   a.) Large differences of estimates of natural mortality (M) for age 3 pollock.
   b.) M for age 4 and older to be modelled using M = 0.2-0.3
   c.) M of pollock older than age 11 may be higher on the shelf.
   d.) Different values of M may be applied to different areas.

4. Found data to be sufficient to accomplish a catch-age analysis of Bering Sea pollock.
   a.) Detailed data of sufficient quality exist for the eastern Bering Sea from 1978 to present.
   b.) Detailed data of sufficient quality exist for the Aleutian Basin from 1985 to present, and possibly as far back as 1980.
   c.) Basic data exists for the western Bering Sea, but additional data needed to facilitate full model development.

5. Two framework models incorporating migration were developed; one based on forward calculation, and the other on backward calculation.
   a.) Models will examine a range of migration rates.
   b.) Models will examine a range of area mixtures.

6. Data provided for meeting will be compiled in standard format and distributed to all participating nations.
   a.) The Alaska Fishery Center will evaluate the data received and contact each nation on additional data needs.
   b.) All nations have agreed to provide additional data by June, 1991.
   c.) A database will be assembled by October, 1991 and distributed to each nation.

7. All nations agreed to utilize the standard fishery data form agreed to at the April 1990 Khabarovsk meeting as presented at this workshop.
   a.) It was agreed that 1991 and following years data will be collected using the form.
   b.) The data must be submitted to the Alaska Fisheries Science Center by July 31 of the following year by all nations for all fishing operations in the Bering Sea.
   c.) All data submitted by the participating nations should be distributed to each nation annually.

8. Age determination is a critical element in age-structured modelling; nations should take special care in methods of aging and validation.

9. Migration rate information is crucial for model development. A synoptic (Bering Sea-wide) tagging study should be conducted to provide this information.

10. The workshop recommends that the Alaska Fisheries Science Center develop the models and data for age-structured modeling; that each nation be provided with these materials prior to a model workshop of specialists from each nation.

11. The next meeting will be in Seattle following model development and evaluation by specialists from each nation.