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Proceedings of the International Scientific Symposium on Bering Sea Fisheries

July 19-21, 1988,
Sitka, Alaska U.S.A.

William Aron, Chairman
James Balsiger, Coordinator

April 1989

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PROCEEDINGS OF THE INTERNATIONAL SCIENTIFIC SYMPOSIUM ON BERING SEA FISHERIES

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Symposium Chairman

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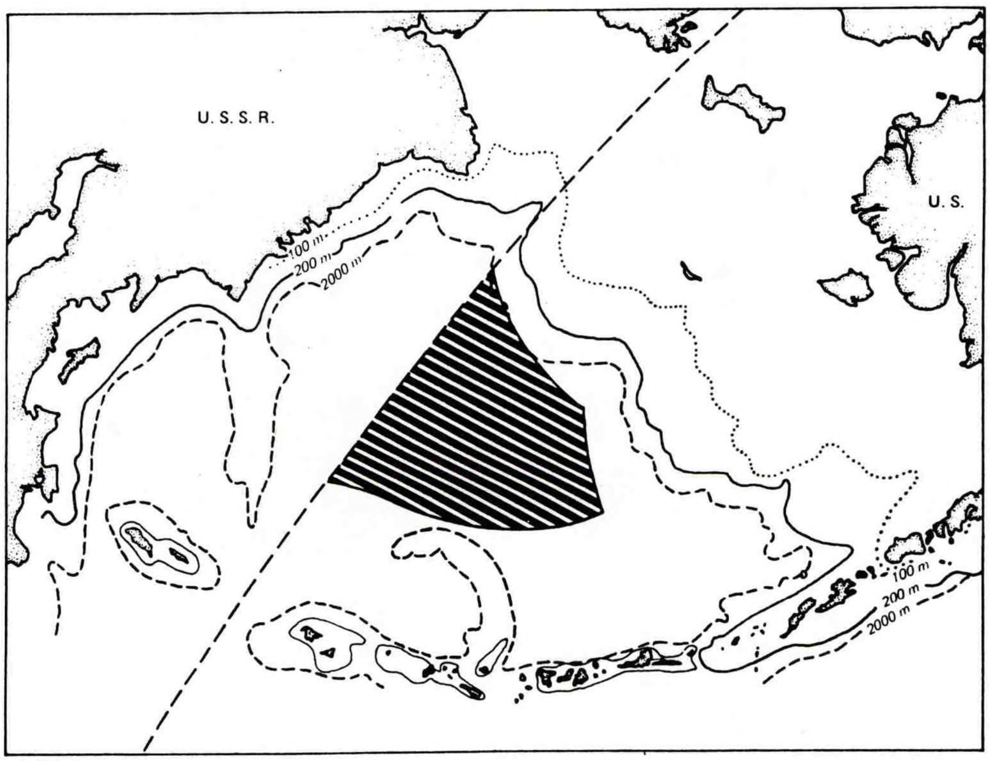
Symposium Coordinator



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PREFACE

Recent expansion in the exploitation of Bering Sea walleye pollock (*Theragra chalcogramma*) resources has raised questions on how the resource and associated fisheries might be affected. Of particular concern is the impact of catches in the central Bering Sea on the pollock resource. Scientists from Canada, Japan, People's Republic of China, Polish People's Republic, Republic of Korea, Union of Soviet Socialist Republics, and United States of America met 19-21 July 1988 in Sitka, Alaska, U.S.A., to present information and discuss this issue.

Information was exchanged and discussed on critical biological and oceanographic factors that control the pollock population. This document summarizes these discussions and includes most of the scientific papers that were used during the meetings. While the document carefully details both our knowledge and the critical gaps in our information base, these proceedings only partially reflect that which happened during the Sitka meeting. Perhaps even more important than the data exchange; the revelations and views on stock structure, abundance, and early life histories; and the information about the basic oceanography of the Bering Sea, was the spirit of cooperation that grew during the course of the sessions. This spirit, in my view, evolved from the clear recognition of the participants that the problems facing the resources of the Bering Sea are important, very serious, and complex. Furthermore, it was clear to all that solution of the problems would require the development of a data base that could only be acquired through a coordinated and cooperative program involving all of the nations with interests in the Bering Sea. Sitka represented a first step in developing this effort.

A further major contributor to the meetings was the extraordinary reception provided by the host city and its people to the scientists and other participants. Sitka threw open its arms and, with help from its distant neighbor, Unalaska, and a number of fishing industry groups, provided both a setting and a set of entertainments that helped catalyze cooperation. On behalf of all of the Symposium participants, I toast our hosts and thank them for their untiring and generous efforts on our behalf.

William Aron
Symposium Chairman

SCIENTIFIC DELEGATES TO INTERNATIONAL SYMPOSIUM

SITKA, AK, 19-21 JULY 1988

CANADA

Mr. Mark Saunders	Pacific Biological Station, Nanaimo

JAPAN

Dr. Sigeiti Hayasi	Director, Far Seas Fishery Research Lab Fishery Agency of Japan, Shimizu, Japan
Mr. Kenji Kagawa	Vice-Chief, Research Division Fishery Agency of Japan, Tokyo
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Dr. Takashi Sasaki	Groundfish Section Chief Far Seas Fishery Research Lab Shimizu, Japan

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Mr. E. Budzinski	Polish Embassy Commercial Counselors Office, New York
Dr. J. Janusz	Sea Fisheries Institute, Gdynia
Mr. M. Kucharski	Ministry of Transportation Shipping & Communications, Warsaw

Mr. J. Latanowicz	Deep Sea Fisheries Enterprise, Gdynia
Mr. L. Lukasik	Ministry of Foreign Affairs, Warsaw
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Dr. O. A. Bulatov	TINRO, Vladivostok
Dr. A. A. Churikov	Senior Researcher, VNIRO, Moscow
Dr. N. S. Fadeev	TINRO, Vladivostok
Dr. B. G. Ivanov	VNIRO, Moscow
Dr. A. G. Slizkin	TINRO, Vladivostok
Dr. M. A. Stephanenko	TINRO, Vladivostok
Mr. V. Y. Sukhov	Fishery Attache, USSR Embassy
Dr. V. P. Tumanov	TINRO, Vladivostok

Dr. A. N. Vylegzhanian	Ministry of Fisheries, Moscow

VNIRO - All-Union Scientific Research Institute of Marine Fisheries and Oceanography

TINRO - Pacific Scientific Research Institute of Marine Fisheries and Oceanography

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Mr. Pierre Dawson	Northwest and Alaska Fisheries Center Seattle, WA
Dr. Douglas Eggers	Alaska Department of Fish and Game, Juneau
Dr. William Karp	Northwest and Alaska Fisheries Center Seattle, WA
Dr. Richard Marasco	Northwest and Alaska Fisheries Center Seattle, WA
Mr. Bernard Megrey	Northwest and Alaska Fisheries Center Seattle, WA
Dr. Timothy Mulligan	University of Washington, Seattle, WA
Dr. James Overland	Pacific Marine Environmental Laboratory Seattle, WA
Dr. Ellen Pikitch	University of Washington, Seattle, WA
Dr. A. J. Paul	University of Alaska, Seward, AK
Mr. Donald Rosenberg	Mount Vernon, WA

Dr. Gary Stauffer	Northwest and Alaska Fisheries Center Seattle, WA
Mr. Vidar Wespestad	Northwest and Alaska Fisheries Center Seattle, WA

PANEL A - REPRODUCTION AND EARLY LIFE HISTORY

Participants

Chairman: Dr. A. J. Paul

Rapporteur: Dr. William Karp

Panel Member	Nation
Dr. Sigeiti Hayasi	Japan
Dr. Kei-ichi Mito	Japan
Dr. Takashi Sasaki	Japan
Mr. Tang QiSheng	People's Republic of China
Dr. Z. Karnicki	Polish People's Republic
Dr. J. Janusz	Polish People's Republic
Ms. Hur, Young Hee	Republic of Korea
Dr. Zhang, Chang Ik	Republic of Korea
Mr. Bernard Megrey	United States
Dr. N. S. Fadeev	Union of Soviet Socialist Republics
Dr. B. G. Ivanov	Union of Soviet Socialist Republics
Mr. V. P. Tumanov	Union of Soviet Socialist Republics

Paper or Presentation Titles and Authors

O. A. Bulatov	Reproduction and abundance of spawning pollock in the Bering Sea.
B. Megrey	An overview and synthesis of available information on eastern Bering Sea walleye pollock reproduction and early life history.
T. Sasaki	Synopsis of biological information on pelagic pollock in the Aleutian Basin. (Section on early life history.)

Panel Summary

Three reports were presented during the session. Most of the information dealt with spawning ground location and when spawning takes place. No reports on larval or juvenile pollock biology were presented.

Fecundity

Information on pollock length-weight-fecundity relationships was presented. The most recent review of this subject occurs in the papers by Hinckley (1987) and Teshima et al. (1988) (cited in the review paper of Sasaki). Hinckley (1987) reports lower fecundity for Aleutian Basin fish compared to those captured on the slope or shelf regions. Differences in fecundity and growth rates were suggested as possible indications of separate spawning stocks. However, the panel discussion determined that our level of understanding on this subject is too imperfect to identify spawning stocks at this time. Panel suggestions included a coordinated survey of fecundity and spawning throughout the range of pollock in the Bering Sea. Samples for this study should be taken at the same time, and standard methods of estimating fecundity should be used. This work is necessary to determine if different populations of pollock inhabit the Aleutian Basin, "the doughnut hole" (the waters beyond the respective 200-mile zones of the U.S. and U.S.S.R.), and the area within the U.S. and U.S.S.R. 200-mile zones. In the panel on biomass and yield, a comprehensive acoustic survey during the spawning period was suggested concurrent with the collection of small samples of pollock for fecundity measurements. The review of Dr. Sasaki suggests that late January is the best time to collect oocytes for counting. It was noted during the discussion period that regional differences in fecundity exist, but the interannual aspect of energy allocation to spawning is poorly described and requires additional study. Likewise, the reason for regional differences in growth and fecundity remains unknown. Differences in food supplies may be responsible. However, reports of zooplankton abundance were not available to analyze this relationship. Panel discussion suggested that a comprehensive zooplankton survey should be conducted, especially in the Aleutian Basin and the doughnut hole region.

Spawning

Spawning occurs from January through March, with dense aggregations of spawners observed in the southeast portion of the doughnut hole. Based on the eastward movement of the fishery, Dr. Sasaki estimated in his paper that pelagic pollock spawn in the area of 180^0 degrees longitude from early January to late March. He further noted that Teshima et al. (1988) identified a relationship between fecundity and fork length of pelagic pollock in the Aleutian Basin that is quite different from the relationship reported by Hinckley (1987). The report of Dr. Bulatov notes that the main centers of reproduction are in Olyutorsky Bay and off Unimak Island.

In the latter region, interannual differences in egg abundance can vary from 3- to 12-fold. Bulatov's report suggests that about one-half of the spawning pollock biomass is concentrated in the southeastern part of the Bering Sea, whereas in the Olyutorsky-Navarinsk region only 3.8% of the stocks spawn. Dr. Sasaki's review states that eggs and larvae were distributed broadly in the Aleutian Basin, but juvenile fish over 40 mm were not collected in the larval net surveys conducted there. Panel discussion identified obtaining knowledge on movements of juveniles as an important prerequisite in determining the source of recruitment of pollock for the Aleutian Basin.

In other panels, additional information on spawning areas was presented. It was suggested that all this information be compiled to make a map of spawning and egg density from existing information.

Early Life History

No estimates of mortality or information on causes of mortality were presented for eggs, larvae, and juveniles. Currently, little effort is being expended on the study of survival of early life stages. This work must be undertaken if there is to be an understanding of recruitment. In the Bering Sea a complex food web exists in which pollock play a major role both as prey and as predators. They are also cannibalistic. Topics of discussion during the symposium centered on pollock biology and oceanography, but ecosystem studies are also necessary if population fluctuations of pollock are to be understood.

Dr. Bulatov's report speculates that the strong year classes that appeared during the warm periods of 1977-81 are responsible for the current abundance of pollock eggs and larvae. He also speculates that changing oceanographic conditions may cause decreases in pollock biomass in the future.

References

Hinckley, S. 1987. The reproductive biology of walleye pollock, _Theragra chalcogramma_, in the Bering Sea, with reference to spawning stock structure. Fish. Bul. U.S. 85(3):481-498.

Teshima, K., H. Yoshimura, J. Long, and T. Yosimura. 1988. Fecundity of walleye pollock from international waters of the Bering Sea Aleutian Basin. (MS prepared for the International Symposium on the Biology and Management of Walleye Pollock, November 1988, Anchorage, AK.)

PANEL B - STOCK IDENTIFICATION PANEL

Participants

Chairperson: Dr. Ellen Pikitch

Rapporteur: Bernard A. Megrey

Panel Member	Nation
Dr. Sigeiti Hayasi	Japan
Dr. Kei-ichi Mito	Japan
Dr. Takashi Sasaki	Japan
Dr. J. Janusz	Polish People's Republic
Dr. Z. Karnicki	Polish People's Republic
Ms. Young Hee Hur	Republic Of Korea
Dr. Chang Ik Zhang	Republic Of Korea
Dr. O. A. Bulatov	Union of Soviet Socialist Republics
Dr. N. S. Fadeev	Union of Soviet Socialist Republics
Dr. M. A. Stephanenko	Union of Soviet Socialist Republics
Mr. V. P. Tumanov	Union of Soviet Socialist Republics
Mr. Peter Craig	United States
Mr. Pierre Dawson	United States
Dr. Tim Mulligan	United States

Paper or Presentation Titles and Authors

P. Dawson	Stock identification of Bering Sea walleye pollock.
T. Mulligan	Pollock stock identification--ongoing research.
T. Sasaki	Synopsis of biological information on pelagic pollock in the Aleutian Basin. (Section on stock structure.)

M. A. Stephanenko	The state of stocks and distribution of pollock in the Bering Sea.
Sobolebskiy, E. I., Shuntov, V. P., and A. F. Volkov	The composition and the present state of pelagic fish communities in the western Bering Sea. (Paper presented by Dr. O. A. Bulatov.)
N. S. Fadeev	The spatial structure of the Bering Sea pollock and the general directions of the fish resources investigations.
J. Janusz, T. B. Linkowski, and M. Kowalewska-Pahlke	Results of the population studies of walleye pollock <u>Theragra chalcogramma</u> in the Bering Sea.

Panel Summary

We began the panel session with some general comments on the stock identification question. Specifically, the definition of what constitutes a stock is somewhat open to interpretation. The complexity of fish populations suggests that an appropriate definition should encompass a broader view of a population than simply its breeding structure. We must define the nature of stocks in the production sense as well as in the reproductive sense. In the panel discussion the movement patterns of fish were also considered. This is a topic that is strongly relevant to the stock identification question.[1]

Just as there may be numerous definitions of what constitutes a stock, there are numerous methods for identifying stocks, and these may produce conflicting results. There is a need to explore new methods and refine existing methods.

There were seven papers presented during the panel session, and these covered both ongoing research and research results. The methods discussed ranged from traditional approaches to some recently developed high-technology methods. This summary report attempts to provide a brief synopsis of each of the papers.

Presentation by Dawson

Mr. Dawson presented a data summary and proposed five hypotheses regarding the unit stock question in the Bering Sea. These hypotheses encompass a wide range of views--from that of the first hypothesis, that pollock in the doughnut hole form a separate

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[1]The Japanese delegation believes that the comments in this paragraph should be attributed only to the chairperson and not to the panel at large.

stock, to that of the fifth, that all pollock in the Bering sea form a single stock. Mr. Dawson expressed his view that his third hypothesis (moderate in position between hypotheses one and five) was the most likely based on the available data. Under this third hypothesis the recruits to the basin population (of which the doughnut hole pollock are a part) come from the surrounding shelves while the eggs and larvae spawned in the basin develop on the shelves. According to this hypothesis the recruits to the basin make a one-way migration and do not move back and forth. This is the main difference between this hypothesis and the hypothesis of one stock in the Bering Sea. A few tag recoveries from a very large tagging program show that some of the fish recovered did migrate over long distances in the Bering Sea and possibly also from the North Pacific into the Bering Sea. Differences in length-at-age, fecundity, growth, and age composition between pollock from the Aleutian Basin and from the eastern Bering Sea shelf and slope areas were noted. In 1988 the age composition of pollock from the Bogoslof Island area was similar to the age composition of pollock from the doughnut hole, but the age composition of Bogoslof Island fish differed from the age composition of fish from the shelf. The similarity in age composition of pollock in the doughnut hole to the pollock in the Bogoslof Island area suggests interchange between the two areas. The lack of young adults and juveniles in the doughnut hole suggests that recruitment comes from other areas.[2]

Presentation by Mulligan

Dr. Mulligan presented a summary of four techniques he is using to try to discriminate among pollock stocks in the Bering Sea: elemental analysis, mitochondrial DNA analysis, morphometric analysis using a new truss network approach, and X-ray assisted meristic studies. The samples he is examining were obtained from the doughnut hole and three areas in the eastern Bering Sea. He hopes to have some results by the end of this year.

Presentations by Fadeev and Stephanenko

Drs. Fadeev and Stephanenko presented related papers which are summarized together. Both authors presented information on pollock stock distributions in the Bering Sea based on survey data. It was proposed that there are two stable spawning groups in the Bering Sea, one on the western shelf and one on the eastern shelf. No concentrations of spawning pollock were found in the doughnut hole. Fadeev and Stephanenko stated that pollock disperse throughout the Bering Sea for feeding, and there is a broad area of mixing of the

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[2]After review of the draft proceedings, the Japanese delegation believes that these last two statements should be attributed only to the U.S. representative and not to the panel at large.

eastern and western stocks in the northern portion of the central Bering Sea.[3]

Presentation by Bulatov

Dr. Bulatov presented a paper on behalf of the authors Drs. Sobolebskiy, Shuntov, and Volkov. He reported on the results of midwater trawl and bongo net surveys of epipelagic waters in 1986 and 1987 in the entire western Bering Sea within the U.S.S.R. exclusive zone. The data included samples of fish stomach contents and zooplankton. Although the ratio of zooplankton to pollock was generally very high, it differed among areas. Large pollock appear to solve the food deficit problem by migrating to the deepwater areas of the Bering Sea that are rich in plankton. This may explain the large concentrations of pollock to the northeast of the Kommander Islands.

Presentation by Sasaki

Dr. Sasaki stated that there are several views of stock structure. Regarding the relationship between basin and shelf populations he noted that differences have been found in size-at-age by area and season. He indicated the possibility that the basin population consists of more than one stock based upon different growth processes and nursery areas. Dr. Sasaki also noted that the majority of pollock in the basin are greater than 5 years of age; age 0-4 fish have not been observed in abundance. Both a biochemical (electrophoretic) study and a study of meristics and morphometrics do not show distinct differences of pollock within the entire Bering Sea. Dr. Sasaki expressed the view that greater geographic coverage of research within the Bering Sea is needed to clarify population structure.

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[3]After review of the draft proceedings, the Japanese delegation suggests the addition of the following paragraph:

They also noted that increases in catch toward Kamchatka Strait during the feeding period suggest that large pollock migrate from the areas off east Kamchatka into the deeper waters of the Bering Sea, specifically into the Kommander trough.

Presentation by Janusz

Dr. Janusz discussed differences in characteristics between pollock from the doughnut hole and those from the southeast shelf. A number of morphometric, meristic, and growth characteristics were examined. Three multivariate statistical techniques were also used to analyze the data. Differences in length-at-age were reported, with doughnut hole fish being smaller than those in the southeast shelf. No differences in length-weight relationships were found up to 45 cm length, but at longer lengths, doughnut hole fish have lower weight than the southeast shelf pollock. Multivariate analysis of morphometric and meristic characteristics revealed significant differences.

Conclusions

To summarize, a number of comparative studies have been attempted examining pollock from different areas of the Bering Sea. Most of these studies have been very limited in geographical extent, temporal extent, and/or sample size. A number of these studies have revealed differences among fish from different areas, including differences in age structure, growth, meristics, morphometrics, and reproductive characteristics. Areas where differences were found included the doughnut hole and shelf areas. However, a number of studies, including biochemical (electrophoretic) studies and meristic-morphometric analyses, have failed to detect differences among pollock from within the entire Bering Sea. A few tag recoveries from a very large tagging program show that some of the fish recovered did migrate over long distances in the Bering Sea and also possibly from the North Pacific into the Bering Sea.[4] However, the very limited results cannot rule out the possibility that large-scale movements in other directions may occur.

This panel presented some conflicting results and views. In particular, there was some disagreement about what is happening within the doughnut hole. The Soviet scientists have not detected spawning concentrations in the area in all years of research, whereas Polish and Japanese scientists have detected very significant concentrations based on several years of commercial fishing observations. There are some conflicting views on how long pollock remain within the doughnut hole, and the nature and extent of movements of pollock both within the doughnut hole and from this area to other areas. More than one view was expressed regarding the age structure of pollock, in particular, the location of the very oldest fish. Perhaps some of these differences may be due to differences in methodology and the geographical and temporal extent of sampling.

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[4]After review of the draft proceedings, the Japanese delegation suggests the addition of the following sentence:

U.S.S.R. scientists also suggested that pollock migrate from east Kamchatka into the Bering Sea.

One point on which no disagreement was raised was that no significant concentrations of juvenile or young adult pollock have been found within the doughnut hole.

The panel did not reach a consensus on the stock structure of pollock in the Bering Sea. A number of hypotheses were presented. Some members of the panel expressed the view that the extreme hypotheses proposed (i.e., a separate doughnut hole stock or a single Bering Sea stock) were less likely than other hypotheses. However, other panel members expressed a view that because of the very limited data available, it was premature to reject any of the hypotheses that had been put forth.

There did seem to be broad agreement that presently there are very few data available with which to determine the stock structure of pollock in the Bering Sea, and more research is needed to resolve the issue. The studies needed should be of broad scope, particularly in geographic extent and perhaps in temporal extent. Sample collection, analysis of methods, and data analysis procedures should be standardize comparisons can be made.

PANEL C - BIOMASS AND YIELD

Participants

Chairperson: Dr. Doug Eggers

Rapporteur: Mr. Pierre Dawson

Panel Members	Nation
Dr. Sigeiti Hayasi	Japan
Mr. Kenji Kagawa	Japan
Dr. Kei-ichi Mito	Japan
Dr. Takashi Sasaki	Japan
Mr. Tang QiSheng	People's Republic of China
Dr. Z. Karnicki	Polish People's Republic
Dr. J. Janusz	Polish People's Republic
Mr. Hong K. An	Republic of Korea
Ms. Young Hee Hur	Republic of Korea
Dr. Chang Ik Zhang	Republic of Korea
Dr. O. A. Bulatov	Union of Soviet Socialist Republics
Dr. N. S. Fadeev	Union of Soviet Socialist Republics
Dr. B. G. Ivanov	Union of Soviet Socialist Republics
Dr. A. G. Slizkin	Union of Soviet Socialist Republics
Dr. V. P. Tumanov	Union of Soviet Socialist Republics
Mr. Vidar Wespestad	United States
Dr. William Karp	United States

Paper or Presentation Titles and Authors

A. G. Slizkin and S. D. Budkin	Distribution, biology, and abundance of blue crab, <u>Paralithodes platypus</u> in the Bering Sea.

A. G. Slizkin and V. Y. Fedoseev	Distribution, biology, population structure, and abundance of tanner crabs in the Bering Sea.
B. G. Ivanov and K. A. Zgurovskiy	The shrimps of the Bering Sea: distribution, biology, abundance.
Gong Yeong, Joo Yeoul Lim, and Young Hee Hur	Abundance index for Alaska pollock by Korean trawlers in the Bering Sea. (Presented by Young Hee Hur.)
Takashi Sasaki	Synopsis of biological information on pelagic pollock in the Aleutian Basin. (Section on biomass.)
E. Jackowski and B. Trocinski	Features of fishery and biology of Alaska pollock taken in open waters of the Bering Sea on the basis of Polish catches in 1985-1988. (Presented by Z. Karnicki.)
V. Wespestad	Abundance and yield of walleye pollock on the eastern Bering Sea and Aleutian Islands shelf and in the Aleutian Basin.
V. Wespestad and B. Megrey	Assessment of walleye pollock stocks in the eastern North Pacific Ocean: an integrated analysis using research surveys and commercial fisheries data.
W. Karp and J. Traynor	Assessments of the abundance of the pelagic portion of central and eastern Bering Sea pollock stocks.

Panel Summary

Substantial information has been reviewed in the panel discussions on biomass and yield. The information has included estimates of biomass and potential yield for pollock in the eastern Bering Sea and western Bering Sea, and biomass estimates for the Aleutian Basin area as well as detailed catch-and-effort statistics for doughnut hole fisheries. These data are the most comprehensive assembled to date for the Bering Sea, and the panel members are to be congratulated for accomplishing this task under the extreme time constraints imposed by the scheduling of the meeting.

In addition to the papers on pollock, papers were presented by scientists from the U.S.S.R. on blue king crab (*Paralithodes platypus*), snow (Tanner) crabs, and (*Chionoecetes* spp.), and shrimps of the Bering Sea. The data presented suggest similar patterns of abundance since the late 1960s among western and eastern Bering Sea stocks of shellfish. The information presented suggests that *C. opilio* in the Bering Sea may be a single stock.

The information assembled on pollock was discussed in two broad areas. The first relates to the biomass and yields for the eastern and western Bering Sea pollock, and the second relates to movements of pollock in the Aleutian Basin.

Biomass estimates have been derived for the eastern and western Bering Sea, and catches from these areas have been relatively stable since the mid-1970s. At present, estimates of biomass and equilibrium yield by U.S.S.R. scientists for the western Bering Sea are 5.5-7.0 and 0.5-0.6 million metric tons, respectively. The biomass and potential yield for the eastern Bering Sea estimated by U.S. scientists are 6-8 and 1.2-1.4 million metric tons, respectively. There was substantial disagreement over the estimates of biomass of pollock in the Aleutian Basin area. Existing survey information was incomplete, and surveys for different areas were conducted at different times of the year.[5]

Comprehensive, synoptic surveys of the entire range of pollock in the Bering Sea in a time frame necessary to discount migrations of pollock out of the survey areas have not been conducted. Until these surveys are conducted, it will not be possible to resolve controversy over the extent of pollock biomass in the Aleutian Basin area.

It was noted that the technology exists for conducting such a comprehensive acoustic/trawl survey. It would be expensive, however, and involve extensive international scientific cooperation.

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[5]After review of the draft proceedings, the Japanese delegation suggests the addition of the following two paragraphs:

U.S. scientists believe that in addition to estimates for the eastern Bering Sea (6-8 million metric tons above), the biomass in the Aleutian Islands area may be about 1 million metric tons and the Bogoslof Island area may also contain about 1 million metric tons. Harvest levels in the Bogoslof Island area were 328,000 and 219,000 metric tons in 1987 and 1988, respectively.

Japanese scientists presented the results of acoustic surveys conducted in the Aleutian Basin during the years of 1983, 1985, and 1987. The biomass estimates from these basin surveys were 1.14 million metric tons from the 1983 survey of the U.S. 200-mile zone, 5.24 million metric tons from the 1985 summer survey of a limited portion of the U.S. 200-mile zone off the Pribilof Islands, and 9.10 million metric tons from the 1987 summer survey of the waters beyond the respective 200-mile zones of the U.S. and the U.S.S.R.

With regard to the movement of pollock, there is substantial evidence of significant movements of pollock within the Bering Sea.[6] There were consistent seasonal trends in catch rates and sex ratios within the doughnut hole. These trends were clearly related to the general timing of spawning which has been established for pollock. There were differing opinions as to whether these movements were within the doughnut hole, or whether these were movements across the doughnut hole boundary. Some panel members argued that these patterns of movements were due to pollock forming local spawning aggregations and later dispersing to feed within the doughnut hole and not due to migration out of the doughnut hole.

However, it was pointed out by the panel that the boundary of the doughnut hole is strictly political and is not related to biological or oceanographic features in the Bering Sea ecosystem.[7] Some panel members argued that it is highly unlikely that movements of pollock are strictly within the doughnut hole. This view is supported by the observation of high densities of pollock within this area adjacent to the boundary. Several broad-scale surveys of the Aleutian Basin area presented by Japanese scientists found pollock widely distributed over the entire survey area.

U.S. panel members examined available data on chinook salmon (Oncorhynchus tshawytscha) bycatches. The panel found the data to be inadequate to estimate the magnitude of salmon interception in the doughnut hole fisheries. Pacific herring (Clupea harengus pallasi) bycatch was also discussed and it was noted that herring have never been encountered in fishery or survey samples within the doughnut hole.[8]

It was the view of the U.S. panel members that the magnitude, species composition (including bycatches of Pacific salmon), and location of catches in the doughnut hole need to be verified. The U.S. panel members suggested that the need for verification of catch would also apply to other trawl fisheries in the Bering Sea.

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[6]After review of the draft proceedings, the Japanese delegation does not believe that available evidence demonstrates significant pollock movement in the Bering Sea and suggests that this sentence should be attributed to the U.S. representative and not to the panel at large.

[7]After review of the draft proceedings, the Japanese delegation believes that the information available is insufficient to conclude that biological and/or oceanographic features coinciding with the doughnut hole do not exist.

[8]After review of the draft proceedings, the Japanese delegation believes that the statements in this paragraph should be attributed only to the U.S. delegation, and not to the panel at large.

The documented removals of pollock from the doughnut hole were comparable in magnitude to sustainable catch levels in the eastern and western Bering Sea areas. An appropriate level of harvest for the doughnut hole was not discussed.

There was disagreement whether any hypothesis of Bering Sea pollock stock structure presented by the panel could be rejected based on the information reviewed by the panel.

Walleye Pollock Catches in the Bering Sea
(in thousands of metric tons)

	Doughnut Hole Zone					U.S. EEZ	U.S.S.R. EEZ
Year	P.R.O.C.	JAPAN	R.O.K.	P.P.R.	Doughnut hole total	All nations	
1980		2.4	12.5			958.3	928.0
1981		.2	0			973.5	890.9
1982		1.2	2.9			955.9	1,019.1
1983		4.1	66.6			982.4	971.0
1984		100.9	80.3			1,098.8	785.9
1985	1.6	136.5	82.4	115.8	336.4	1,178.8	712.8
(No. vessels)	3	61	26	unk			
1986	3.2	698.0	155.7	163.2	1,020.1	1,189.4	936.7*
(No. vessels)	3	98	30	unk			
1987	4.1	802.6	241.9	230.3	1,279.0	1,253.5	1,108.3*
(No. vessels)	3	95	32	unk			
1988	17.4						
(No. vessels)	5						

* Preliminary information suggests that between 5 and 20% of these figures is taken from the doughnut hole but is not included in the doughnut hole catch total in this table.

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.

PANEL D - OCEANOGRAPHY

Participants

Chairman: Dr. Vera Alexander

Rapporteur: Mr. Vidar Wespestad

Panel Member	Nation
Dr. Sigeiti Hayasi	Japan
Dr. Kei-ichi Mito	Japan
Dr. Takashi Sasaki	Japan
Mr. Tang QiSheng	People's Republic of China
Dr. J. Janusz	Polish People's Republic
Dr. Z. Karnicki	Polish People's Republic
Ms. Young Hee Hur	Republic of Korea
Dr. Chang Ik Zhang	Republic of Korea
Dr. N. S. Fadeev	Union of Soviet Socialist Republics
Dr. B. G. Ivanov	Union of Soviet Socialist Republics
Mr. V. P. Tumanov	Union of Soviet Socialist Republics
Dr. Knut Aagaard	United States
Dr. James Overland	United States

Paper or Presentation Titles and Authors

T. Sasaki	Synopsis of biological information on pelagic pollock in the Aleutian Basin.
V. Alexander	Oceanography.
G. Khen	Oceanological conditions of the Bering Sea biological productivity. (Paper presented by V. Tumanov.)

R. Reed, J. Schumacher, and K. Aagaard — Some remarks on Bering Sea oceanography. (Paper presented by K. Aagaard and J. Overland.)

Panel Summary

There has been a dearth of oceanographic attention given to the Aleutian Basin, and in order to accomplish the essential research, international coordination will be essential.

We know some elements of water column structure of the Aleutian Basin. Overall circulation in the Aleutian Basin is cyclonic: a marked summer temperature minimum lies between 100 and 200 m, with warm water above and below, capped by a seasonal halocline. Below 200 m the water column is dominated by inflow from the North Pacific. Above the temperature minimum there are thick layers of reduced temperature and also salinity gradients caused by local convective mixing processes. A principal source of water in the Aleutian Basin is from inward flow through Near Strait in the Aleutian Islands. The wind field greatly influences oceanographic conditions, and winter wind velocities are 10 times greater than velocity of summer winds.

Eddies may be important, as Dr. Aagaard's and Dr. Khen's papers identified eddies of different signs as a major feature of the Bering Sea Basin. Mesoscale eddies have been observed, and these may persist for extended periods. Anticyclonic gyres are found on the shelf, one south of Cape Navarin and another between St. Matthew and St. Lawrence Islands. These features may influence pollock distribution and productivity. Current patterns are known to affect pollock stocks, and the high standing stocks of pollock in the western Bering Sea probably correlate with high primary production in this area brought about by the northwest movement of water along the shelf break. This water has a high nutrient content, which may result in a high carrying capacity.

On the eastern Bering Sea shelf, currents are weak and circulation is primarily a function of wind and tide. It was noted that at times surface circulation may be strong but the movement of underlying bottom water is not influenced by surface circulation.

Storms move through with varying frequency, and shift north or south from the average storm track in some years. As a result of the shift, the waters are cold some years and warm in others. Wind direction is very important in determining the shift. The wind field influences the extent of the winter ice distribution and either advances or retards the southward distribution of ice depending on the wind direction.

The position of ice on the eastern Bering Sea shelf influences the timing and intensity of the spring phytoplankton bloom on the middle shelf. This has been shown to affect the productivity of some fishery resources. However, pollock appear to be only weakly affected by interannual variations in oceanographic conditions with above average year classes in both cold and warm years. There does appear to be a weak correlation with icing.

It was noted that there have not been any measurements of primary productivity in the Aleutian Basin, and even nutrient profiles are scarce. We have yet to determine if the doughnut hole region is indeed productive. It was suggested that anticyclonic circulation may concentrate nutrients in the doughnut hole, and the nutrients could support high levels of productivity. This circulation may also affect larval transport and serve as an isolating mechanism for the various groups of pollock found throughout the Bering Sea. However, these ideas are highly speculative.

Although we have a basic understanding of the oceanography of the Bering Sea, the current level of knowledge is insufficient to address the questions raised in this panel about the productivity, pollock distribution, and interannual variation in pollock year-class strength. New technology, such as the acoustic doppler current profiler, may be useful in measuring currents and determining circulation patterns in the Aleutian Basin.

PANEL E - FUTURE RESEARCH

Participants

Chairman: Dr. Donald Bevan

Rapporteur: Dr. Richard Marasco

Panel Member	Nation
Mr. Mark Saunders	Canada
Dr. Sigeiti Hayasi	Japan
Dr. Kei-ichi Mito	Japan
Dr. Takashi Sasaki	Japan
Mr. Tang QiSheng	People's Republic of China
Dr. Z. Karnicki	Polish People's Republic
Dr. J. Janusz	Polish People's Republic
Mr. Hong K. An	Republic of Korea
Mr. Sung Hwan Ha	Republic of Korea
Ms. Young Hee Hur	Republic of Korea
Dr. Chang Ik Zhang	Republic of Korea
Dr. N. S. Fadeev	Union of Soviet Socialist Republics
Dr. B. G. Ivanov	Union of Soviet Socialist Republics
Mr. V. P. Tumanov	Union of Soviet Socialist Republics
Dr. James Balsiger	United States
Dr. Gary Stauffer	United States

Paper Title and Authors

D. A. Stolyarenko and B. G. Ivanov	A new approach to stock assessment by means of trawl surveys: The method of spline approximation of stock density for the result analysis and design of surveys.

Panel Summary

The chairman opened the panel by asking if there were any biological, oceanographic, or fishery-related issues that had not been discussed by panels A through D that should be identified and discussed prior to addressing research needs. None were identified by the panel. During the course of the discussion, delegates from several of the countries present stressed the importance of coordination, cooperation, and sharing research costs.

The chairman moved next to the presentations prepared for the panel. Summarized below are selected parts of the presentations given by each delegation.

Union of Soviet Socialist Republics

The unity of the ecosystem throughout the Bering Sea, common stocks of some species, and the growth of fisheries on the high seas necessitates a close cooperative research effort to determine the status and population structure of the pollock resource. Such a program should include standardized surveys and selected research activities that would take place or occur over a 5-year time period. The primary focus of these efforts should be on the monitoring of the state of resources and the environment. It is suggested that ichthyoplankton surveys be conducted each year on all known pollock spawning grounds. The purpose of these surveys would be to estimate spawning rates, to measure the size of the spawning biomass, and to study recruitment. April to May is the optimal time to conduct these surveys. Further, these surveys should be conducted throughout the Bering Sea at the same time. The collection of samples for morphological and genetic-biochemical studies should be undertaken. Samples that allow for the determination of size-age structure, fecundity, and maturity rates also should be taken. Scientists from the U.S.S.R. are willing to collect samples for other interested parties.

A second component of the program would be a bottom trawl survey to be conducted over the shelf of the eastern and northern parts of the Bering Sea for the purpose of studying the distribution and status of groundfish and crab resources. If the gear is properly rigged, these surveys would provide information on abundance of 1- and 2-year-old pollock. These data could be used to forecast abundance of pollock. June and July are the best months of the year for this survey. Ichthyoplankton sampling with the objective of collecting flatfish and pollock eggs and larvae should be conducted during the survey.

Additional surveys that were suggested included an acoustic/trawl and ichthyoplankton survey conducted every 2 or 3 years beginning in 1989 in the high seas area of the Bering Sea, including the Aleutian and Kommander Basins, a bottom trawl survey conducted over the continental slope of the whole Bering Sea or selected areas in turn every 3 years, and special research cruises including acoustic/trawl and ichthyoplankton surveys to investigate fish resources in Pacific waters adjacent to the eastern islands of the Aleutian Range.

It was also suggested that a large-scale pollock tagging project on major spawning grounds be conducted during the 1989-91 time period to study migrations and mixing.

During 1989 the U.S.S.R. plans to use two vessels to conduct ichthyoplankton-bottom trawl surveys in the western and eastern Bering Sea, including the high-seas area. Funding for the remainder of the suggested activities is uncertain.

The last topic discussed was the spline approximation method for conducting stock assessment surveys (Stolyarenko and Ivanov 1987; Stolyarenko, 1987.)

United States

Primary emphasis of discussions during this symposium has been placed on fishery resources associated with the Bering Sea doughnut hole, with pollock being the dominant species. It is known that to understand pollock dynamics in the doughnut hole, scientists must research pollock in the entire Aleutian Basin and over the eastern and western shelf regions of the Bering Sea. U.S. scientists are interested in the dynamics of pollock and other fishery resources in the Bering Sea ecosystem. Historically, both research surveys and analyses of fishery data have been used to assess the status of fishery resources in the eastern Bering Sea. The following provide examples of surveys that have been conducted:

1. Annual summer bottom trawl survey for groundfish and crab on the eastern Bering Sea shelf.

2. Triennial summer survey (1988, 1991, etc.) that includes the annual crab and groundfish trawl survey of the eastern Bering Sea shelf, bottom trawl survey of the northern Bering Sea, bottom trawl survey of the upper slope of the eastern Bering Sea, and acoustic/midwater trawl survey over the eastern Bering Sea shelf (with pelagic pollock as the target).

3. Surveys to address special topics. For example, during 1988 a pilot winter acoustic survey was conducted for pollock over the Aleutian Basin. In 1989 a cooperative winter acoustic survey for pollock will be conducted with the Japanese.

The foreign/joint venture fishery observer program has been used to collect fisheries data from foreign and joint venture fisheries in both the doughnut hole and in the U.S. Exclusive Economic Zone. Catch reports filled out by either fishermen or processors are the primary source of catch data from domestic fisheries. While these reports provide information on the catch of retained species, they do not provide data on bycatch.

Both survey and fishery data have been and are presently used to estimate the size of the biomass, determine species distribution, and estimate biological parameters for groundfish and crab stocks.

With respect to oceanography, models of surface flow from wind and pressure data of the Bering Sea have been developed, studies have been conducted on northern Bering Sea circulation and sea ice dynamics, and studies have been conducted on the seawater exchange between the North Pacific Ocean and the Bering Sea through the passes along the Aleutian Islands. A few attempts have been made to examine the relationship between environment and stock conditions. Attention should be focused on determining the importance of physical features to fish movement, the location of spawning areas, the role of transport and circulation near spawning grounds to the survival of eggs and larvae, and role of physical oceanography on growth and feeding ecology.

Future research conducted in the Bering Sea should have as its goal the determination of the abundance and stock structure of the Bering Sea pollock resource. Biomass estimation will require the conduct of comprehensive acoustic/trawl surveys of the entire Bering Sea, as well as the collection and analysis of commercial catch data. Determination of stock structure will require morphometric/meristic studies, genetic studies, tagging studies, egg and larval studies, and fishery oceanography studies. Oceanography studies should have as a priority the determination of the general circulation of the Aleutian Basin. This could be accomplished by summer and winter mapping of temperature, salinity, and oxygen fields throughout the area. Investigation of the nutrient content and current variability should be included. Slope/shelf seawater exchange processes should be studied. This should include monitoring of the currents along the rim of the Aleutian Basin via current meter moorings and drifter releases.

Polish People's Republic (Poland)

Research should focus on biomass estimation, determination of spawning areas, and determination of early life history. With respect to biomass estimation, acoustic surveys should receive top priority. To be most useful, these surveys should cover the entire Bering Sea. However, the high cost of surveying the entire area in 1 year may require a partial approach to sampling. Obtaining information is an urgent concern. Should sampling be partial, the Aleutian Basin should be given high priority. In addition to the acoustic work, plankton samples should be collected to determine productivity. Further, samples should be taken of fish to determine length and age distribution, as well as concentration and distribution.

Location of spawning areas is important to the determination of year-class recruitment strength. It will be necessary to examine the distribution of eggs and larvae. Studies of the early life history of pollock and associated oceanography must also be conducted.

Poland is willing to send a research vessel, The Professor Siedlecki, into the Bering Sea to conduct research. However, because of economic conditions, this will be done only if costs are shared with other interested parties. In any case, there are plans to place scientists on commercial fishing vessels to conduct research. There is also a willingness to take scientists from other nations on board these vessels.

In closing, we would like to stress the importance of conducting research in a coordinated and cooperative fashion.

Republic of Korea (R.O.K.)

Studies of spawning and fecundity, meristics, morphometrics, parasite infestation, and otolith structure by chemical composition; biochemical genetic studies including mitochondrial DNA; tagging studies; egg and larval surveys; and studies of ocean currents will be necessary to determine the relationship between pollock caught in the doughnut hole and those caught in the Aleutian Basin and on the continental shelf and slope. Some of these items are currently being examined. However, there is still a need for more thorough study of these topics. In order for research to be successful, we feel that it should be conducted in a coordinated and cooperative fashion by the nations concerned.

Currently, R.O.K. is carrying out studies on fecundity and spawning, size and age-at-maturity, and meristics and morphometrics for pollock from the eastern Bering shelf and Aleutian Basin including the doughnut hole. Biochemical genetic studies, including those from R.O.K. waters, will be added to the agenda for 1989. In addition, commercial catch and effort information with frozen samples have been collected and analyzed to determine the abundance of pollock.

R.O.K. has one research vessel that weighs 1,126 tons. This vessel has been conducting research in the area of the North Pacific where the high-seas squid fishery has occurred for the past several years. Prior to becoming involved in this activity, the vessel conducted research in the Gulf of Alaska.

In light of the importance of the international zone of the Bering Sea, R.O.K. is prepared to re-examine its priorities. We are not prepared at this time to make any commitments to initiate research in the doughnut hole with this vessel. However, we are prepared to carefully examine the merits of such activity.

Japan

Research activities should be focused on clarification of the biological production mechanism of pollock resources in the entire Bering Sea. This task can be best accomplished by both coastal and fishing nations conducting comprehensive cooperative surveys and studies of pollock stocks throughout the Bering Sea. A broadening of our knowledge of pollock resources will require analyses of stock structure, development of biomass estimates, and the monitoring of fisheries.

Determination of stock structure will require:

1. Confirmation of spawning grounds and determination of the size of spawning stocks.

2. Comparison of the biological parameters associated with each spawning stock (abundance, age composition, growth, condition, fecundity, age of maturity, recruitment, mortality, etc.)

3. Comparison of meristics and morphometrics.

4. Comparison of the shape or the formation patterns of growth rings on age materials from the spawning stocks.

5. Examination of genetic composition using biochemical methods.

6. Examination of movement and migration; in particular, the movement from the spawning to feeding grounds, migration from feeding to spawning grounds, and the movement from the continental shelf to the Aleutian Basin or from the basin to the continental shelf.

7. Examination of larval transport.

8. Collection of samples from broad geographical areas during the summer feeding season to determine the extent of mixing; collection should be done as subpopulation are identified and characteristics of the different stocks isolated (based on surveys regarding items 2 through 5). Consideration should be given to conducting tagging studies. However, there is a need to examine various techniques to determine the most effective method.

Both research surveys and catch-at-age analyses can be used to obtain biomass estimates. To ensure that valid estimates are obtained, surveys should be conducted by qualified personnel. The summer and winter are the most appropriate times for these surveys. When cohort models are used to estimate biomass, it is important to keep in mind that biomass estimates will be invalid if data are incomplete.

As noted above, lack of information from the fishery has an adverse effect on biomass estimates; information from commercial fishing vessels is extremely important to both the determination of stock structure and size. Individual nations should establish systems to collect accurate data from their fisheries, with mechanisms built in that allow for exchange of data between countries. Data collected should include catch, fishing effort, age materials and frozen samples.

With respect to Japan's research plans, there are three surveys scheduled. The first will be conducted from July to October, the second during the month of September, and the third from December 1988 to March 1989. These surveys will cover the Bering Sea with emphasis being given to the Aleutian Basin and doughnut hole. The goal will be to estimate the size of the biomass. As for 1989 and beyond, there are plans to continue these surveys. Survey design will be dependent upon results obtained from those being conducted in 1988 and 1989.

Panel Recommendations

General Recommendations

1. Conduct international scientific symposia in the future to facilitate data exchange/collection and communications among scientists from different countries.

2. Establish an information exchange system for the collection and dissemination of cruise plans, biomass estimates, and catch data.

Research Recommendations

1. Determine the stock structure of Bering Sea pollock.

    a. Morphometric/meristic studies.

    b. Genetic studies.

    c. Tagging studies.

    d. Egg and larval studies.

    e. Study of biological parameters; that is, growth, fecundity, and age composition.

    f. Study of fishery oceanography.

2. Determine the abundance of pollock in the Bering Sea by acoustic, trawl, and ichthyoplankton surveys, as well as other assessment methods such as age-structured models.

3. Conduct multinational workshops to standardize methods for activities such as ageing of fish and acoustic survey calibration.

4. Conduct studies to determine circulation of Aleutian Basin waters by mapping summer and winter temperatures, salinity, and oxygen fields throughout the basin (including nutrients) and to investigate the variability of currents.

5. Investigate slope/shelf water exchange processes by monitoring near-shelf currents along rim of the basin.

6. Investigate trophic interactions in the Bering Sea ecosystem.

References

Stolyarenko, D. A. and B. G. Ivanov. 1987. The new approach to bottom trawl surveys with special reference to deep water shrimp (Pandalus borealis) off West Spitzbergen. ICES, Doc. C. M. 1987/K:30, 35p.

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CLOSING REMARKS - CANADA

Mark Saunders

I would like to thank Dr. Aron and the organizers for the invitation to attend this symposium.

Canada is not actively engaged in fisheries or fisheries research in the Bering Sea and as a result, I have not participated in the formal exchange of data. Canada does, however, conduct research on most of the species discussed, in particular walleye pollock, and we share the same challenges as fisheries scientists. Consequently, a great deal had been exchanged informally.

I sensed, over the course of this symposium, a strong and growing spirit of cooperation. I feel that significant advances have been made--advances addressing the here-and-now issues surrounding the doughnut hole fisheries and, more importantly, recognition of the need for cooperative research between nations of the North Pacific and the development of interdisciplinary, integrated approaches to research.

CLOSING REMARKS - JAPAN

Dr. Sigeiti Hayasi

Japan is the pioneer in the bottom fish fisheries in the Bering Sea and is harvesting the largest amount of pollock in the international waters. The pollock stocks therein are indispensable for our fisheries and therefore we strongly wish to cooperate with all the other nations concerned towards the establishment of an adequate conservation scheme based on the best scientific information in order to assure the continuous utilization of these stocks long into the future.

In this regard, we expended a great deal of scientific effort, including surveys by research vessels, on the pollock stocks. Furthermore, we proposed at the 34th Annual Meeting of the International North Pacific Fisheries Commission (INPFC) in November 1987, to hold a meeting including the representatives of such nations as the People's Republic of China, the Republic of Korea, Poland, and the U.S.S.R. in addition to the three member countries of the INPFC. The meeting had as its goal the exchange of opinions among the nations interested in the pollock resources in the Bering Sea, including the establishment of a new international organization dealing with the said resources, based on the INPFC convention, inclusive of enhancement of research activities. Unfortunately, the meeting was not held because the United States did not accept the above proposal. This gravely disappointed me in my role as the Japanese scientific representative at the INPFC.

However, scientists of all the concerned nations have gotten together here in Sitka, and in consequence, a symposium was realized to discuss the fisheries resources in the whole Bering Sea (including those in its international water portion) with special attention upon pollock, even if it was organized jointly by the U.S.A. and U.S.S.R. Eventually, it has been confirmed that the cooperation among the related nations is of extreme importance in accumulating scientific knowledge and exchanging the findings obtained, and this view is what has been coming forward since last autumn. It has also been noted that the pollock stocks and the environmental factors in the international waters should be studied in the context of the whole Bering Sea. Thus, although this scientific meeting was realized after much complication, we wish to expend as much effort and cooperation as possible for the conservation and rational utilization of the pollock resources in the Bering Sea, including those in the international waters, which form the common property of man.

I would like to ask you to pay special attention for the necessity of implementation of cooperative surveys by the related nations and enhancement of exchange of views upon obtained scientific information. All the participants of this symposium have already accepted the importance of such cooperation. Here is a remarkable example to support our view. Japan has conducted, in cooperation with the United States, research surveys on fisheries resources in the U.S. 200-mile zone for many years. In 1978, at the beginning of such cooperative research activities, significant differences existed in the allowable biological catch estimates of pollock stocks between the two sides, that is, about 900,000 metric tons by the Northwest and Alaska Fisheries Center and about 1,900,000 metric tons by the Far Seas Fisheries Research Laboratory. These figures reflect considerable difference in biological views between the two scientific groups.

This gap has been reduced during our cooperative surveys conducted continuously year after year. The estimates presented at the Standing Committee on Biology and Research of the 34th Annual Meeting of the INPFC were about 1.4 million metric tons by U.S. scientists and over 1.5 million metric tons by Japanese scientists, and thus showed a fairly good agreement.

I heartily wish to utilize our experience from the U.S. 200-mile zone as a good example in dealing with the pollock resources in the international waters in the Bering Sea. For this purpose, I believe it desirable to hold a meeting of scientists to accelerate systematic and efficient research activities in the related matters, as we agreed during the Panel E this morning. We, therefore, stress now the effectiveness of such a meeting. Also, I would like to express that Japan is willing to host the next scientific meeting, as the occasion arises.

Finally, we have greatly benefitted from attending this meeting. It provided us with a good opportunity for oral exchange of views with scientists from the six nations. I should like to express my hearty appreciation to Dr. Aron and all the responsible persons who successfully arranged this extensive meeting during the very short lead time of less than 2 months.

CLOSING REMARKS - POLISH PEOPLE'S REPUBLIC

Dr. Z. Karnicki

Mr. Chairman,

On behalf of the Polish delegation I would like to thank the initiators as well as the organizers of this symposium. As it has been said before, this is the first time that all the countries exploiting the resources of the Bering Sea have sat together to discuss scientific problems of common interest.

The urgency with which this meeting has been called and the events that preceded this decision created a lot of controversies and worries among the countries concerned. However, it happened-- and in this connection my thanks go to Dr. Aron, Chairman of the symposium, the Chairmen of all the panels, and participants of the panels--that this meeting became a clearly scientific meeting, gathering all valuable materials on Bering Sea resources and identifying the areas of future research which should receive priority. I do hope that all respective governments will accept our recommendations. In Senator Murkowski's opening ceremony speech we have heard how important pollock fisheries are for expanding Alaskan and American fisheries. But, Mr. Chairman, this is only one side of the coin. The pollock fishery is also important for other countries as well. Poland has been exploring and exploiting North Pacific grounds since 1973, and fishing operations in this area, particularly in recent years, have become most important. I would say even more, taking into account so-called "americanization" of fisheries in the U.S. EEZ, the grounds of the international waters of the Bering Sea have become vital for our long-distance fishing operations and the economy of my country as well. Hundreds of Polish fishermen are exposed to the hardship of the Bering Sea to make their living. Their families at home depend on their incomes. According to the International Convention of the Law of the Sea, we have a full right to fish in international waters which are free for all. Although we have enjoyed the right to fish in these waters, we did not forget about obligations, particularly in the area of conservation and proper utilization of the resources. Therefore, my country, Mr. Chairman, is willing and prepared to discuss any issues in this regard on a multinational basis taking into consideration the available scientific data as well as provisions of the Convention of Law of the Sea.

CLOSING REMARKS - PEOPLE'S REPUBLIC OF CHINA

Song Zhiwen

Mr. Chairman,

Delegates,

We have come to Sitka, Alaska, for the International Scientific Symposium On Bering Sea Fisheries. First of all, please allow me on behalf of the Chinese Fishery Delegation to express our gratitude to the host, the Northwest and Alaska Fisheries Center, for the excellent arrangements made for the symposium and warm hospitality extended to us.

The symposium has provided us an opportunity to exchange academic information and to discuss the problems of the fishery resources in the Bering Sea together with the participating scientists from various countries. We are very much pleased with it. We have taken a great interest in the information presented by the participating scientists at the symposium and the views expressed in the course of discussion, and we further recognize that some of the largest fisheries resources in the world exist in the area of the Bering Sea, and that the problems in fishery resources are complex, so I think it necessary for the scientists concerned to work in close cooperation with each other more frequently.

We have noted that the scientists attend the symposium in their personal capacity, and that the provided information and expressed views are not official but are all based on personal experience or do not imply the expression of views on the part of any organization. We have also noted that many of the views at the symposium are quite different. If the materials are going to be edited and printed, the views in them are merely personal views which have not been unanimously agreed upon.

The symposium shows the surveys and studies made formerly mainly concentrated upon coastal waters and within 200-mile zones. Information about the Bering high seas is scarce and not much is known or published about stock structure and identification, migration patterns, and biological characteristics, to say nothing of the evaluations of maximum sustained yield, acceptable biological catches, or equilibrium yields. This demonstrates that at present it is essential for the countries concerned to give full cooperation to make surveys and studies in these fields. To conserve living resources in high seas, including sea mammals, is a commitment to those countries which share the freedom of fishing in high seas. In reality, only by making a concerted effort by the countries concerned can living resources be better utilized in a sustained, steady, and reasonable way, and make them serve mankind, with no exception of the fisheries resources in the Bering Sea, including the Bering high seas. We think the symposium is a good beginning. We are ready to do our best to further the development of the work in the above-mentioned fields with all of you in a cooperative way.

CLOSING REMARKS - REPUBLIC OF KOREA

Sung Whan Ha

Mr. Chairman,

First of all I would like to thank you for inviting us to this symposium. I wish in addition to express gratitude on behalf of my delegation to Dr. Aron and his colleagues for planning and organizing this symposium, and all the scientists who participated in this symposium.

Mr. Chairman, my government attaches great importance to this symposium, as my country has a vital interest in pollock fishing in the high seas of the Bering Sea. Korean vessels have been fishing in the so-called "Doughnut hole" since 1980, catching 242,000 metric tons in 1987.

Pollock has been widely used for direct human consumption in Korea from ancient times. However, due to nationalization trends of coastal states, we have lost traditional fishing grounds here and there. The "Doughnut hole" is the only remaining pollock fishing ground for us.

Therefore, we are very much concerned with the rational management and utilization of the pollock resources in the area.

Mr. Chairman, my delegation firmly believes that management and utilization of fishery resources in the high seas should be dealt with by a multilateral consultative system, preferably establishing a regional fishery body, where all the countries concerned are participating.

I think this symposium is a part of the preparation for such a system. I understand this symposium was planned and organized by limited countries.

Should all the invited countries here have participated in the preparation of this symposium and should the invited countries have been informed about this symposium well in advance, we could have prepared for this symposium more effectively and more in detail.

Mr. Chairman, in conclusion, my government is ready to participate in scientific activities in the area, including joint research to identify pollock stocks.

Thank you, Mr. Chairman.

CLOSING REMARKS - U.S.S.R.

Dr. Studenetsky

Ladies and Gentlemen,

Our International Symposium is focusing upon the most important fishery problems in the Bering Sea. This scientific forum, represented by nations fishing in this area, is taking place in proper time. All countries, and particularly those fishing in the central part of the Bering Sea, are greatly concerned over how sharply increased catches in the area, surrounded by economic zones of the U.S.S.R. and U.S.A., affect fish stocks in general and those of pollock in particular. As a result of an exchange of views, it came out that so far we are not able to make any definite conclusions on that score. We'll therefore have to study further the state of stock, distribution, and biology of pollock and other fish species.

We do realize that we have to step up the investigations in the Bering Sea. We are aware of the structure, complexity and unity of the Bering Sea ecosystem and believe that in this case, emphasis is to be placed on coordinated research works. Taking this opportunity I would like to assure all the participants that our scientists will be doing their utmost, as far as available material and human resources allow, to seek the solution to all these matters.

I believe I will express the feeling of all present here, that this is a timely symposium to tackle the most urgent fishery problems. Having brought together leading scientists from the fishing countries concerned it will certainly contribute to a greater knowledge of the biology of this important species and development of more rational management of fisheries in the area.

Special thanks are to be expressed to the sponsors of the symposium, its chairman Dr. W. Aron, and all participating colleagues.

Thank you.

APPENDIX 1

Papers from Panel A

REPRODUCTION AND ABUNDANCE OF SPAWNING POLLOCK IN THE BERING SEA

O.A.Bulatov TINRO

Walleye pollock (Theragra chalcogramma (Pallas)), the most abundant representative of the Gadidae family, is the main commercial species in the Pacific ocean. The most intensive pollock fishery is in the Sea of Okhotsk and Bering sea where the harvest in 1987 was 1.6 and 0.9 mln. tons respectively. In the Eastern Bering sea the walleye pollock is predominantly harvested by the Japanese fishermen whose annual catch has been around 1 mln. tons for the last 10 years. The open waters of the Bering sea where the combined catch of Japan, Taiwan, South Korea and Poland has been over 1 mln. tons in the last 2 years is of great importance too.

The level of knowledge of reproduction and abundance of walleye pollock over the shelf and the open areas of the Bering sea is not equivalent. The present paper is an attempt to sum up the available data on the basis of which one could formulate some aspects of working hypothesis in relation to fluctuations of walleye pollock abundance in the nearest future.

Materials and Methods

The data collected in TINRO cruises conducted in 1976 - 1987 (in the Western Bering sea the surveys were made in 1984 - 1987) have been put in the basis of this paper. The ichthyoplankton samples were collected with IKS-80 net having 80 cm diameter opening ($S=0.5m^2$). Horizontal sampling was performed at the vessel cicular manoeuvres with the opening kept completely under the surface at the speed of of 1.0 - 1.2 m/sec. Vertical sampling was conducted from 400 m depth to the surface in winter and from 200 m depth to the surface in spring. Samples were taken in all the seasons. The eggs development stages were identified by 4-point scale of Rass T.S.(1965). Since 1980 the ichthyoplankton sampling have been carried out by the standard grid of stations. Over 4,000 samples were examined during the study period. The samples were taken over the isobaths from 10 to 3,500 m (the Central and Western Aleutian Isls and the Norton Sound were not surveyed).

The eggs and larvae abundance were calculated by the method of Aksyutina Z.M.(1968):

$$N=\sum_{i=1}^{n}\left(\frac{Q_i \cdot \tilde{x}_i}{k \cdot q}\right) \qquad (1)$$

where N-abundance of eggs or larvae, Nos.

$\tilde{x}_i$-average catch under 1m^2 of conventional sea surface,Nos.

q-IKS-80, net sampling area, 0,5m^2

Q_i -a zone area(1-100,101-500,501-1000, more than 1000 Nos./m^2), km^2

k-fishing efficiency of IKS-80 net(according to the data of Shapiro L.S.(1971) is accepted as 0,7);

n- a number of zones

The correction for survival was introduced at qualitative eggs calculation, and that one for both small and large larvae as well (0,105 and 0,012).

The biomass of the spawning part of population of each region (Pj) was defined by the following equation(Bulatov,1987b):

$$Pj = \frac{\sum_{i=1}^{n} Ni/Si(1 + m/f) \quad W}{a \ . \ R} \ 100\% \qquad (2)$$

where i -index of stages of eggs and larvae development, in one cycle from 1 to n (where n is a completion of a stage of a formed larvae);

Ni - abundance of eggs and larvae at i stage of development

Si - survival of eggs and larvae at i stage of development in relation to the 1st stage;

m/f - female-male ratio of spawning population part(%);

W - average mass of spawning individuals(kg);

a - a share of spawned females(%);

R - average absolute fecundity of females of modal group (Nos)

The following assumptions were introduced to the above formula: 1) removal of eggs and larvae by predators is extremely small; 2) correction for survival was not taken into account for the 1st stage eggs; 3) absolute fecundity corresponds to a quantity of spawned eggs.

Discussion of Results

The spawning period of the Bering sea walleye pollock is rather significant and lasts for 10 months (January-October), as have shown the investigations carried out by different authors (Musienko,1963; Serobaba,1968,1971,1974;Fadeev, 1981; Waldron,1981; Bulatov,1986;1987a; Hinckley,1987). Ripe females and spawned eggs occurred in the range from 40 m to 3300m at the temperatures of -1,8° to +8,5°C.

The Bering sea walleye pollock have two discrete spawning peaks (Fadeev,1981; Bulatov,1987a). The first peak is marked in the end of February-early March, the second one from the end of April to early May. The winter spawning takes place in the south-eastern Bering sea over the depths of 2000-3000m, in a layer of 200-400m (see Fig.). Eggs develop at the temperatures of 3,0-4,0°C and high salinity 33,3-34,3‰. The spring spawning is related to the shelf zone, the spawning takes place at night in the above bottom horizont over the isobaths 75-125. The spawning temperatures vary from -1,0 up to 1,5°C. In the western and northern parts of the Bering sea (regions III-IV, see fig.), where weather conditions are most severe, the spawning and development of eggs are frequently found at temperature below or close to 0°C, and in the eastern part at t° = 0,5-1,5°C.

The spawning area where walleye pollock eggs occur in spring is rather significant and covers 300-450 thousand km². The main centers of reproduction are in the Olyutorsky Bay and off Unimak Island, the rest of them intensively function at the high abundance periods only.

During the period of low abundance a quantity of eggs in the northern spawning grounds is not large. For example, in 1981 off the Pribyloff Islands the maximum catch of eggs was some dozens and in 1984 it sharply increased -to 9400 Nos./m².

Eggs abundance in different regions of reproduction in spring of 1984-87 varied from 3-4 up to 10-12 fold value (Table). The least range of variability was marked in Unimak and Pribyloff regions, the maximum one - in the northern and western parts of the Bering sea (St.Matthew, Olyutorsko?navarin and Korfo-Karagin regions), where in cold years the ice regime influences the conditions of reproduction.

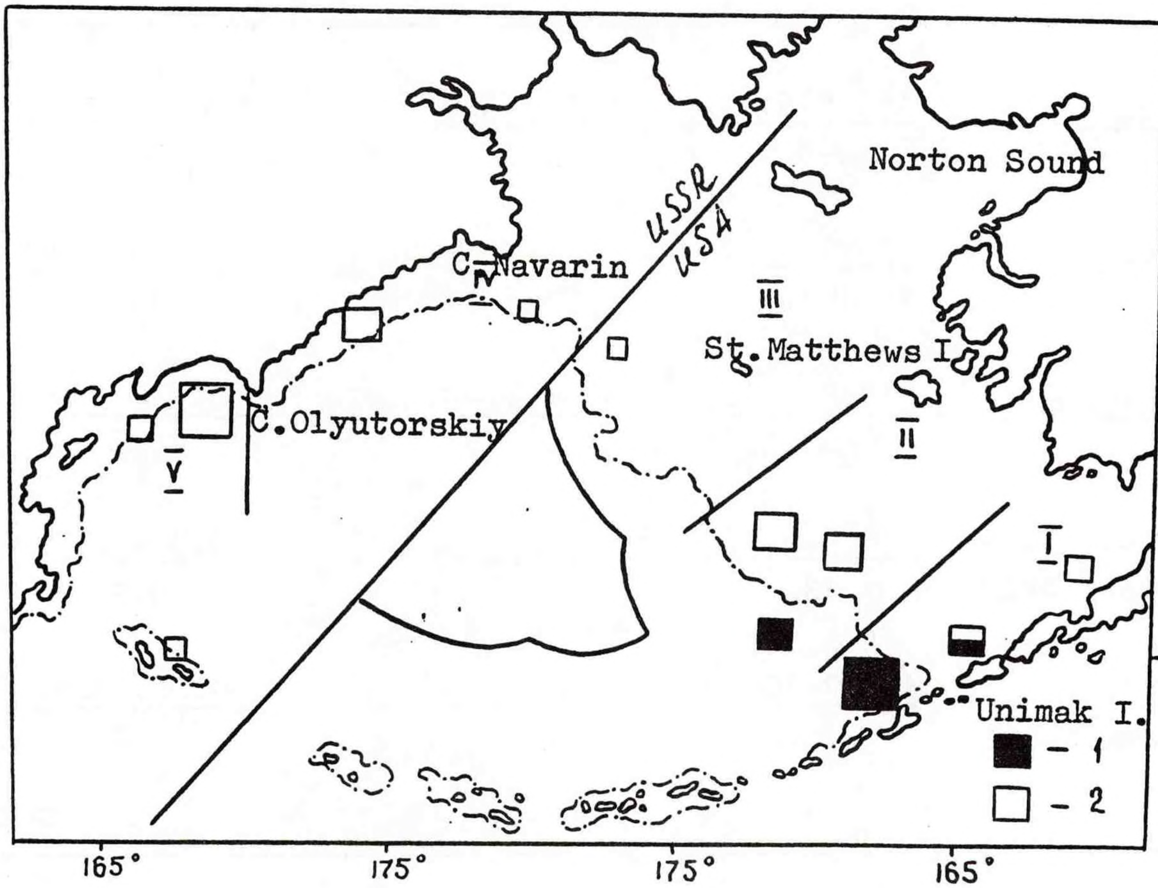

Fig. 1 The main spawning grounds of waleye pollock of the Bering sea (generalized)

Legend: I - Unimak grounds, II - Pribilof grounds, III - St.Matthews grounds, IY - Olyutorskiy-Navarinskiy grounds, Y - Korfa-Karaginskiy grounds.

1 - winter spawning 2 - spring spawning

Table

Abundance of eggs and larvae and biomass of pollock in the Bering sea (1984 - 1987)

A r e a	Abundance, 10^{11} Nos eggs	larvae	Biomass million tons
Unimak	155.1-610.7 / 299.7	6.1-223.0 / 72.6	3.2 - 6.5 / 4.9
Pribilof	156.7-475.2 / 291.8	2.7-190.6 / 73.3	1.1 - 3.3 / 2.2
St.Matthew	18.2-164.5 / 81.1	6.5-16.4 / 8.2	0.5 - 2.2 / 1.4
Olyutorskiy-Navarinskiy	6.9-83.9 / 46.1	0.8 / -	0.3 - 0.7 / 0.4
Korfa - Karaginskiy	20.7-206.2 / 98.2	- / -	0.6 - 4.1 / 1.7

Note: 1. Periods of observations are standard: late April - May.

2. Extreme values are in numerator, average ones in denominator.

3. In the US zone the biomass was not assessed in 1987, in the USSR zone it was not assessed in 1985.

The pollock eggs abundance is subjected to the largest interannual variability in the Unimak and Pribyloff regions(I,II). The ichthyoplankton investigations carried out in the standard terms took into consideration predominantly larvae resulting from the winter spawning. The quantitative study of eggs in winter for the first time was made in 1979. These investigations have shown that the overwhelming part of eggs had been developing beyond the shelf limits (96,1%). In 5 years the spawning potential has significantly increased and abundance of studied eggs increased 15 times. The maximum abundance of the pollock larvae of the winter generation have been observed in 1986-87, that proves the high efficiency of reproduction of the winter-spawning pollock race. Thus, the data obtained testify of the "blast" growth of the winter spawning pollock in abundance.

On the basis of the surveys the state of the spawning pollock stock was assessed. Taking into account the imperfection of ichthyoplankton method of assessment, it is necessary to underline that figures obtained are approximate and can be accepted as comparative data. The minimum stock according to our calculations, was 3,7mln.t, the maximum one - 16,8mln.t. The relative share of the Unimak region in the reproduction of Bering sea pollock is the most significant during periods of the abundance reduction. On the average, about half of the spawning pollock biomass is concentrated in the south-eastern part of the Bering sea whereas in the Olyutorsko-Navarinsk region only 3,8% of stocks spawn (see table.).

The analysis of data of fishery statistics, scientific information, interannual variability of solar activity and temperature in the after-spawning period has allowed to conclude that strong year-classes of the eatsren-Bering sea pollock appear in warm periods on the uprising curve of the solar activity (Bulatov,1987). The cold expected period in the end of the XX century (Girs,1974) will negatively influence the reproduction of the Bering sea pollock. It is obvious that negative consequences will result, first of all, in the regions with ice edge (Korfo-Karaginsk, Olyutorsko-Navarinsk, St.Matthew and partly Pribyloff regions), that after all, will result in the decrease of the spring-spawning pollock race abundance and localization of reproduction of the Bering sea pollock in one region - Unimak, in fact.

Insufficient information on pollock inhabiting the high seas of the Bering sea (the winter-spawning race) does not allow to forecast the changes of stocks conditions of pollock for the nearest future with a sufficient confidence. However, the information at our disposal shows that the "blast" growth of abundance of pollock eggs and larvae observed in 1984-87 is attributedto, probably, a number of strong year classes that appeared during the warm period (1977-81). In that case, if the mechanisms of stocks fluctuation for the winter and spring spawning races are similar and eventually related to the oceanological factors, the abundance of the Bering sea pollock is expected to decrease by the end of the 20th century, that, in its turn, will influence many components of ecosystem of the Bering sea.

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AN OVERVIEW OF AVAILABLE INFORMATION ON EASTERN BERING SEA WALLEYE POLLOCK REPRODUCTION AND EARLY LIFE HISTORY

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INTRODUCTION

The purpose of this paper is to present a synthesis and overview of available information on aspects of reproduction and early life history for walleye pollock (Theragra chalcograma) stocks in the eastern Bering Sea.

SPAWNING

Location and Timing

Based on U.S. Foreign Fisheries Observer coverage of the 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. 1). 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.

U.S. Foreign Fisheries Observer data from the Bering Sea in 1985 shows a similar spawning pattern when compared to 1984 data with respect to intraannual variation. Of interest in 1985 was the observed spawning in the doughnut hole area during February (Fig. 2) and March (Fig. 3).

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Distribution of Eggs and Larvae

Distribution of eggs and larvae tends to be observed to the north and west of the Aleutian Basin and eastern Bering Sea shelf and slope spawning locations. This is due to the prevailing circulation in the Bering Sea (Fig. 4). Results from egg and larval surveys (Incze et al. 1984) indicate that the geographic distribution and density of pollock eggs and larvae show substantial intra- and interannual variation.

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 is quite restricted compared to adult distributions in warm years (Fig. 5).

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).

Sex Ratios

Maeda (1986) presented evidence from the Bering Sea in 1973 demonstrating that pollock sex ratios exhibit intraannual variations (Fig. 6). 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 and Nakayama (1983) from the 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. 7).

MATURITY

Maturity-at-length Relationships

Few maturity studies have been carried out. Smith (1981) presented information on 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. This is in agreement with data from the Gulf of Alaska (Megrey 1989) where the size at 50% maturity for male and female pollock was reported to be 36.4 and 38.7 cm, respectively (Fig. 9).

Maturity condition is not constant from year to year. Data from pollock in the Gulf of Alaska (Megrey, unpubl. manuscr.) show that the length at 50% maturity varies substantially over the 1983-88 period (Fig. 10) for both males and females. The range for female pollock is almost 8 cm. Data presented by Okada and Nakayama (1983) from the Bering Sea during the time of pollock spawning (18 January to 20 March 1983) show that maturity also exhibits substantial temporal and geographic variation for males (Fig. 11) and females (Fig. 12).

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.

FECUNDITY

Fecundity-at-length Relationships

Comparison of pollock fecundity from different systems (Miller et al. 1986) shows that the fecundity-length relationship can be quite variable (Fig. 13). 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.

Factors Influencing Egg Production Rates

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

Egg Size, Energy Content, and Viability

In the 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).

Because the specific gravity of the egg changes as they develop, the depth of neutral buoyancy changes with different stages of development. A schematic of this from (Nishiyama et al. 1986) is presented in Figure 14. The implications of this aspect of reproduction are important for survival. If the neutral buoyancy properties of the egg allow it to be deposited below the pycnocline, then survival probabilities would increase since this is an area of the water column where nauplii densities are high. For this reason Nishiyama et al. (1986) have called the area at or near the pycnocline the nursery area. Kendall and Kim (1989) have investigated buoyancy properties of pollock eggs from the Shelikof Strait area of the Gulf of Alaska.

FACTORS AFFECTING RECRUITMENT

Observed Trends in Recruitment and Spawning Abundance

Trends in spawning population abundance and the resulting recruitment time series for Bering Sea pollock have been estimated from analysis of commercial fisheries statistics (Wespestad and Traynor 1988). Spawning abundance (Fig. 15, panel A) was about 2 million t in 1963, and then rapidly increased to a peak abundance of 15 million t in 1971 or 1972. Abundance declined and remained stable between 8 and 10 million t from 1974 to 1980. Since 1980, abundance increased once again to about 13 million t and has been declining in the past 3 years.

The age 3 recruitment abundance time series (Fig. 15, panel B) has been fairly variable, showing a range of an order of magnitude. Three strong year classes are evident, 1965, 1972, and 1978, with the 1978 being the strongest on record.

Qualitative/Quantitative Relationships Between Spawners and Recruits

Plotting the paired data points for recruitment and spawner abundance from Figure 15 after accounting for the recruitment time lag is one method of revealing the existence of any relationship between spawners and recruits. These data from Wespestad and Traynor (1988) are presented in Figure 16. The spawner/recruit plot shows the typical wide scatter of data points. Of interest is the fact that the 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 prerecruit mortality during these 3 years was highly variable.

Also included in Figure 16 is a line describing a Ricker spawner recruit curve fit to the data with nonlinear regression statistical methods (Wespestad and Traynor 1988). Despite the wide scatter in the data, the Ricker curve shows a statistically significant fit to the data ($P < 0.05$) and explains 61% of the variation in recruitment. According to the Ricker curve, as spawning abundance increases, recruitment reaches a maximum and then decreases as the number of spawners increases further because of increased compensatory density-dependent mortality. 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).

Egg, Larval, and Juvenile Mortality Rates and Causes of Mortality

Not much is known regarding mortality rates during prerecruit life history stages. Kim and Gunderson (1989) provide estimated mortality rates for pollock eggs in the Shelikof Strait region of the Gulf of Alaska. They estimate that before peak spawning, instantaneous mortality was about 0.40/day and decreased to about 0.10/day toward the end of spawning. Mortality for 4-10 mm larvae was less than 0.09/day.

Other than these relatively new estimates, not much information is available on egg and larval mortality rates. Figure 17 (Kajimura and Fowler 1984) demonstrates the complex role that pollock play in the Bering Sea ecosystem, serving as both predators and a source of food to a host of other organisms during all life history stages.

FISHERY EFFECTS ON RECRUITMENT

The effects of a commercial fishery on the reproductive characteristics of the pollock stock can be quite substantial. The fishery has the potential to alter the size and age composition of the exploitable stock through selective removals, either by size or sex. Indirectly, this could affect growth and ultimately the maturity or fecundity characteristics of the stock. When the fishery operates during the time of spawning as it does in the Bering Sea roe fishery, reproductive products that would normally contribute to the population are removed through directed harvest of fecund females.

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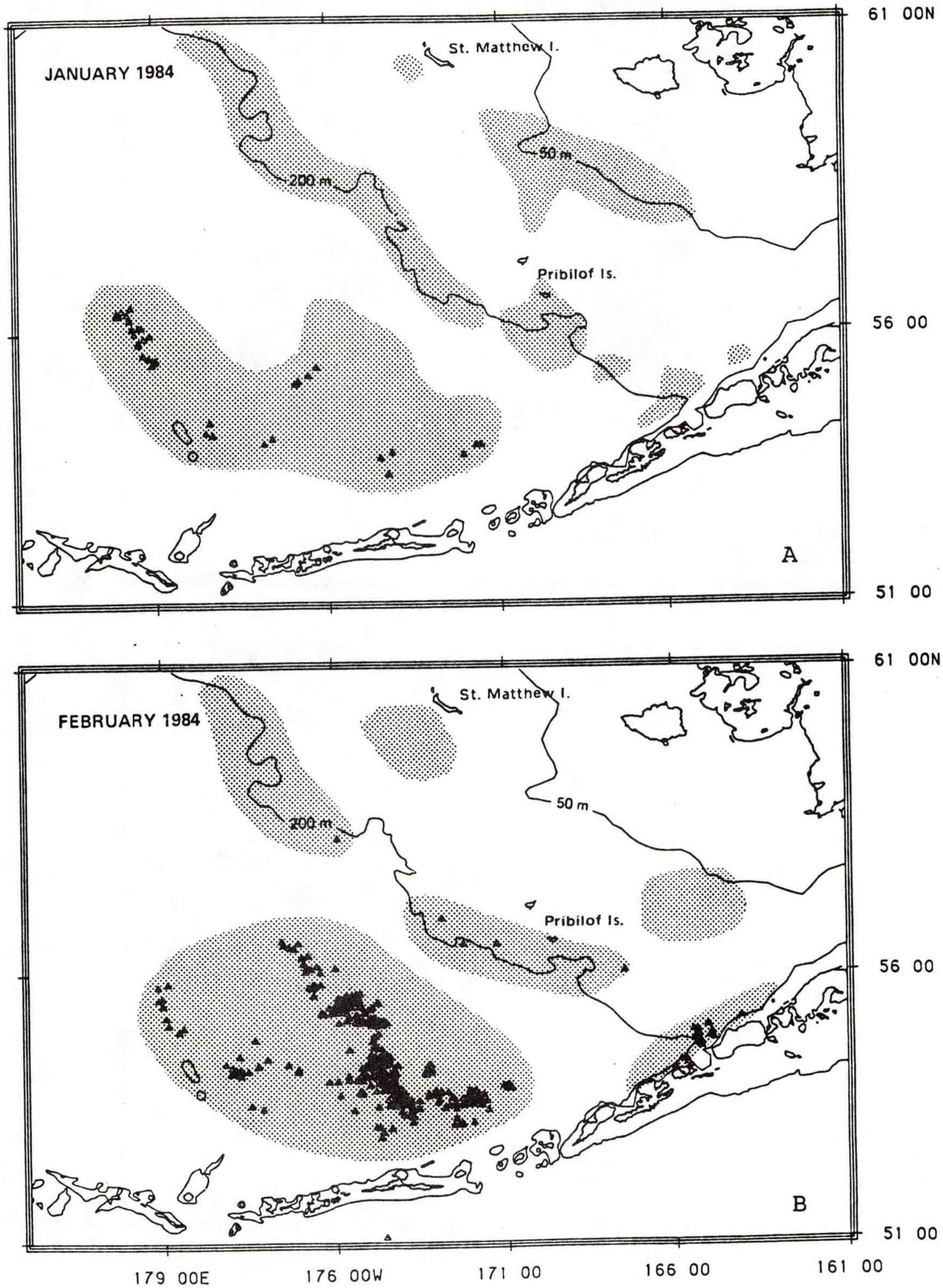
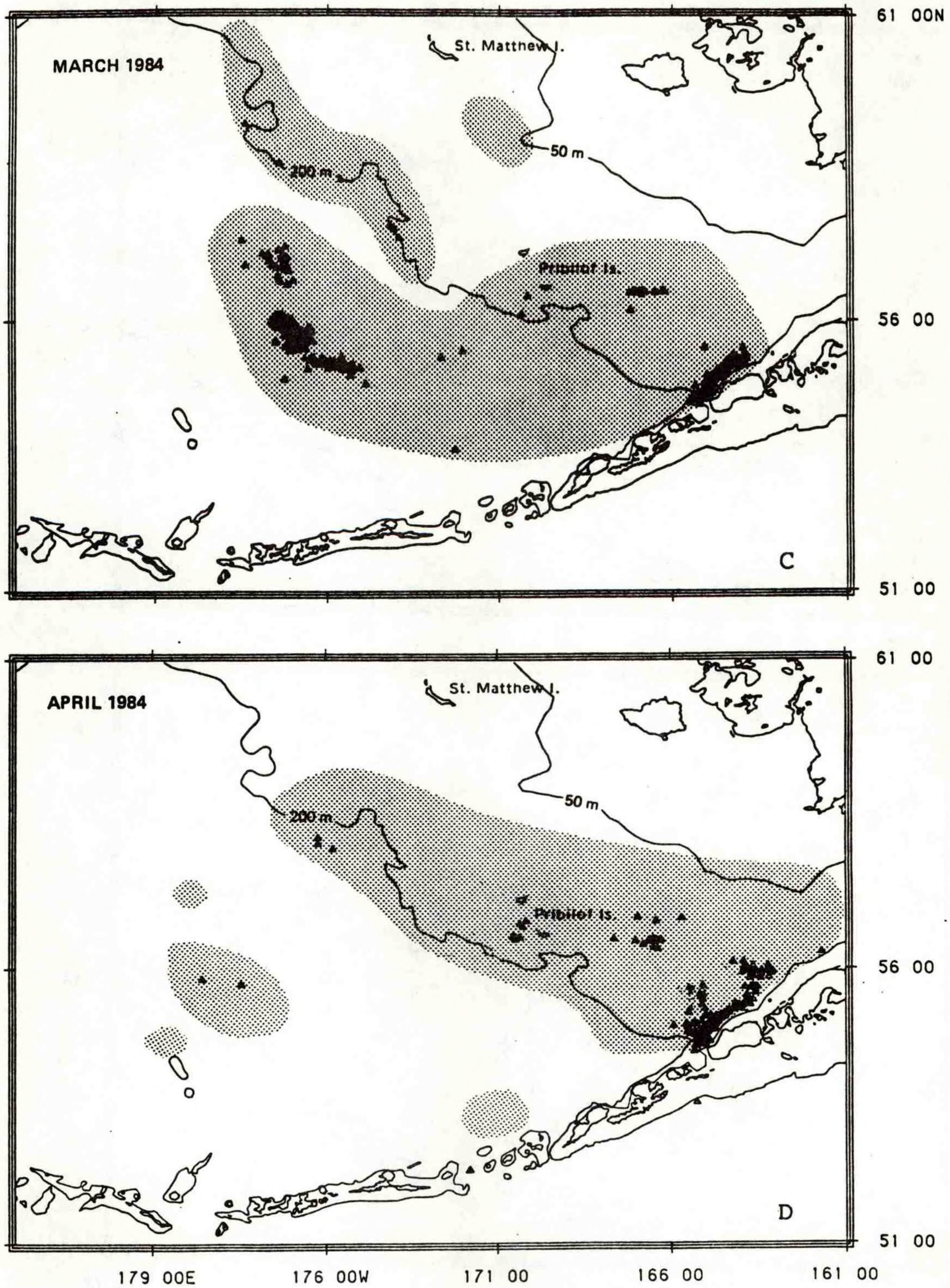


Figure 1.--Observed distribution of spawning pollock in the Bering Sea by month, 1984. Shaded areas indicate effort distribution of the commercial fleet. Triangles indicate observed spawning locations (from Hinckley 1987).



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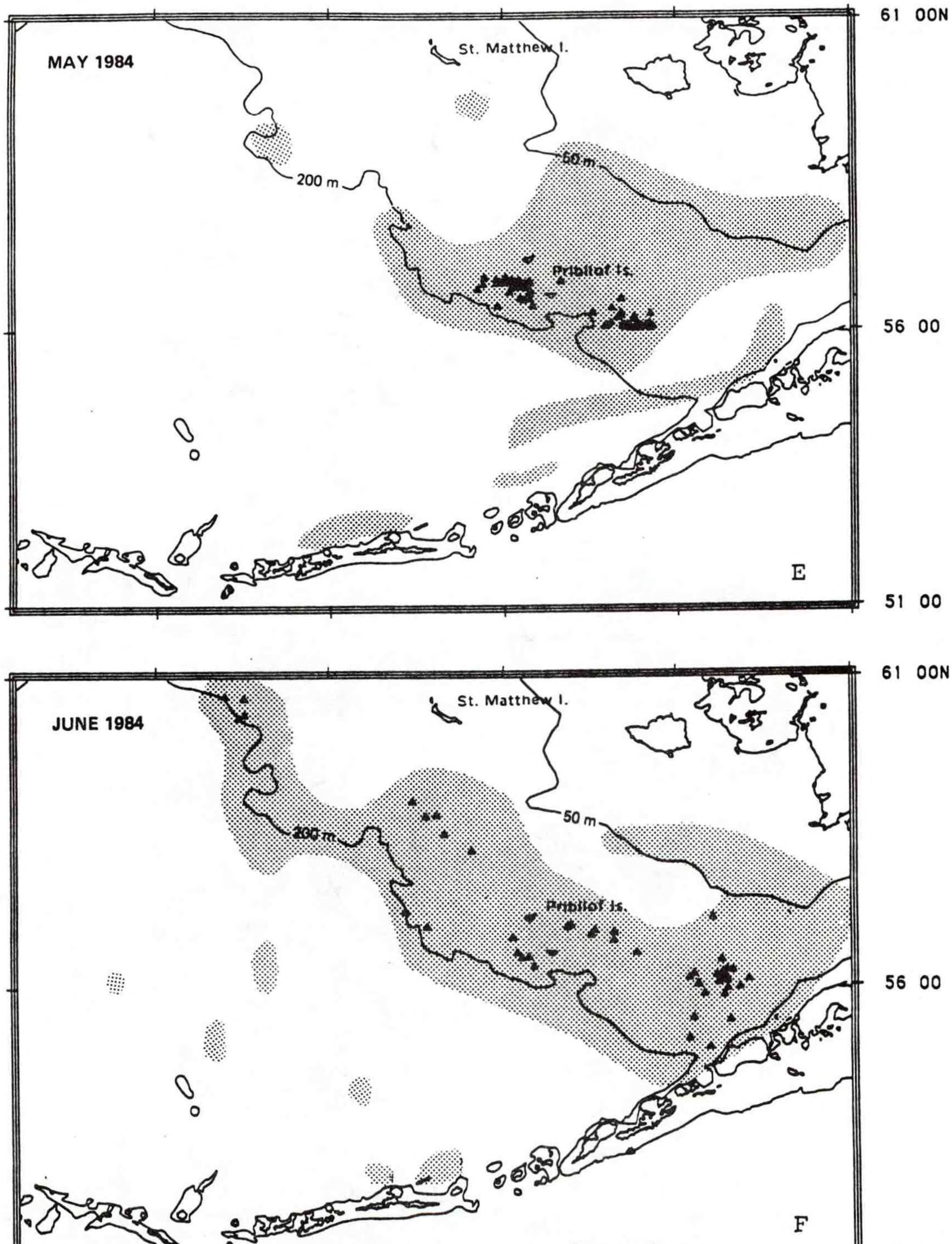

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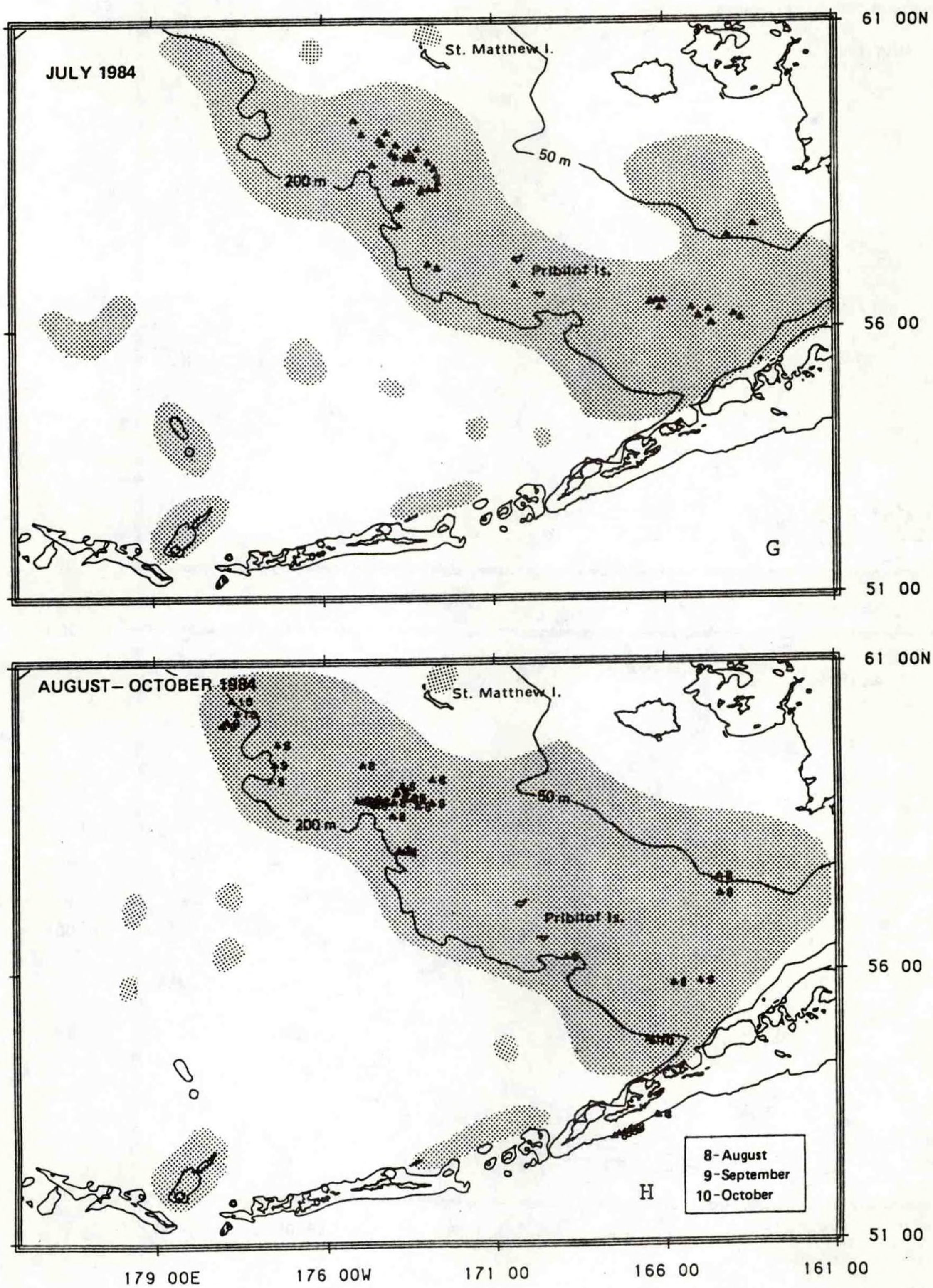

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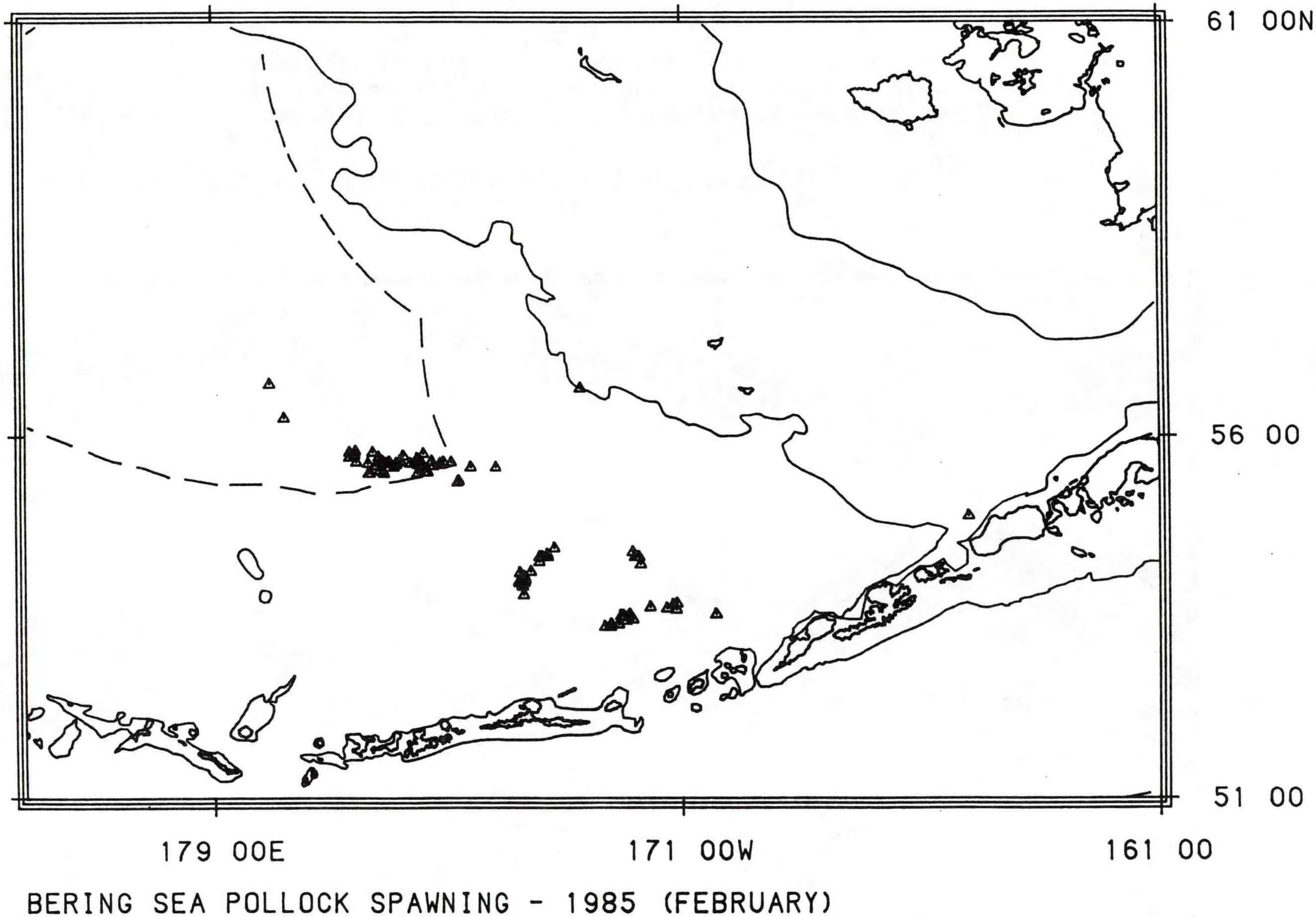


Figure 2.--Observed distribution of spawning pollock in the Bering Sea during February 1985. Triangles indicate observed spawning locations.

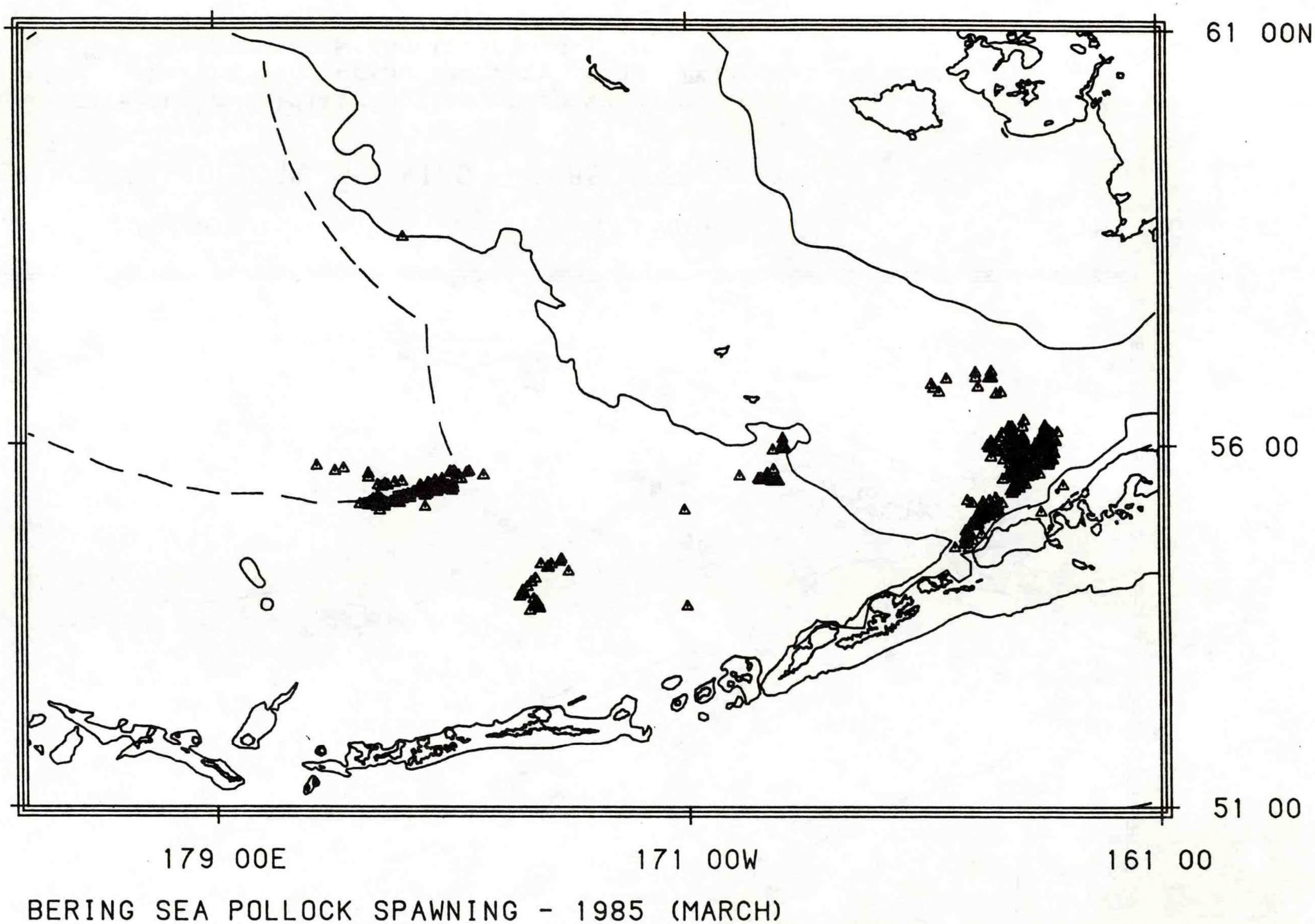


Figure 3.--Observed distribution of spawning pollock in the Bering Sea during March 1985. Triangles indicate observed spawning locations.

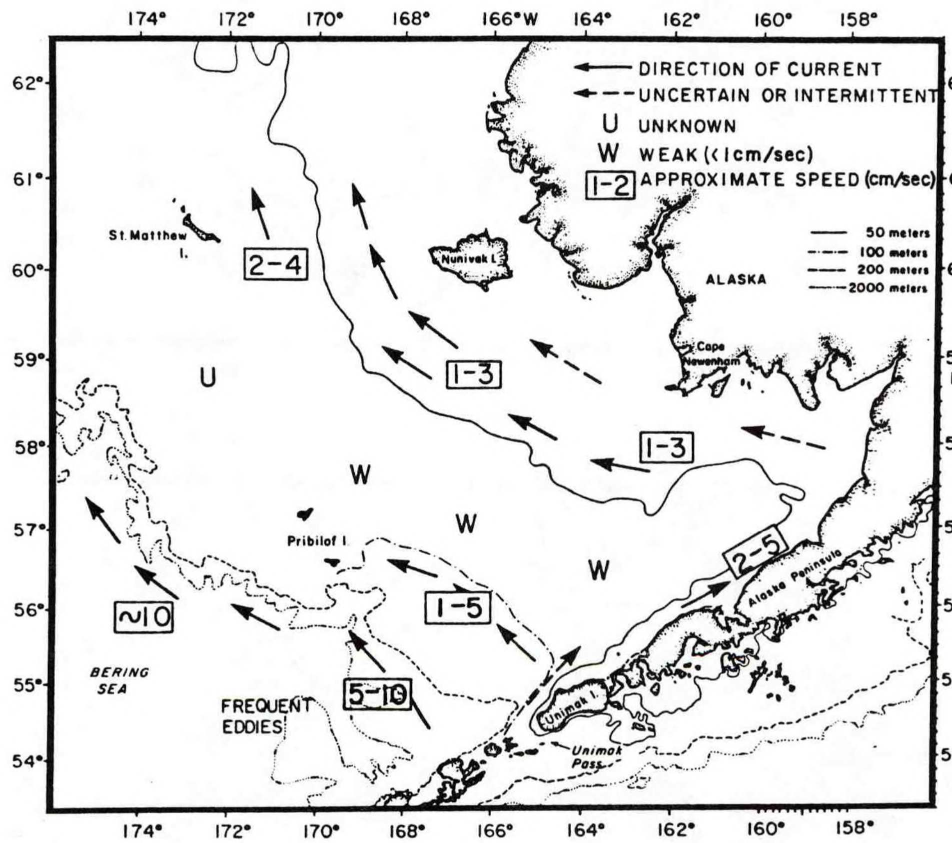


Figure 4.--Schematic of the prevailing current systems found in the eastern Bering Sea (from Lynde 1984).

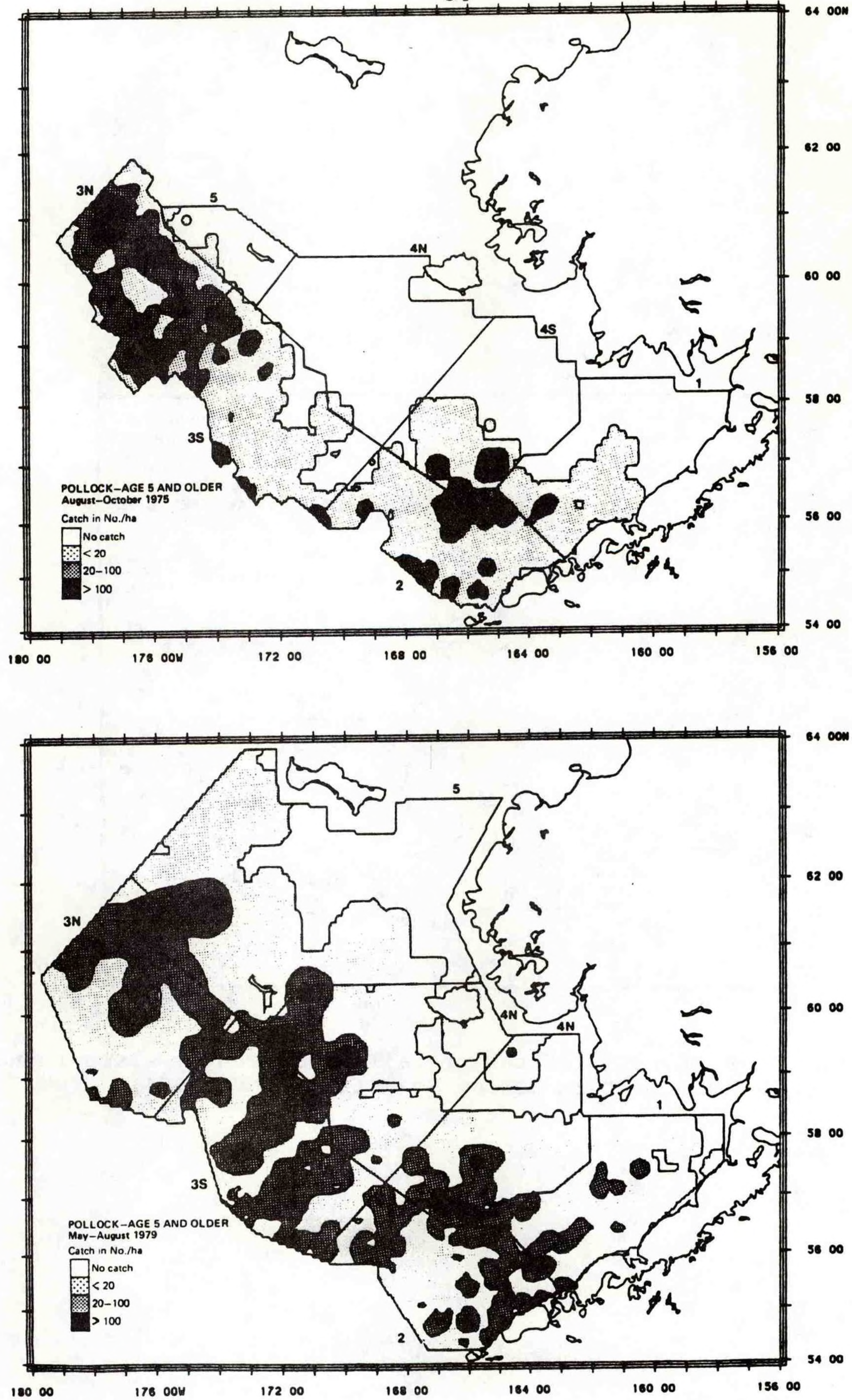
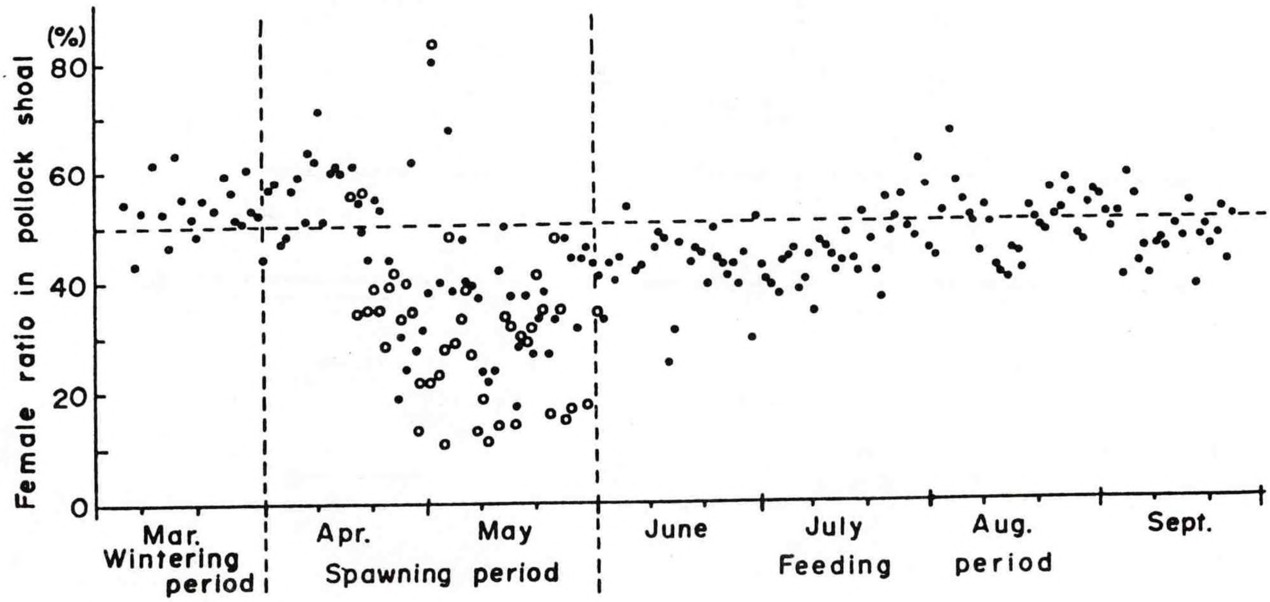


Figure 5.--Distribution of adult pollock in relatively cold year of 1975 and relatively warm year of 1979 (from Bakkala and Alton 1986).



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

Figure 6.--Seasonal variations of the sex ratio of pollock caught by bottom trawl in the eastern Bering Sea (from Maeda 1986).

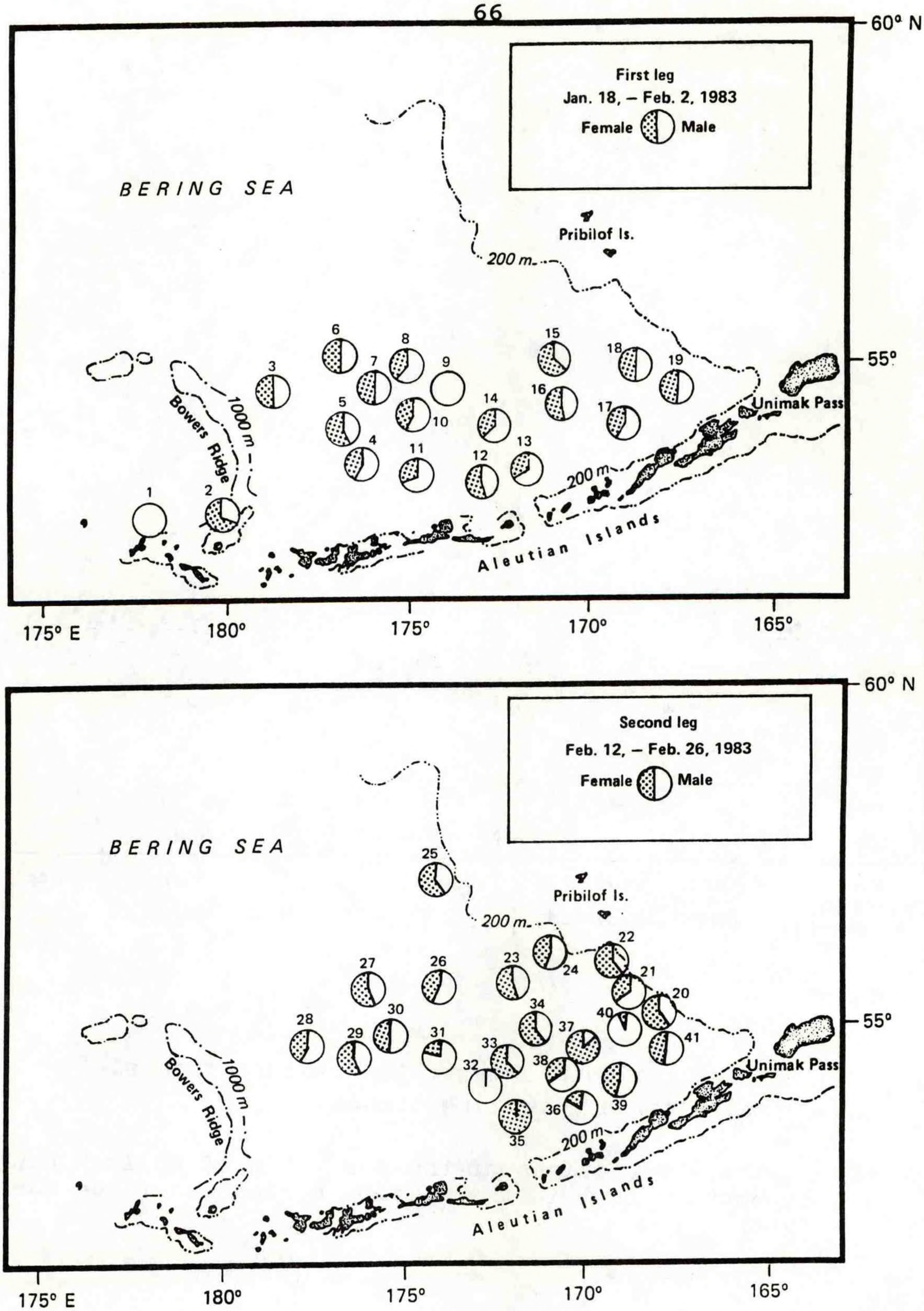
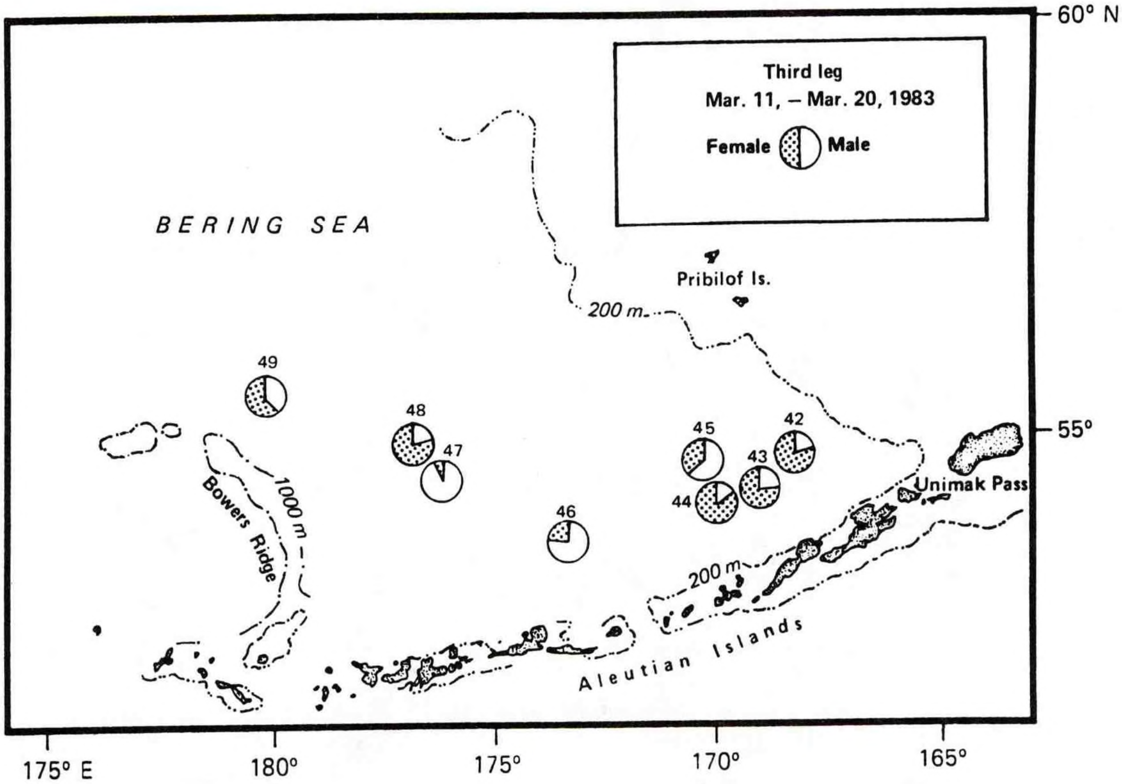


Figure 7.--Sex ratios of pelagic pollock caught by midwater trawls in the Aleutian Basin during the spawning period, 1983 (redrawn from Okada and Nakayama 1983).



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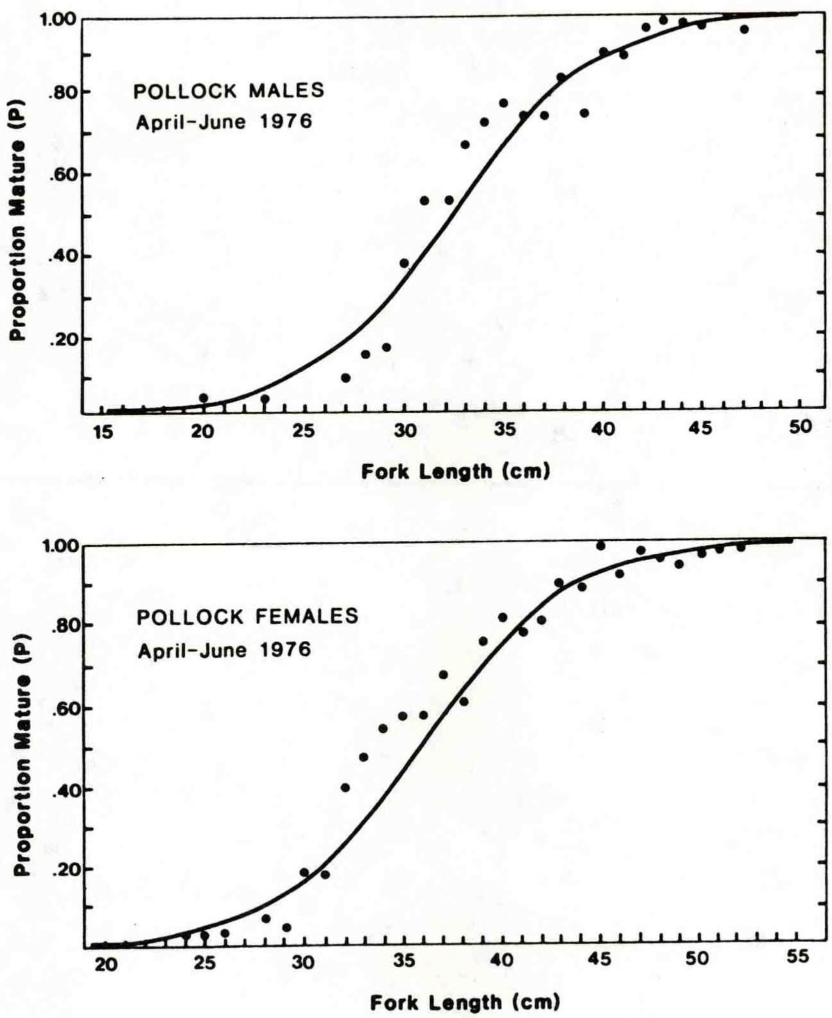
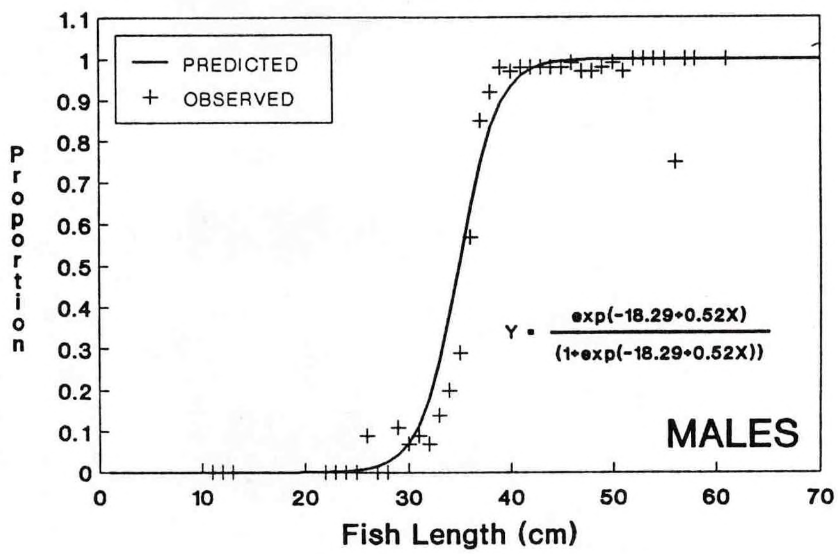


Figure 8.--Length-maturity relationship for Bering Sea pollock taken during April-June 1976 (from Smith 1981).



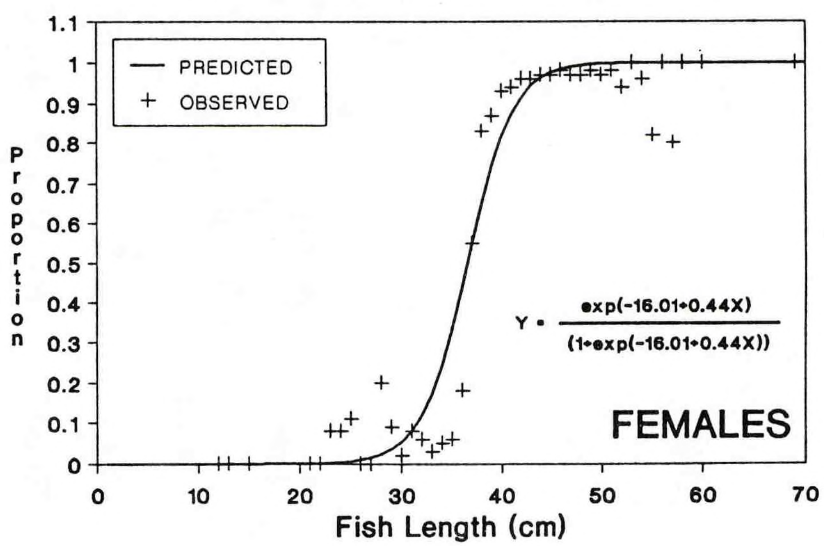
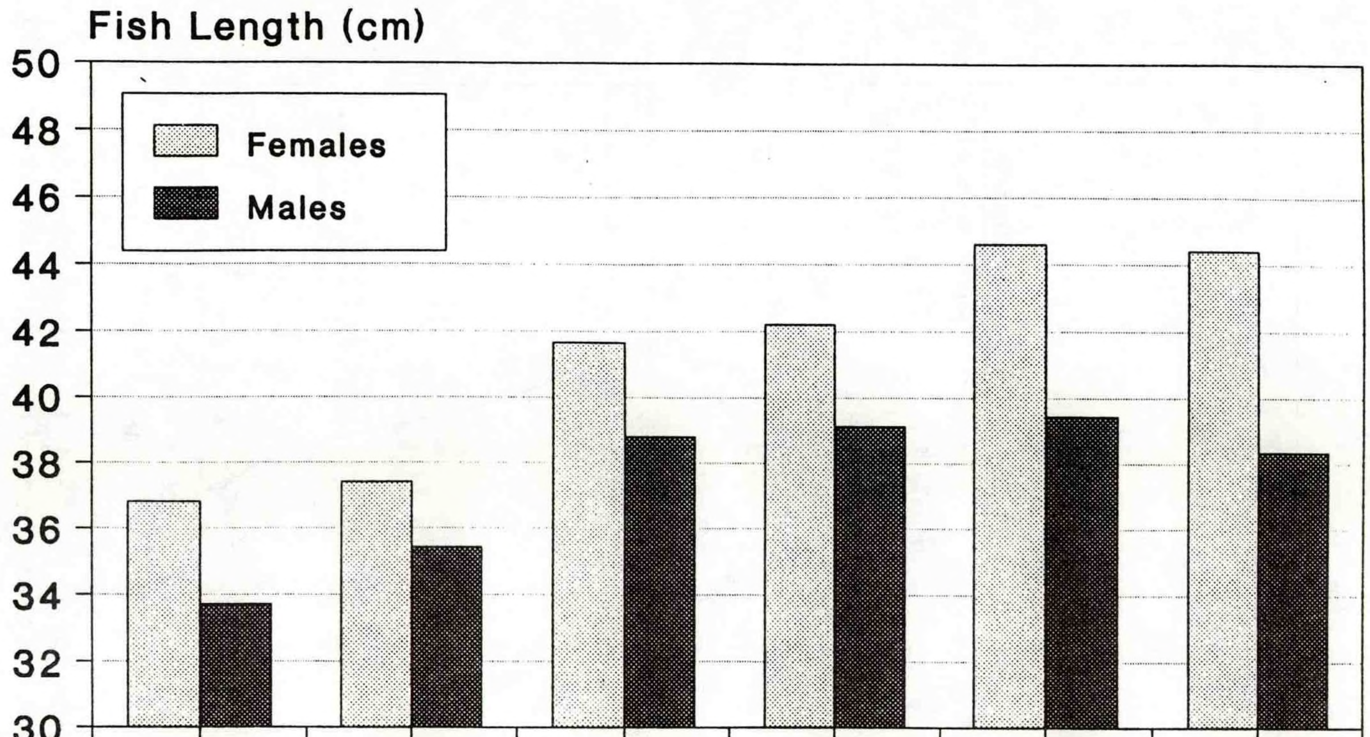


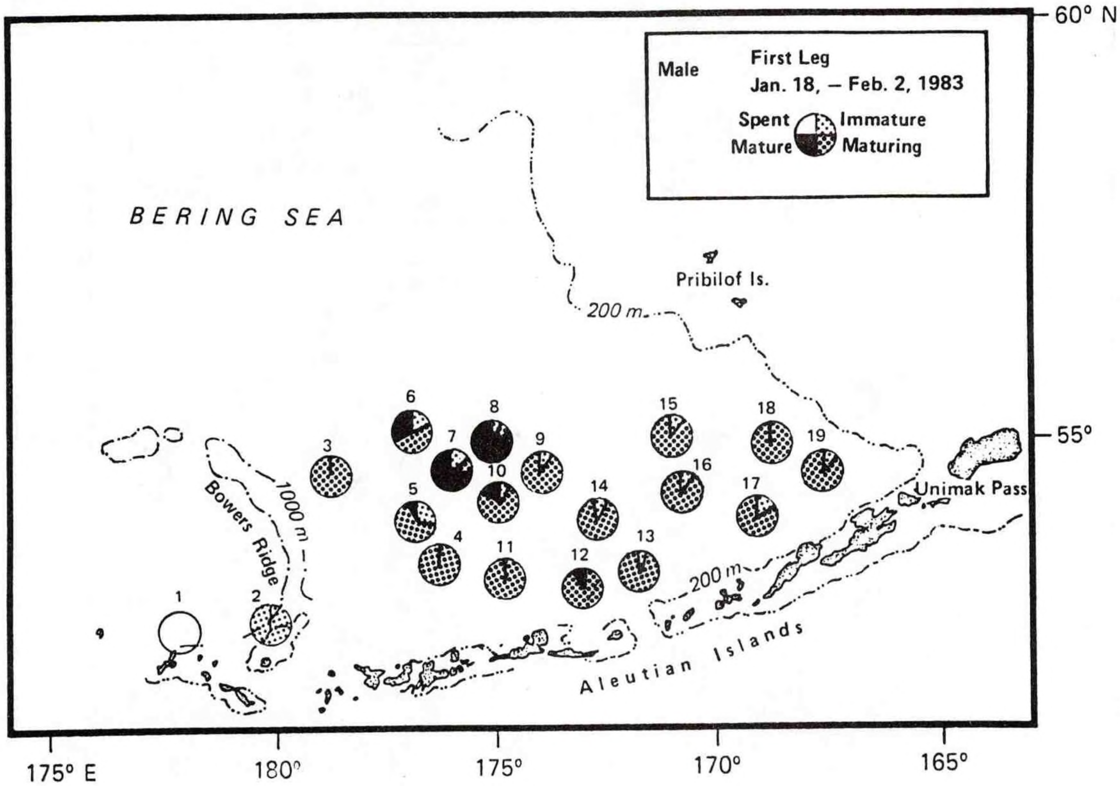
Figure 9.--Length-maturity relationship for Gulf of Alaska pollock taken from Shelikof Strait during March-April 1984 (from Megrey 1989).



	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 10.--Interannual variation in estimates of length at 50% maturity for male and female pollock from the Gulf of Alaska (from B. Megrey, unpubl. manuscr.).



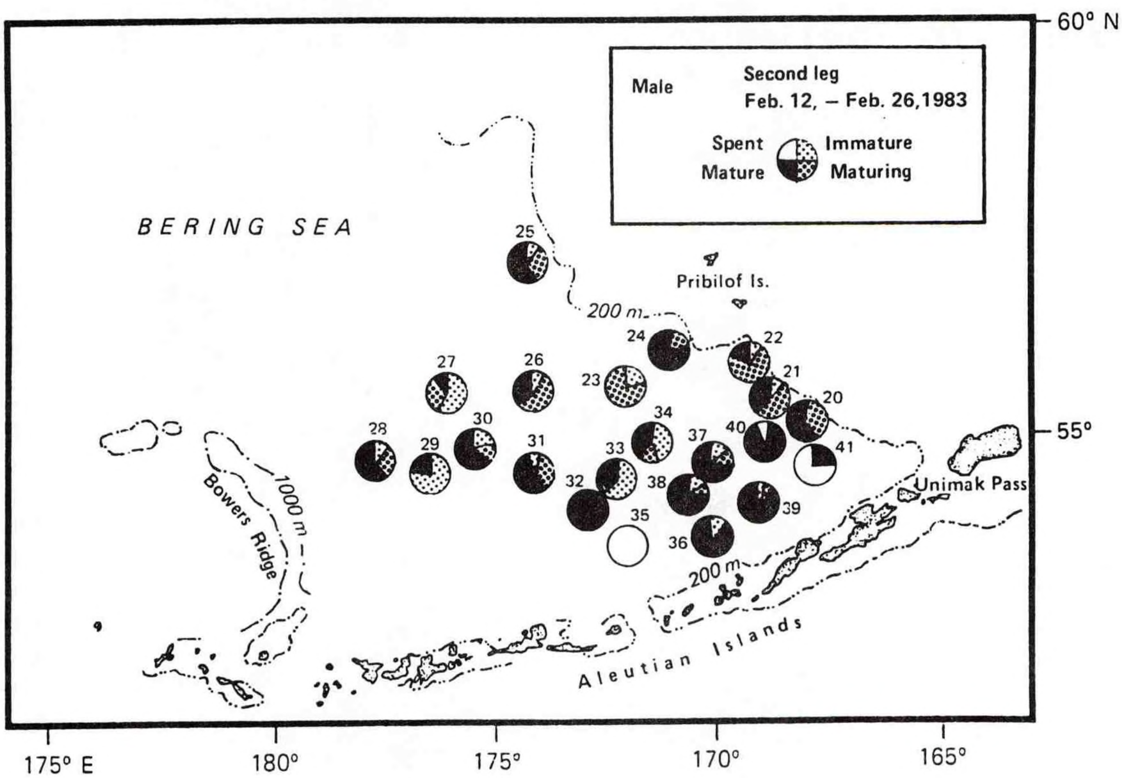
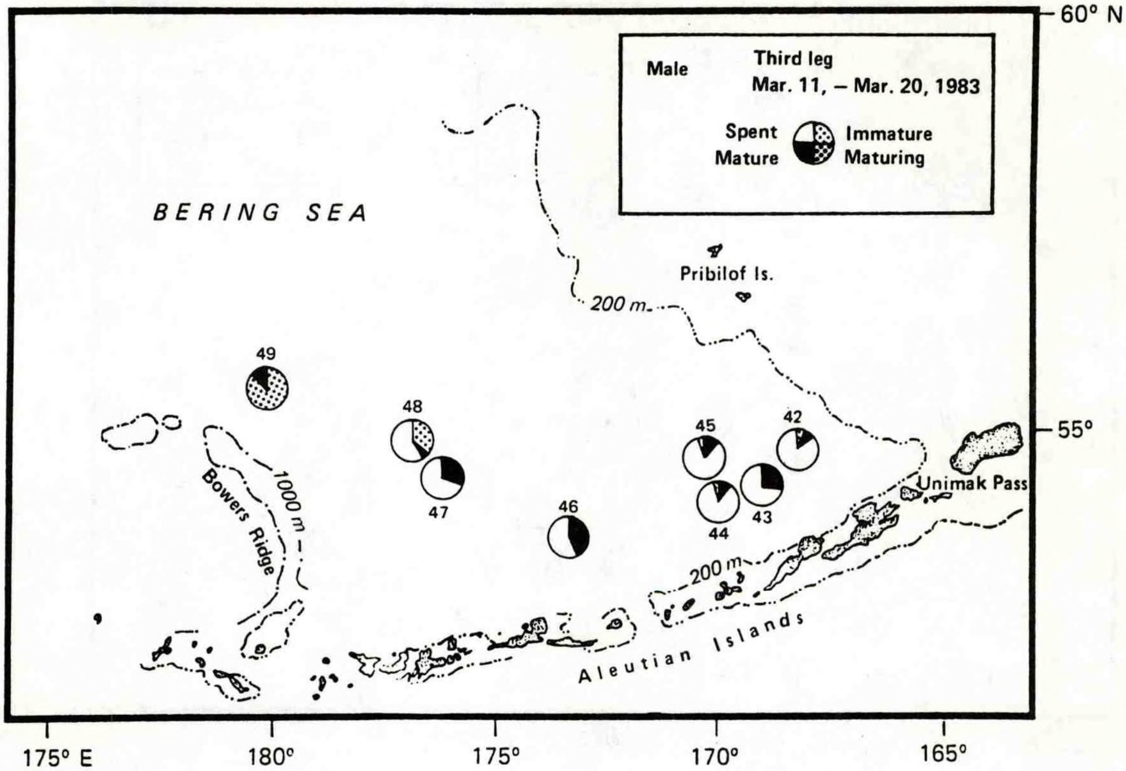


Figure 11.--Maturity composition of male pollock caught by midwater trawl in the Aleutian Basin during the spawning period, 1983 (redrawn from Okada and Nakayama 1983).



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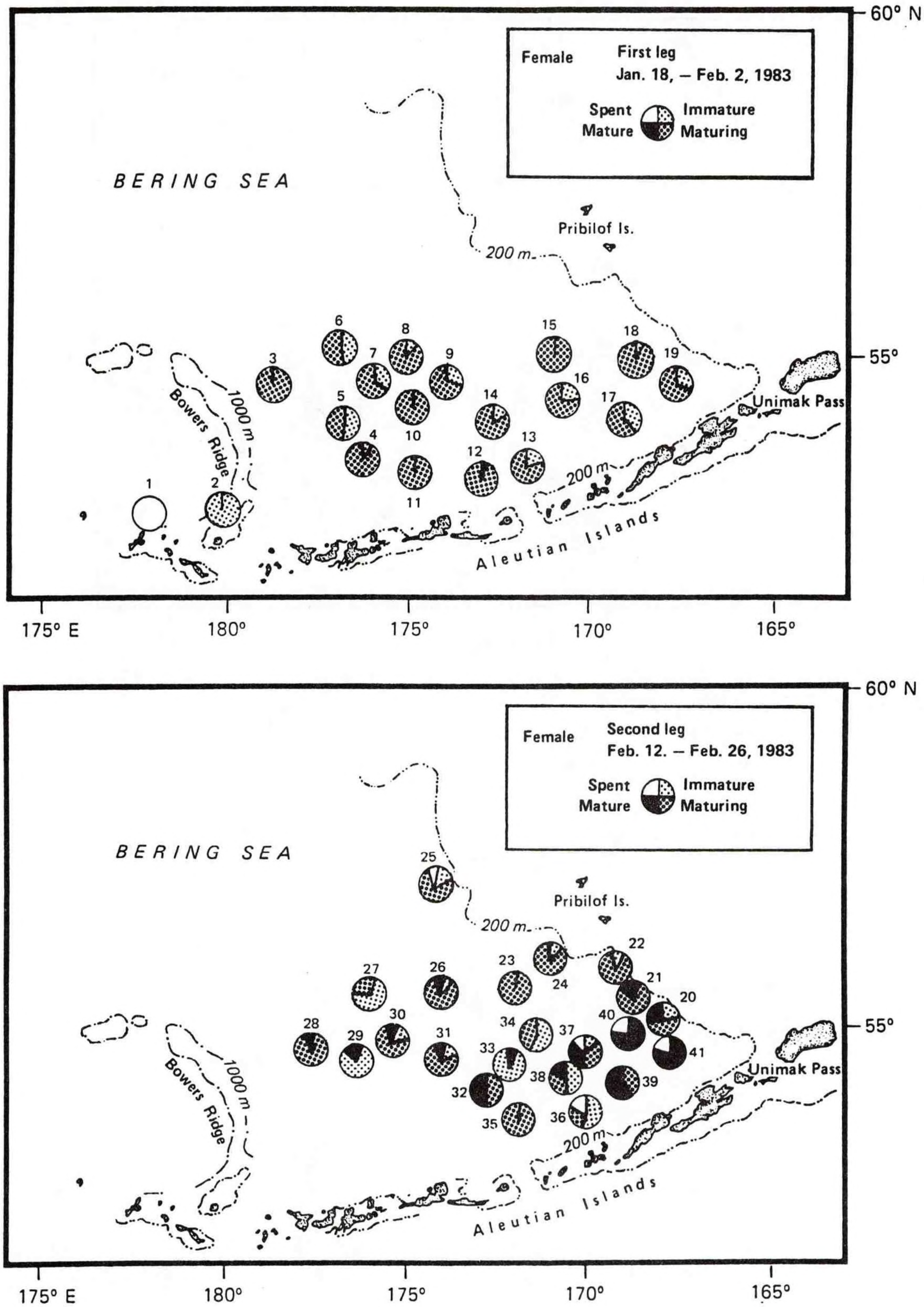
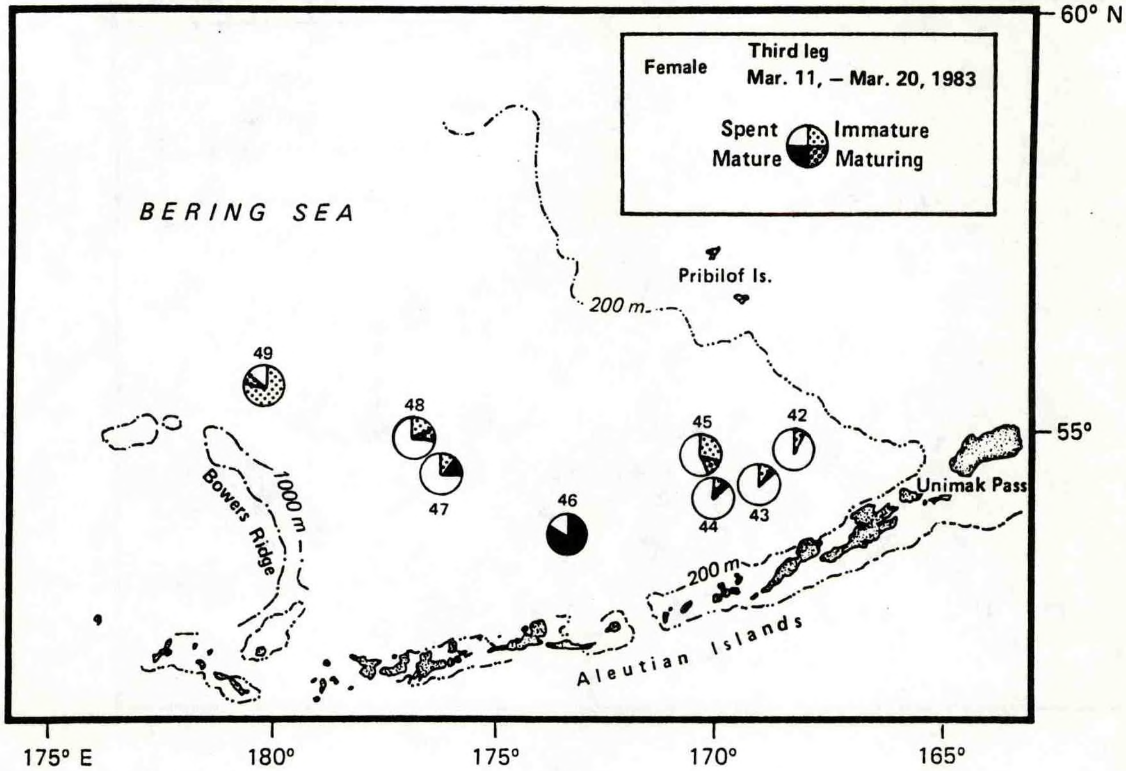


Figure 12.--Maturity composition of female pollock caught by midwater trawl in the Aleutian Basin during the spawning period, 1983 (redrawn from Okada and Nakayama 1983).



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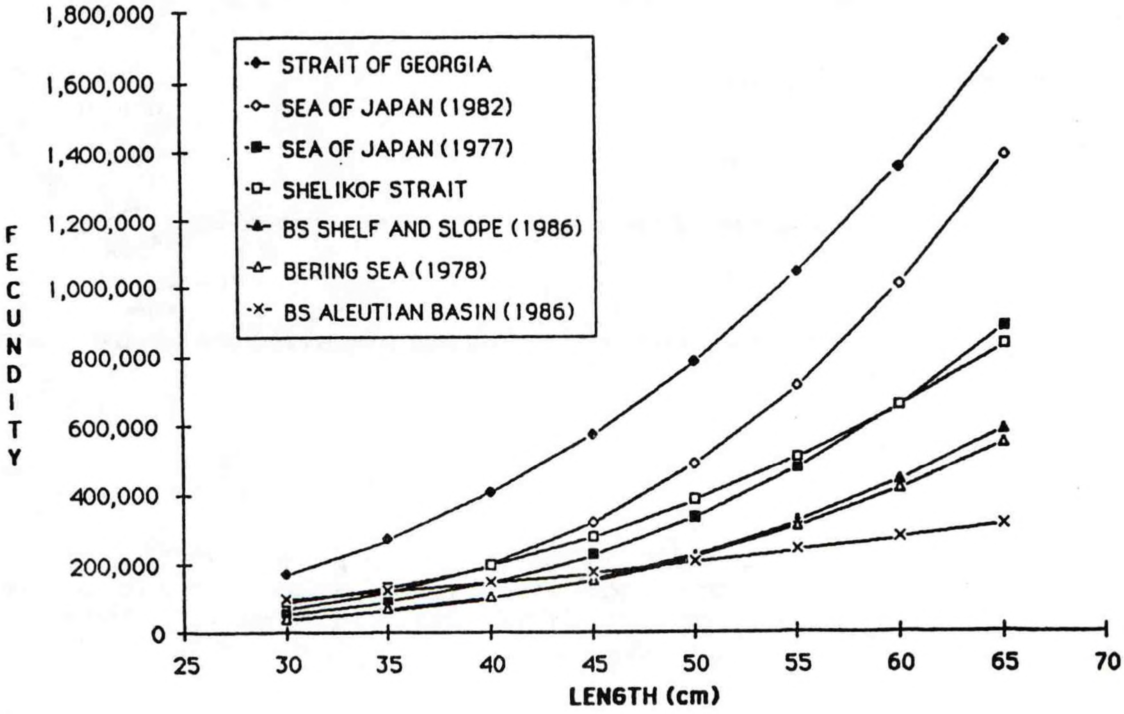


Figure 13.--Fecundity-length relationship for walleye pollock from different regions in the North Pacific Ocean (from Miller et al. 1986).

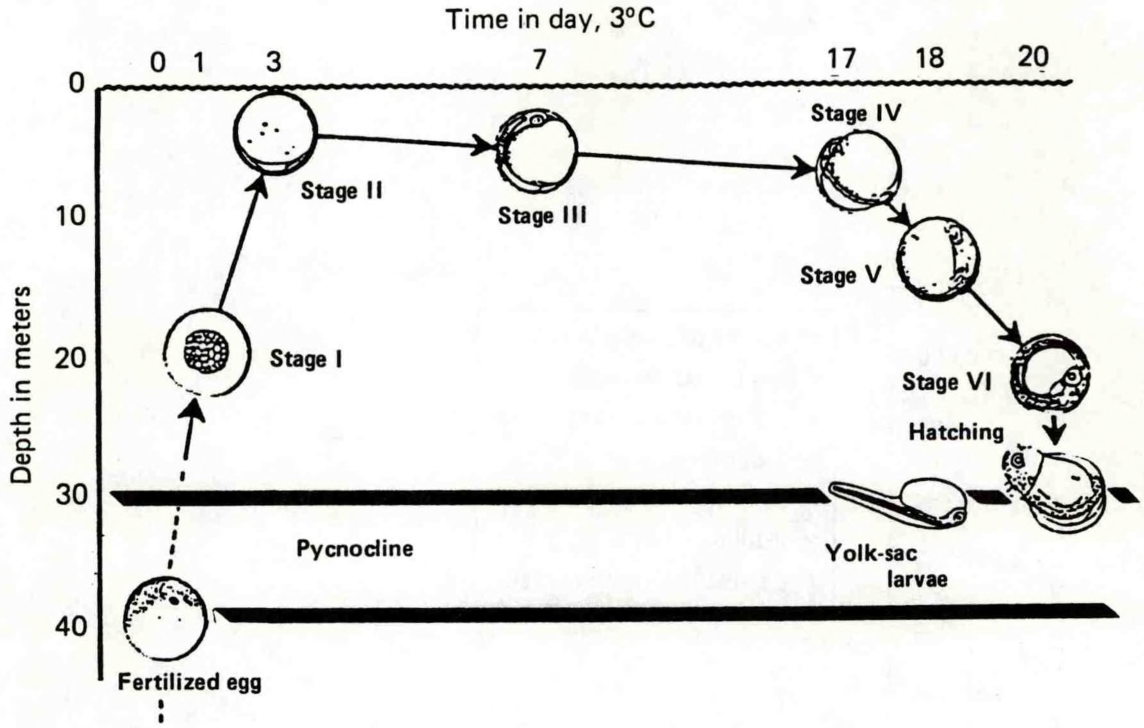


Figure 14.--Schematic illustration of vertical distribution of pollock eggs and larvae at different stages of development (from Nishiyama et al. 1986).

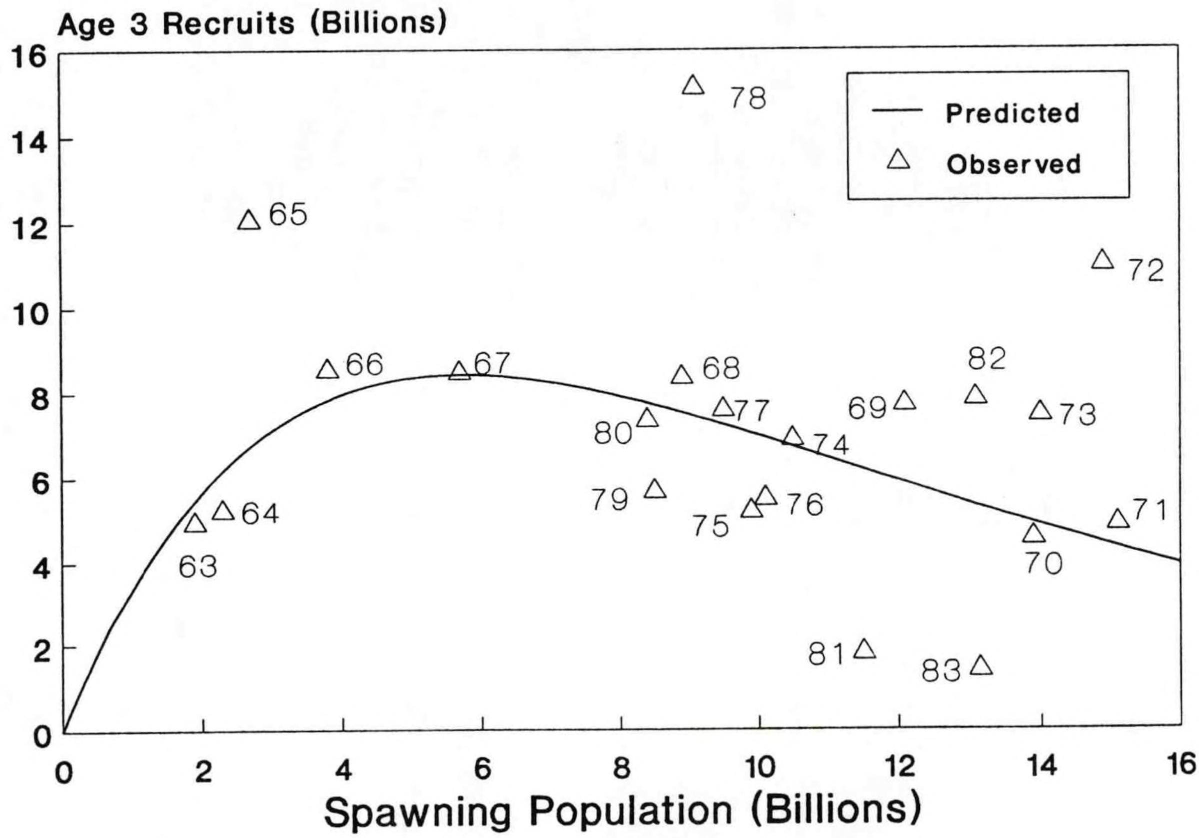
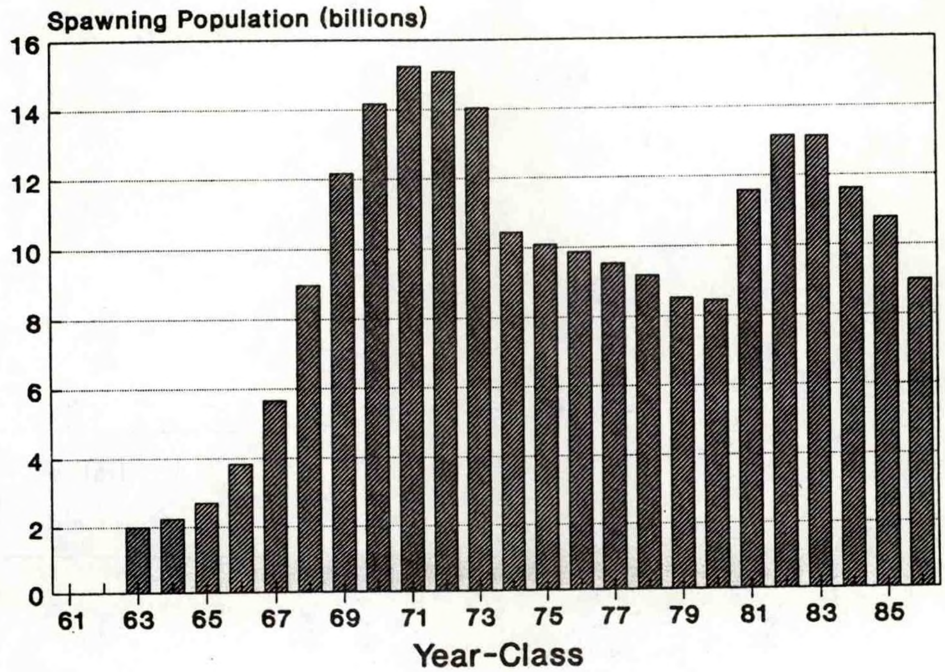


Figure 15.--Estimated spawning (panel A) and recruit (panel B) abundance by year class (from Wespestad and Traynor 1988).



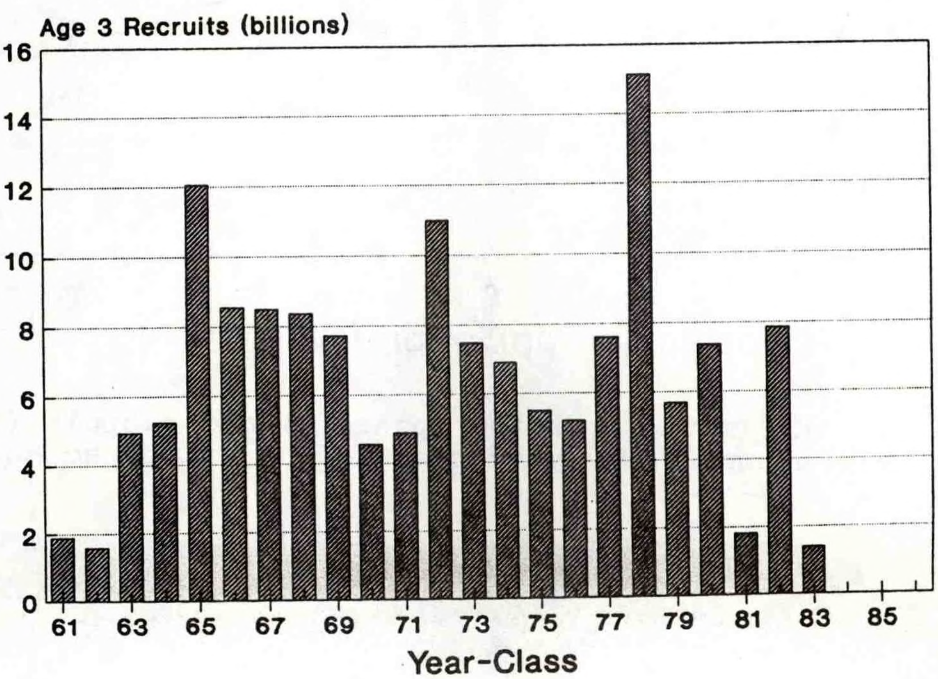


Figure 16.--Spawner-recruit plot for eastern Bering Sea pollock and estimated Ricker spawner-recruit curve (from Wespestad and Traynor 1988).

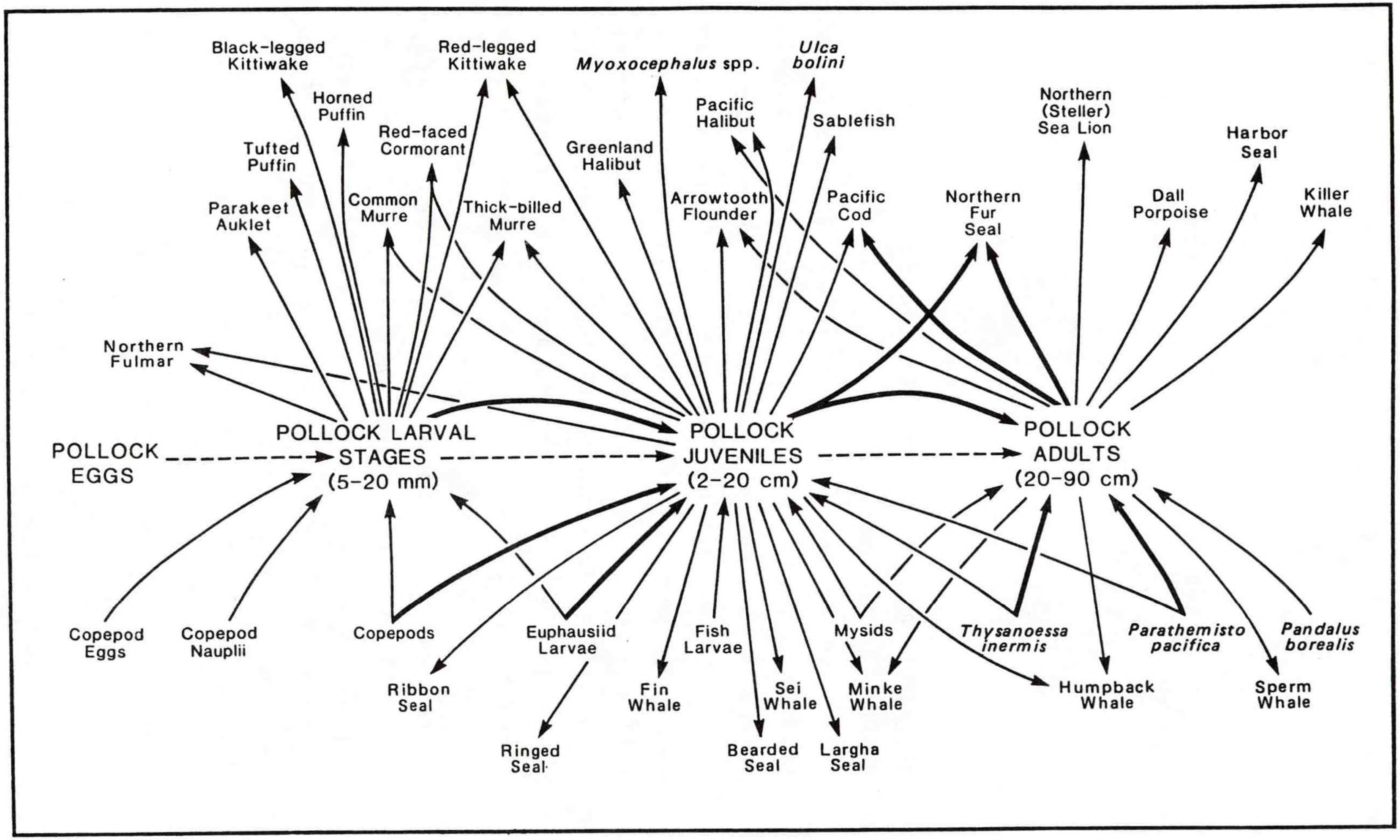


Figure 17.--Walleye pollock food web diagram for the eastern Bering Sea (from Kajimura and Fowler 1984; modified from Smith 1981).

Synopsis of Biological Information on Pelagic Pollock Resources in the Aleutian Basin

Far Seas Fisheries Research Labratory

Takashi Sasaki

Introduction

Pollock (Theragra chalcogramma (Pallas)) is widely distributed in the North Pacific Ocean, and is generally known as a groundfish living on the continental shelf and slope. However, it is distributed in the upper and middle layers on the high seas, and it also has a characteristic of pelagic fish. In the Bering Sea, this species is also widely distributed in the midwaters on the Aleutian Basin. The density distribution of pelagic pollock is considerably low in summer as compared with on the continental shelf, consequently the large scale fisheries had not targeted on this stock. However, it is identified that pelagic pollock forms extremely high density of the school in winter, which is widely distributed in summer. Consequently, recently the midwater trawl fishery targeting on this stock has been rapidly developed (Sasaki and Yoshimura, 1987). Following the large reductions of the allocations in the US and USSR 200 miles zones, the international waters located in the center of the Basin has become most valuable fishing ground for the traditional far sea fisheries nations. Those nations are Japan, South Korea, Poland, and newly the People's Republic of China. It is estimated that the total harvest of pelagic pollock from those nations exceeded 1.0 million mt in 1986, and exceeded previous year in 1987.

Pelagic pollock which forms the concentrated school in winter, spawns on the Basin in February to March (Fisheries Agency of Japan (FAJ), 1984;Okada, 1986;Hinckley, 1987). Only part of the biological characteristics of this stock is known at present,however it is estimated that the biomass is considerably large, and it seems that this stock contribute greatly to the reproduction of the pollock resources in the Bering Sea. Consequently, it is urgently required to acumulate the biological informations in order to rationally manage and effectively utilize this stock. On this report, the informations available which are inevitable to promote further surveys and studies, were reviewed as detailed as possible.

1.Distribution and Migration

(1) Geographical Distribution

It has been known since long time ago that pelagic pollock is widely distributed in the upper layer on the Aleution Basin, because this species were incidentally caught in the surface driftnets (Okada and Kobayashi, 1968;Suzuki, 1976). Based on the report which analysed the bycatch data from the surface driftnet survey conducted from 1965 to 1973 (Yamaguchi et al., 1979), pelagic pollock was widely distributed and observed on the Aleutian Basin at least for three months from June to August when the surveys were conducted (Fig.1). However, the survey stations on where the amount of bycatch was exceeded 100 fish, were limited nearby continental shelf and on the center of the Basin. And in general the amounts of bycatch were 5 fish or less and primarily 1 fish on the each station. And also based on the vertical longline survey conducted in June 1971, pelagic pollck was widely observed on the Aleutian Basin (Kikuchi and Tsujita, 1977).

The distribution in summer (June to August) was also observed by the survey for pelagic pollck conducted from 1977 to 1979 (Okada, 1977,1978,1979a,1979b,1986,;Okada and Yamaguchi, 1985). The survey area was east of the US-USSR boundary (Fig.2) and pelagic pollock was widely distributed in the survey area. The density distributions were relatively high on the Bowers Ridge and northwest of the Bowers Ridge and southeast of the Basin from 174°W to 178°W where is contiguous to the Aleutian Islands (Fig.3).

Based on the acoustic/midwater trawl survey conducted by the Japan Marine Fishery Resource Research Center (JAMARC) in the international waters in August to September 1987 (FAJ, 1988), it was observed that the density of the school was high in the southeast area and low in the northwest area (Fig.4,5,).

The distribution of pelagic pollock on the Basin in winter was not totally analysed yet. However, the research vessel KAIYO MARU conducted the survey from January to March in 1983 in the southeast area of the Basin east of 180° and north of the Aleutian Islands, and the distribution of pelagic pollock was observed (Okada, 1984,1986;Okada and Nakayama, 1983;FAJ, 1984). This survey was primarily conducted within the US 200 miles zone and only one midwater trawling operation was conducted in the south end of the center (180°) of the international waters (Fig.6). The distribution of pelagic pollock was observed in the region east of 180° including one survey station in the international waters. Because the trawling operations were quite limited, it was not clear in the region west of 180° (Fig.7). However,the results of acoustic survey conducted at the same time shows the density in the waters west of the Bowers Ridge was considerably lower than one in the southeast region of the Basin(Fig.8).

The density in the survey area was high in the southeast area of 176°-178°W,53°30'-55°N adjacent to the boundary of the international waters, in the area of 173°W,53°-30'N and the southeast area east of 172°W, south of 55°N.

The information in connection with the distribution of winter pelagic pollock in the international waters of the Bering Sea was not available from the research vessel. However, the catch statistic data from the commercial fleet are available. According to the statistics till 1985 from the North Pacific Trawl Fishery, fishing were conducted primarily in January through February (Sasaki and Yoshimura, 1987). Pollock was widely harvested in the international waters, however, most of the harvests were recorded in the area southeast of the international waters adjacent to the US 200 miles zone (Fig.9). However, the catches in November and December increased and the main fishing ground was formed on the north side of Bowers Ridge northwest of 180° in the international waters in winter 1986. This trend became conspicuos in 1987 (Fig.10), large part of catches was taken in the waters west of 180° (data file in Japan Deep Sea Trawlers Ass.). It is not yet dinstinct whether this change is due to the learning effect on the fishing grounds and movement of school of fish, or reflects the annual fluctuation of the distribution pattern of school.

Two scientists from the Far Seas Fisheries Research Laboratory were on board two land-based trawlers in winter 1987, for the purpose of collecting samples of fish and observing the actual situation of the Japanese pelagic pollock fishery on the international waters (Sasaki and Yoshimura, 1987). Two observations were conducted in January 24-25, and in February 27 to March 2, respectively.

The fishing ground was located in the international waters on the north side of the Bowers Ridge area between 55° and 56° N, 178° and 179° E for both times. The extremely dense fish school was observed in late January, and the vessel recorded 31.5 t of the average catch per hour of trawling. However, the density decreased in late February and the CPUE was 4.2t.

Okada (1979a) reported that pelagic pollck was distributed in the Aleutian Basin from April to May and from October to December based on the records of fish finders from the commercial fleet. And also according to the catch statistic data, the part of Japanese commercial vessels have engaged in fishing and havested a small amount of pollock in summer in the international waters since 1985 (data file in Far Seas Fisheries Rsearch Laboratory).

Based on the informations described above, pelagic pollock is widely distributed all year in the Aleutian Basin, and in summer the school is spread out and distributed in the broad area, and in winter it is concentrated and forms extremely dense school.

(2) Vertical Distribution.

Based on the data from the research vessel in summer (June-August), the echograms from fish finder of pellagic pollock were observed from the depth zone of 30m-150m (Okada, 1979a). The echograms were spotted and the primary distribution layers were varied by year. And, the daily vertical migrations were observed due to the echograms came from relatively deep range in the day time and shallow range in the night time. It is obvious that the density distribution was relatively low on the shallower than 30m.

Because the surface driftnet research vessel used the driftnet with 7m net depth from the surface and the pollock bycatch was 5 fish or less on each station on the Basin (Yamaguchi et al., 1979). And also based on the vertical longline survey conducted in June 1971, pelagic pollck was caught in the depth zone of 5-100m on where the gears were set (Kikuchi and Tsujita, 1977). Furthermore, Suzuki (1976) reported that the distribution of pelagic pollock was observed primarily on the shallower than 60m or 80m and occasionally observed deeper than 100m based on the echograms obtained on the Basin.

In contrast to these observations, based on the survey conducted in the international waters of the Bering Sea from August to September in 1987 (FAJ, 1988), the density distribution was highest on the depth zone of 150-200m (Fig.11,12). Though this survey was not conducted deeper than 200m, it is estimated that the density deeper than 200m was extremely low based on the echograms. Based on the result of the survey by the quantitative echo sounder, the density distribution of pelagic pollock shallower than 140m was higher in the northwest region than in the southeast region (Fig.11).

Based on the winter survey conducted by KAIYO MARU in 1983, the echograms of pelagic pollock were observed on the depth range from 75m to 600m from January to February. The mean depth of the observation was deeper than one in summer (Okada, 1984;FAJ, 1984). Pelagic pollock was primarily distributed on the layer of 250-300m from late January to mid or late February and the distribution zone became shallow to 100-200m depth on the mid March. In winter the daily vertical migration was also observed as well as in summer. Based on the fish finder records available from the land-based trawlers operated on the Basin in winter 1982 (Yoshida and Ueda, 1986), the school of pelagic pollock had been distributed on the layer of 250-350m till around February 20. and then the distribution gradually became shallow around early March. Based on the fishing logs of the land-based trawlers oparated from December 1986 to late January 1987, the trawling depth (the depth from the surface to the baitings of the net opening) was relatively shallow on 160-200m in mid December and 140-200m in late December, however it became gradually deeper to 160-220m in early January and 200-300m, in mid January and 230-320m in late January respectively. And also based on the data in late January, the deepest echogram was observed from the 420m depth.

In brief, the vertical distribution of pelagic pollock on the Basin is seasonally fluctuated, and it is distributed on the relatively shallow depth from the surface to 200m in summer and the primary depth zone of the distribution moves to 230-320m from late January to mid February in winter and moves again to shallow depth on 100-200m in early March. The patterns of these distributions are varied by year and area in the same season. It seems that these fluctuations are closely related to the changes of the oceanic environmental conditions.

(3) Migration.

Though the migration of the school covered all of the Aleutian Basin is still unknown, on the limited the international waters, it is able to estimate the migration of the school based on the changes of the monthly catch distribution on the asumption that the formation of fishing grounds are in connection with the movement of fish school. The Figuire 13 shows the monthly catch distributions of the Japanese North Pacific Trawlers from October 1986 to October 1987 (data file in Japan Deep Sea Trawlera Ass.). The school appeared on the west end of the international waters nearby the boundary of the USSR 200 miles zone in October, and then the school tended to move eastward month by month. It seems that the school was gradually disappearing in February and the large school disappeared from the international waters in March. This phenomenon was also reported by Sasaki and Yoshimura (1987). The school was observed in the west of 180° in April and May, and it was spread out and widely distributed from June to September. As there were a few fishing activities during summer season, the information regarding the migration of the school was not available in summer. In October the school appeared again in the west of the international waters.

The Figure-14 shows the sampling locations where FAJ (Fisheries Agency of Japan) obtained the pollock samples from the joint venture between Japan and USSR targeting on pollock in the USSR 200 miles zone of the Bering Sea in 1987. This figure shows that the school was also formed in the USSR waters of the Basin. It is necessary to promote the extensive surveys to make clear the migration pattern and apawning ground of these fish.

(4) Structure of school.

The structure of the pollock school which appeared on the echograms, has completely different shapes between summer and winter season (Okada, 1977,1978,1979a,1984;Okada and Yamaguchi, 1985;FAJ, 1984;Suzuki, 1976). It was spread out and spotted in summer (Fig.15), and it was concentrated and formed belt shape or patch shape in winter. Based on the result of the winter survey by KAIYO MARU in 1983 (FAJ, 1984), the school primarily appeared with the belt shape (Fig.16) and occasionally the large school extending over 100 miles was observed. As an example of the school formed patch shape (FAJ, 1984), the school with 22km long, 5.5km wide and the mean thickness of 65m was formed on the mean depth of 280m (Fig.17,18).

The auther was on board a land-based trawler in late January 1987 and observed the school which was distributed with the belt shape and its thickness was approximately 100m and 200m at the maximum. The particular dense school was formed on the upper range in the school zone, which was observed by the color fish finder. Acoording to Yoshida and Ueda (1986), in late February a lot of the echograms shaped fleeting cloud were observed above the concentrated school. It seems that this school which consisted of the sexually matured fish and separated from the dense prematured school, formed small school and spawned in the mid waters basically with a pair of male and female. Given this observation, it seems that the dense concentration of the school which is formed before spawning season, would be gradually collapsed during the spawning season and then move to the spotted distribution observed in summer.

2. Stock Structure

In connection with the stock structure of pollock being distributed in the eastern Bering Sea, there are two different theories. One is single population theory

(Takahashi and Yamaguchi, 1972), which advocates that the pollock stock on the continental shelf in the eastern Bering Sea is the single unit (Fig.19). The other is two subpopulations theory (Maeda, 1971,1972), which advocates that there are northwest subpopulation and southeast subpopulation across the Pribilof Islands (Fig.20). Furthermore, it is estimated that the another independent subpopulation exists around the Cape Navarin (Maeda, 1979). Maeda (1979) reviewed the stock structure of pollock in the Bering Sea, and supported the likelihood of the two subpopulation theory, but the final conclusion was not made. However, it is estimated that the main spawning school of the northwest subpopulation is distributed in the region from the continental slope through the Aleutian Basin during the period between the wintering and spawning season, and moves into the continental shelf during the feeding season. Because pollock larvae on the surface layer is distributed in relatively small on the continental shelf and in abundance on the Aleutian Basin west of 170°W (Maeda and Hirakawa, 1977), and though the wintering and feeding schools exist in abundance on or around the continental shelf in the region, the large spawning school is not observed.

On the other hand, Lynde et al.(1986) conducted comparative study on the age and growth by area and season based on the samples of pollock, consequently it is estimated that there are two different units of populations which have own reproduction process in the eastern Bering Sea and the Aleutian Basin respectively. One is the population which has main spawning ground in the southeast region of the Pribilof Islands, lives on the continental shelf and slope throughout the life and the part of over 4 years old is distributed in the north of the Pribilof

Islands. This population is rapidly grown. The other is the population which has the main spawning ground on the Basin is slowly grown. The egges and larvae are transferred into the continental shelf in the eastern Bering Sea by the anticlockwise circulation, and the fish stay untill 3-4 years old in the north region of the Pribilof Islands and the fish moves into the Basin from the coninental shelf as they sexually mature.

This assumption is similar to Maeda's two subpopulation theory, which assumes that the main spawning school of the subpopulation which lives in the northwest region of the Pribilof Islands, is distributed and spawns on the Aleutian Basin in winter. The origin of pollock which is distributed on the Basin in summer, is not explained from the Maeda's theory. However, Yamaguchi (1984) assumed that the majority of the premature pollock (primary 4 years old) left from the continental shelf for wintering and spawning, and the ones with rapid growth rate or high condition factor among the old pollock (over 5 years old), return to the continental shelf but the majority of the old pollock remains on the Basin, because there are differences of the age and growth of pollock on the Basin between in summer and in winter, and it seems that the fish in winter is larger than one in summer in terms of the mean size at age.

And also, Hinckley (1987) conducted the comparative study on the mean size at age, the fecundity and spawning season based on the samples of pollock collected during the spawning season in the eastern Bering Sea including the Aleutian Basin, and reported the existence of at least three separated spawning populations. Those populations are on the Aleutian Basin, and on the continental shelf in the southeast and northwest region and the slope in the southeast region, and on the continental slope of the northwest region. She indicated that the fish in the northwest slope which Lydre et al.(1987) assumed as a origin of pelagic pollock on the Basin, was the separated spawning population from the others.

As a result of the study in detail on the size composition at age of pelagic pollock which the research vessel KAIYO MARU sampled on the southeast part of the Aleutian Basin from January to March 1983 (Sasaki and Yoshimura, 1988), pelagic pollock consists of several different groups in the same age class which have the different growth rates (Fig.21). Especially, fish of the full 5 years and 6 years old fish consist of the group of 4+, 4++, 5- and the group of 5+, 5++, 6- respectively. As reference, these ideograms mean the differences of the growth zones on the scales. This is hardly explained by the single origin theory in which Yamaguchi (1984) and Lynde et al. (1986) assumed that the fish living on the continental shelf in the northwest region of the Pribilof Islands was the origin of the fish of pelagic pollock on the Basin. It is estimated that the several groups which grow up in the different regions are mixed up.

And also, the size composition at age in the southeast region on the continental shelf of the eastern Bering Sea is obviously larger than the fish in the northwest region through the different age groups in May and June. However, in July through September the size composition over 5 years old unnaturally becomes small and similar to the size structure at age of the fish in the northwest region (Sasaki and Yoshimura, 1988). Based on this, it is estimated that the population structure in the southeast region may considerably change in summer.

The relationship between the stocks on the Basin and the ones on the continental shelf of the Asian side have not been discussed so far. However, according to the result of tagging experiments (Fig.22), the two of pollock tagged and released on the continental shelf between the Cape Navarin and the Cape Olyutorskii were captured on the Basin (FAJ, 1977;data file in Far Seas Fisheries Research Laboratory). And two of pollock tagged and released off the Cape Govena were captured on the continental shelf around 59°N of the eastern Bering Sea (Yoshida, 1979). Furthermore, one tagged fish released off the Pacific coast of the Hokkaido Island in April 1979 recaptired by the Korean trawler in the Aleutian Basin at 54°35′N and 176°05′W in October 1981 (data file in Hokkaido Regional Fisheries Research Laboratory, Kushiro). Based on these data, it is obvious that the stocks of the Asian side is related to the stocks on the Basin and in the eastern Bering Sea.

In connection with the stock structure of pollock in the North Pacific including in the Bering Sea, the results of the biochemical study (Grant and Utter, 1980;Iwata, 1973) and the study based on the geographic variations of the meristics and morphometrics (Hashimoto and Koyachi, 1977;Koyachi and Hashimoto, 1977;Serobaba, 1975) are available. Based on the biochemical study, the regional interchange of the stock was not identified between onshore of Japan and the Bering Sea, however the populations indicated the genetic differences were not identified in the Bering Sea (Iwata,1973). As a result of the study compared the samples of the eastern Bering Sea and the Gulf of Alaska, there were a few genetic differences between them, but the genetic differences between the northwest and southeast populations were not identified (Grant and Utter, 1980). In contrary, according to the study of comparison between the meristics and the morphometrics, pollock in the Bering Sea is separated into four regional subpopulations as eastern, northern, western and southern (subpopulation of the Aleutian Islands) subpopulations (Serobaba,1975). And also, the differences were not identified on the number of vertebrae but were identified on the diameter of eye between the population around the Cape Navarin and the population of the eastern Bering Sea (Hashimoto and Koyachi, 1977;Koyachi and Hashimoto, 1977).

As described above, there are several interpretations on the stock structures. Except the cases indicated distinct differences on the results of the tagging and biochemical study, every study does not provide the conclusive evident on the subpopulations and those interpretations still remain as the assumptions. However, the majority of pelagic pollock living on the Basin is the old fish over five years old (Lynde et al.,1986;Okada and Yamaguchi, 1985;Traynor and Nelson, 1985;Yamaguchi, 1984;Yoshida and Ueda,1986), and there is not observed in abundance of 0-4 years old fish, though it was identified that the fish spawns on the Basin, and the egges and larvae are distributed on the Basin. It is likely that the juvenile fish during the period (0-4 years old) is distributed on the continental shelf, however the positive evidence is not yet available. Therefore, in order to clarify the origin of pelagic pollock on the Basin, it is required to comprehensively study the structure of the pollock populations in all of the Bering Sea.

3. Age and Growth

Based on the samples obtained from the research vessel on the Basin in summer 1979 and in winter 1983 respectively, it is estimated that the growth of pelagic pollock

(Fig.23,24,25) was considerably slow as compared with the one on the continental shelf southeast of the Pribilof Islands, however, fairly similar to the one on the continental shelf north of the Pribilof Islands in the eastern Bering Sea (Okada and Yamaguchi, 1985;Traynor and Nelson, 1985;Yamaguchi, 1984). But regarding four years old fish on the Basin, its growth was remarkedly similar to the one of the southeast population. The range of the ages observed were from 3-12 years old. Lynde et al.(1986) and Hinckley (1987) also reported that the growth of pelagic pollock was slow on the Basin. Lynde et al. (1986) indicated that the slow growth of pelagic pollock over 4 years old on the Basin was connected with the growth till 4 years old of the slow growth fish which is distributed on the continental slope north of the Pribilof Islands. As a result, regarding the 4 years old fish it is not same as the result of Yamaguchi (1984) described above.

The longivety of pollock is generally believed about fifteen years on the continental shelf (Smith, 1981), and according to Lynde et al. (1986), the oldest pelagic pollock is thirteen years old. The two of pollock tagged and released onshore of Siberia in 1973 were captured (Fig.22). One of them was captured nearby the Bowers Ridge in winter 1981 (data file in Far Seas Fisheries Research Laboratory). Assuming that the fish was four or five years old based on the size when released, it is estimated that the age of the fish was twelve or thirteen years old when it was captured. Based on this, it is obvious that the aged fish is distributed on the Basin as well as in the continental shelf.

4. Size and Age compositon

(1) Size Composition

Based on the samples of pelagic pollock obtained from the research vessel on the Aleutian Basin in summer in 1977 to 1979 respectively, the size composition (Fig.26) was the range of 38-56cm in fork length and indicated the unimodal frequency distribution, which had the mode of 46-48cm (Okada, 1977,1978,1979a,1986). And also based on the samples of pelagic pollock obtained from the research vessel in the iternational waters of the Bering Sea in August to September 1987, the size composition (Fig.27) was the range of 36-58cm in fork length and the mode was 46-48cm (FAJ, 1988). This type of the distribution was almost same as the one of pelagic pollock incidentally caught in the surface driftnet fishery on the Basin (Yamaguchi et al.,1979;Kikuchi and Tsujita, 1977;Suzuki, 1976;Yoshida and Yoon, 1981). The remarkable characteristic is that there were very few fish under 42cm and over 52cm in fork length.

On the other hand, the size composition of pelagic pollock (Fig.28) obtained from the winter survey on the Basin in 1983 indicated the unimodal frequency distribution, which had the mode of 44-46cm. The mode was 2cm smaller than the one in summer (Yamaguchi, 1984;FAJ, 1984). It was remarkable characteristic that the fish of the small size which had the modes of 38-40cm or 40-42cm, were observed. Based on the size composition at age, the fish of small size were four and five years old (Sasaki and Yoshida, 1988). It seems that the fish temporarily appeared on the Basin in winter for wintering because those fish were not observed in the summer survey (Fig.29). The fish of small size were observed in all areas covered by the survey

(Fig.30), however those fish were observed in amall in the area of 170° W to 175° W and relatively in abundance in the areas of the both sides. On seasonalwise, those fish were observed in abundance in February east of 170° W and in March in 175°W to 180°.

The size compositions (Fig.31) of the catch obtained from the land-based trawlers which operated in the south part of the international waters west of 180° in late January and from the end of February to early March respectively in 1987, were the range of 38-58cm in fork length and indicated the unimodal frequency distribution which had the mode of 46-48cm. The mean length of pelagic pollock caught from the end of February to early March was slightly larger than the end of January because the fish over 48cm was increased in the size composition. As compared with the size composition of pelagic pollock sampled by the research vessel in the southeast region of the Basin from January to March 1983 (FAJ, 1984;Yamaguchi, 1984), there was not differece on the mode between 1983 and 1987. However, the composition of pelagic pollock among the 1983 survey, which were caught in where the land-based trawlers operated in 1987, had the mode of 38-42cm which was completely different from the one in 1987. The data of 1983 were collected in mid March, when was two weeks later than in 1987. And because the data of 1987 were collected from the extremely limited area, whether the difference of composition between the both years indicated the annual fluctuation on the abundance of the appearance of the small size fish, or the annual changes of the geographic distribution pattern, remains to be studied.

As compared with the size composition of pelagic pollock in the international waters between in winter (Fig.31) and in summer (Fig.27) in 1987, there was very few changes.

It indicated that the fish which had the constant size composition, was distributed all year round in the international waters.

According to the past studies, there is difference of the size composition of pelagic pollock on the Basin between the male and female, the size composition of the female is larger than the male in both of summer and winter (Okada and Yamaguchi, 1985;Suzuki, 1976;FAJ, 1984;Yoshida and Yoon,1981). Based on the size composition of pelagic pollock which land-based trawlers caught in the international waters in winter 1987 (Fig.32), the female was larger than the male (Sasaki and Yoshimura,1987).

(2) Age composition

The age composition of pelagic pollock which the research vessel collected on the Basin in summer 1979, comprised of the 3-9 years old fish (Fig.33). The 5-7 years old fish dominated 94% of the composition, and there was not difference of the composition between male and female (Okada and Yamaguchi, 1985). It may be possible that the older fish were somewhat underesimated because the scales were used as the age material for this report.

Based on the result of the winter survey (Yamaguchi, 1984), the range of the age was 4-12 years old. In general, the 5-7 years old fish dominated the majority as well as in summer (Fig.34). The percentage of the 6 years old fish was extremely high in summer, however in winter this trend was not observed remakably and the percentage of 5 years old fish was also high (Fig.35). The fish of small size which had the mode of 38-42cm in the size composition (Fig.30), comprised of primarily 5 years old fish (Fig.36).

And also, it indicated the unimodal frequency distribution in the age composition, at where the bimodal frequency distribution was indicated in the size composition in the Figure 30. In other words, the mode of the size composition was not equivalent to the one of the age composition. It is indicated that there is likelihood of the several groups which have different growth rates being mixed up (Yamaguchi, 1984). On this point, as described above, the size composition at age in winter shown in the Figure 21 could give a good explanation.

5. Reproduction

(1) Sexual Maturity and Sex Ratio

The majority of pelagic pollock appeared on the Aleutian Basin in summer was the postspawn fish two or three month after the spawning (Yoshida and Yoon, 1981). The mature size of the male was smaller than the one of the female. On the other hand, based on the result of the winter survey in 1983 (Fig.37), the most of the male over 42cm and the female over 44cm were mature fish (FAJ, 1984; Yamaguchi, 1984). And also, it is estimated that one half of the male and one third of the female below 42cm were mature, while substantial number of fish below 42cm were premature.

In connection with the maturity stage of the gonad of pelagic pollock on the Basin, it is estimated that the male matures earlier than the female and the maturity of the testis proceeds relatively slowly, however the ovary reaches to the ripe stage relatively in short time and then spawns (FAJ, 1984).

Based on the observation of the gonad of pelagic pollock collected from the international waters of the Bering Sea in late January and early March respectively in 1987, it was disclosed that the frequency distribution of the oocyte diameters in the ovary indicated to be unimodal distribution in late January, however it indicated the distinct bimodal distribution in early March (Teshima et al.,1988). The oocytes with almost same diameter which were primarily at the yolk stage, were observed in late January. However, in early March the hydrated oocytes which became large due to sucking up the waters, and the oocytes from the late yolk stage to the premature stage were observed.

As a result of the histological observation of the testis, the males in late January were primarily in ejaculating and the ones in early March were primarily in spent. This shows the possibility that the fish may spawn in the international waters. This is not equivalent to the spawning season of the female in terms of the timing. Further reviews will be required to clarify whether this is due to the bias of the samples or general condition.

The ratio of the female of pelagic pollock on the Basin was the range of 37-41% in the summer survey, and it was lower than the male (Okada, 1986). However, in the winter survey in 1983 and the winter observation conducted in the international waters in 1987, the ratio of the female was 48% and 51% respectively,and the ratio of male and female was about 1 : 1 (Okada, 1984;Sasaki and Yoshimura, 1987).

(2) Fecundity

Teshima et al.,(1988) clarified the relationship between the fecundity and the body length based on the samples collected from the international waters of the Bering Sea in late January 1987. The individual female of pelagic pollock spawns several times during the spawning season (Sakurai, 1983;Kitano, 1979;Hinckley, 1987), and the oocytes with the different diameter due to differences of maturing stage are mixed up in the ovary during the period before and in spawning (Teshima et al., 1988). Consequently, it seems that sampling in late January is most appropriate to count the number of oocytes, when the oocytes with almost same diameter are in the ovary. It is identified that there is the relationship between the fecundity and the fork length, which indicated in the Figure 38. And the appropriate formula is as follows;

$$F = 1.3350L^{3.1470} \quad (r=0.91)$$

F: Number of ova

L: Fork length (cm)

This result is quite different from the relationship between the fecundity and the fork length of pelagic pollock on the Aleutian Basin reported by Hinckley (1987). The fencundity of the same size fish is higher than the ones reported by Hinckley (1987), (Fig.39). Hinckley (1987) indicated that the lower fecundity of pelagic pollock on the Basin was due to the shortage of the food organisms. Further detail analysis based on substantial number of the samples will be required to clarify the differences of the results and whether this means that there are different populations on the Basin within the international waters and the southeast of the Basin in the US 200 miles zone respectively, or this is due to the differences of the time of sampling or the counting method of the fecundity.

(3) Spawning Season and Ground

Hinckley (1987) reported that the spawning season of pelagic pollock was in January through March (Fig.40). However, based on the monthly changes in the composition of the maturity stage of the gonad of pelagic pollock obtained on the Basin from the winter survey in 1983 (Fig.41), in late January the part of the males were in the full mature stage but the majority of the females were in the premature stage and did not spawn yet (FAJ, 1984;Okada, 1986;Yamaguchi, 1984). In mid February, many of the both of males and females were in spawning and some of them already finished spawning. In mid March, some of fish were in spawning but the majority already finished spawning. And also, Yoshida and Ueda (1986) reported that pollock with the hydrated oocytes appeared in late February and in early March ,which dominated one half of the samples. Furthermore, Teshima et al.(1988) also reported that the hydrated oocytes were observed in the ovary in early March.

Based on the observations described above, pelagic pollock on the Basin spawns in early February through late March, it is estimated that the main spawning season is about one month from mid February to early March. The main spawning season of pollock on the spawning ground in the southeast of the Pribilof Islands on the continental shelf of the eastern Bering Sea is in April through May (Hinckley, 1987), and the spawning season of pelagic pollock on the Basin is considerably earlier than the area.

As reported above, pelagic pollock forms extremely dense school in the southeast region of the Basin during the spawning season. The dense school of pelagic pollock was observed in the south end of the international waters west of 180° in late January 1987, and the gonad of the female was in the premature stage (Sasaki and Yoshimura, 1987). It is estimated that the part of oocytes in the ovary become mature on and after mid February. As described above, it is estimated that the school tends to move to the direction of the east in this time, so that it seems that the fish spawn on the Basin east of 180°. Hinckley (1987) reported that the spawning of pelagic pollock occured widely in the observed area, namely the southeast part of the Basin (Fig.40). It is estimated from the winter survey in 1983 that one of the spawning grounds of pelagic pollock in the area close to 60 nautical miles north of Unimak Island (Okada, 1986).

In connection with the spawning season and ground on the continental shelf surrounding the Basin, it is explained in detail by Hinckely (1987) regarding in the eastern Bering Sea. According to the report, the spawning season is in March to June in the southeast region and in June to August in the northwest region of the Pribilof Islands, and the spawning ground is formed at the depth of 100-200m. The quantitative comparison is not available, however it is estimated that the main spawning grounds are in the north side of Unimak Island and around the Pribilof Islands and around 58° -59° N,173° -176° W. Though the information regarding the western Bering Sea is limited, it is reported that the concentrated spawning schools were observed in the east of the Cape Olyutorskii and in the Bay of Olyutorskii on the survey conducted by Japan in 1961 (Mikawa, 1961). However, it is considered that this spawning population is probably extremely small as compared with the populations in other areas (Kitano, 1979).

(4) Spawning behavior

It is reported that the dense school which pelagic pollock forms during the spawning season, is comprised of two layers in which the male is upper layer and the female is lower layer (Kitano, 1970;Takakura, 1954). This structure was regarded as the behavior for the effective external fertilization (Kitano, 1970). However, based on the observation of the spawning behavior of pollock in the tank (Sakurai,1983), the action of scare or attack was observed among the males untill the spawning, and the courting action for the female was observed, and then the spawning happened with a pair of male and female as they swim. And it is supposed that this spawning behavior is common nature to be displayed in the natural circumstance. On the records of the fish finder obtained from the Basin in late February, a lot of the small echograms were observed above the dense echogram. And it is estimated that the sexually active spawning school separates from the dense premature school, and takes the spawning activity basically with a pair of male and female without forming the large school (Yoshida and Ueda,1986).

On the other hand, the operation of the horizontal trawling was conducted on the winter survey in 1983, which targeted on the upper and lower layer of the dense school in mid to late February. As a result, the structure of two layers comprised of males and femles was observed (Okada, 1984). However, in contrast with the report of Kitano (1970) and Takakura (1954), there were a lot of females on the upper layer and a lot of males on the lower layer respectively. As a result of the observation on the land-based trawler in late January, the sex ratio on the upper layer where the school was particularly dense among the layers of the schools, was 1:1, and the structure of two layers was not observed (Sasaki and Yoshimura, 1987).

Based on the observation in the tank and the histological observation of the ovary, it was observed that pollock did not spawn the whole of the oocytes in the ovary only one time but repeated spawning several times at intervals of several days (Sakurai, 1983;Hinckley,1987). As an example of the observations in the tank, one female spawned four times in eighteen days. The time of the spawning was concentrated at the twilight through the dawn. However, it is supposed that pollock may spawn in the day time under the natural circumstances where is deeper than 100m and in the low illuminance.

(5) Egg and Larva

The egg of pollck is the separated floating type, and is distributed on the mid layer including the depth of spawning through the surface. Based on the result of the vertical sampling with the NORPAC net operated in the winter survey in 1983 (Fig.42), the pollock eggs were observed in the broad area covered by the survey (Okada, 1984,1986).

The density distribution of the eggs was exetremely high on the sampling station east of 171°W. The information regarding the vertical distribution of the eggs is not available. However, the eggs at eyed period were frequently observed in the contents of pollock stomach obtained from the depth zone of 100-200m in mid March (FAJ, 1984). Consequently, it is obvious that eggs are distributed at least deeper than 100m during this period. And also, The vertical distributions of the fertilized eggs through the larvae just after the hatching by the different development stages on the continental shelf in the eastern Bering Sea is available (Fig.43), and it is reported that the eggs at early eyed period are distributed primarily near the surface (Nishiyama et al.,1986).

Based on the result of the larva net surveys which the research vessel of Hokkaido University OSHORO MARU conducted in June through August, it was observed that the pollock larvae were distributed in the broad area on the Basin (Haryu, 1980;Maeda and Hirakawa, 1977). The distribution of the larvae was limited east of 180 in June through July, however it was observed west of 180 in August (Fig.44). On the Basin east of 180°, the density distribution of the larvae was relatively low north of the Aleutian Chains but high in the southwest region of the Pribilof Islands and in the northern central region (Fig.45). Maeda and Hirakawa (1977) estimates that the larvae which were distributed on the Basin, were not transferred from the continental shelf in the eastern Bering Sea but spawned on the Basin.

According to the surveys conducted by the OSHORO MARU in June through August, the juvenile fish over 40mm was not collected on the Basin. However, because the juvenile fish over 40mm has moderate swimming ability, it seems to be able to collect those juvenile fish if the relatively large sampling net such as the Tucker trawl or Marinovich mid water trawl is available.

6. Feeding Habit

Based on the summer survey conducted in 1977 to 1979, the main diets of pelagic pollock on the Basin were identified (Okada, 1984,1986). The rank order of the stomach contents in terms of frequency of appearance was the Copepoda, then

Enphausiacea, Amphipoda and Oikopleura (Table 1). There were very few of fish and squid and non of shrimp in the stomach. On the stomach contents in weight, the Copepoda was extremely in abundance and domonated 80-85% of the total, and the next was the enphausiacea and dominated 7-8% of the total. Pollock of which stomach was empty, were very little and dominated 2-3% of the total. The mean weight of the stomach contents was 4-11g. The result regard ing the composition of the diets was almost equivalent to th e result of Kikuchi and Tsujita (1977) and Yoshida (1985) wh o analysed the stomach contents of pelagic pollock collected from the Basin in summer. However, based on the report of Kikuchi and Tsujita (1977), the feeding quantity of Oikopleu ra was more than the Copepoda in many cases, it seems that o ccasionally the Oikopleura acts the important role as the di ets. And also, the result of Yoshida (1985) indicated that the composition of the the stomach contents was changed by s eason or area.

Based on the winter survey in 1983 (Okada, 1984a,1986;FAJ, 1984), the rank order of the stomach contents in terms of frequency of appearance was fish including eggs (mostly pollock egg), then Enphausiacea, Copepoda, and shrimp and squid (Table 1). On the feeding quantity, Enphausiacea was the most in abundance and dominated 40% of the total, and the next was squid (22%), and Copepoda was 18%. Pollock with empty stomach contents dominated 58% of the total, the mean weight of the stomach contents was 0.3g. As a result, fish which appeared in the stomach were observed in abundance, were identified mostly as fish eggs, and dominated fairly in small on the quantity. Consequently, it seems that the percentage of the empty stomach was substantially higher. Based on the samples collected from the Basin in winter 1982, the percentage of the empty stomach reached 85%, and there were a lot of pollock of which the feeding quantity was less than 1g (Yoshida and Ueda, 1986). As the diets observed in the stomach, there were fish, Copepoda and squid.

It is reported that the mean weight of the stomach contents of large pollock over 40cm which were collected from the continental shelf in the summer feeding season primarily north of the Pribilof Islands, was 1.19% of the body weight (Dwyer et al.,1986). That is, it is estimated that the mean feeding quantity of pollock with the length of 47cm and the weight of 720g which is equivalent to the mean size of pollock on the Basin is approximately 9g.. As reported above, the mean weight of the feeding quantity of pelagic pollock living on the Basin in summer is 4-11g, and it seems that this is almost similar to the one of pollock in summer on the continental shelf north of the Pribilof Islands. Pelagic pollock on the basin is a little skinny in June and its condition factors are lower than the ones of the fish on the shelf. However, then the feeding becomes in active and the both of the liver weight index and condition factor gradually increase and since July those are almost similar to the fish on the continental shelf at least west of 170°W (Yamaguchi et al.,1979).

It is estimated that the feeding of pelagic pollock on the Basin becomes the most in active around the sunset, however it is estimated that pelagic pollock feeds constantly the food organisms because a lot of food items which were in the different digested stages were observed (Yoshida, 1985). It is estimated that the daily feeding quantity to maintain the life is 0.61% of the body weight in case of adult pollock based on the experiment of pollock rearing. However, the weight index of the stomach contents of pelagic pollock on the Basin are mostly more than 0.6%, and though the quantity is not in abundance, it seems that pelagic pollock feeds the sufficient quantity of the foods to survive or expedite its growth (Yoshida, 1985). And also, based on the result of the experiment of pollock rearing and the growth rate of adult pollock, the quantity of foods required per day was estimated 1.1% of the body weight, and almost similar to the one calculated from the growth rate of pelagic pollock on the Basin (Yoshida, 1985).

7. Biomass

The biomass of pelagic pollock on the Basin east of the US-USSR boundary is estimated 2.688 million mt in 1977, 5.442 million mt in 1978, and 1.269 million mt in 1979 based on the summer survey conducted in 1977 to 1979 (Okada, 1979b;Okada and Yamaguchi, 1985). There is not difference between 1978 and 1979 in terms of the survey areas except the survey was extended to the edge of the continental shelf in 1978, however the big difference of the biomass estimate between the two years has not been discussed so far. Nunnallee (1978) estimates that the biomass is 0.84 million mt based on the same data of the survey conducted by Japan in 1978, however Okada (1979b) indicated that this value was extremely underestimated.

These biomass were calculated and estimated from the density of the fish per unit of volume by each layer based on the stratification of the survey area according to the records of the echograms by using normal fish finder equipped on the fishing vessel and the number of catch of pelagic pollock by the midwater trawling (Okada, 1979b). Therefore, there are some fundamental problems including the uncertainty of the catchability of the midwater trawl gears on these estimates (Okada, 1979b).

On the winter survey in 1983, the quantitative echo sounder system was used, and the hydro-acoustic survey was conducted. As a result, the density distribution in the survey area on the Basin showed in the Figure 8, and the biomass was estimated 1.142 million mt (Okada and Nakayama, 1984). The mean density of the fish was 4.13-4.53 t/km^2. The survey area was within the US 200 miles zone southeast of the Basin, and the most of international waters was not covered. As mentioned above, on the winter operations in the international waters in 1987, the extremely high dense school was observed in the north side of the Bowers Ridge west of 180°, Therefore, it is likelihood that the dense school was distributed in the area where the survey did not cover in 1983.

The Fisheries Agency of Japan (FAJ) conducted the hydro-acoustic survey of pollock in 1985, which is important diets for the northern fur seal living in the Pribilof Islands in the summer season. As a result, The biomass of pelagic pollock living on the relatively small area on the basin (0.14 million km^2) off the Pribilof Islands in July was estimated 5.24 million mt (Onoda et al.,1986).

The Japan Marine Fishery Resource Research Center (JAMARC) conducted the survey of pelagic pollock by the quantitative echo sounder system by the two research vessels in the international waters in August to September in 1987. As a result, the biomass in the area equivalent to 78% of the international waters was estimated 9.10 million mt (FAJ, 1988). As compared with the midwater trawl survey conducted at the same time, the general trends which indicated that the biomass increased in proportion as the depth and the biomass in the southeast region was more than in the northwest region, were consistent with the result of the midwater trawl survey. However, the result of the acoustic survey was reviewed in detail, consequently, there were several problems as follows; First, the charging rates in the density of fish was considerably higher in verticalwise or horizontalwise as compared with the CPUEs obtained from the midwater trawl survey. For example, on the midwater trawl survey, the CPUE on the depth of 150-200m was 1.5-2.2 times higher than on the depth of 100-150m, however on the result of the acoustic survey, it was 14.6-22.2 times higher. Secondly, the biomass on the depth of 160-200m in the four subsections (each subsection divided by 1 of the longitude and 30 of the latitude) where dominated only 8.4% of the total survey area, was extremely high and dominated 51% of the total biomass estimated.

From the point of view of the hydro-acoustics, it is pointed out that there might be problem on the selection of the threshold level among the parameters of the echo sounder system used in this survey (personal communication with Mr.Furusawa in the National Research Institute of Fisheries Engineering). In case of the type of echo sounder used in this survey, if the constant threshold was given, the echo levels tend to be overly low on the shallow depths and overly high on the deep depths (Furusawa et al.,1988). Since the high noise was observed in this survey, the considerable high threshold value at -55dB was given. It seems that the threshold effect and the noise considerably affected the result of the survey.

Taking into consideration of the informations described above, it seems that the biomass estimate obtained from the survey in the international waters in summer 1987 should be carefully treated. The Fisheries Agency of Japan will conduct the acoustic survey with the United States on the Aleutian Basin in summer 1988. The quantitative echo sounder system being used in this survey has been newly developed and is the highest level at present in Japan, which is improved to avoid the problems encountered on the survey in 1987. Furthermore, on this survey, the best threshold parameter will be used, which is fit for the characteristic of the noise. It is expected that the accurate biomass estimate will be obtained.

8. Relationship with Oceanographic Circumstances

Pelagic pollock is spread out and widely distributed on the Basin in summer, the relationship between the horizontal or vertical distribution and the oceanographic conditions was not clear (Kikuchi and Tsujita, 1977). The distribution of pelagic pollock is primarily observed on the layer of 30-150m, and the desity distribution of the zooplanktons is high shallower than 150m in summer (Minoda, 1971). And the vertical distribution of pelagic pollock is consistent with the one of the diets such as the zooplanktons.

Based on the result of the winter survey in 1983 (Kitani, 1983;Okada, 1986;Okada and Nakayama, 1983;FAJ, 1984), the vertical distribution of the water temperature was the range of 2.5-4.2°C. The remarkable thermocline was observed on the layer of 150-200m. And the water on the upper layer was the winter surface cooling waters below 3.5°C and relatively cold water temperature, and the waters on the lower layer was the part of the Alaskan stream over 3.7°C and relatively warm water temperature (Fig.46). The water temperature on the surface was the range of 3.0-3.5°C, and the one deeper than 900m was below 3.0°C. The school of pelagic pollock in late January and in mid to late February was primarily distributed on the layer of

250-300m where the water temperature was 3.5-4.0°C under the thermocline (Fig.46,47). The salinity density was the range of 32.8-34.3‰, and the school was primarily observed on the layer of 33.6-33.8‰ (Fig.48). And the resolved oxygen was the range of 0.4-7.4ml/l, and decreased in proportion to the depth. The school was observed on the layer on where the resolved oxygen was relatively low at 1.0-3.0ml/l (Fig.48). In mid March, the fish after spawning moves into the layer of the surface cooling waters above the thermocline, however it seems that pelagic pollock which gonad is in the full mature stage, is distributed under the thermocline layer.

Based on the result of the survey conducted by Japan in the international waters in August to September 1987, the horizontal distribution (Fig.49) of the mean water temperature on the depth of 0-200m was high on the east side and low on the west side (FAJ,1988). It is considered that the Alaskan stream which goes up northward from the southeast side of the Aleutian Islands, affects the water temperature in the international waters, and the one on the east side is relatively higher than on the west side.

On the vertical distribution of the water temperature along the line of 57°N (Fig.50), the thermocline prevails around the depth of 50m (FAJ,1988). This thermocline indicates the sharp gradient in verticalwise on the west side but indicates the slow gradient towards east side. The cold water layer below 4°C is observed under the thermocline, and this cold water layer develops well on the west side but it does not develop on the east side. On the layer under the cold water layer, the water temperature goes up, and particularly on the east side the warm waters over 4°C prevails on the depth zone deeper than 200m.

On the vertical section along with the line of 180 longitude, the coldest layer below 2.5°C is observed on the layer of 150m on the north side, and it becomes warm towards south side and the warm waters over 4°C develop in the layer deeper than 200m (Fig.50).

As compared with the results of the midwater trawl survey and hydro-acoustic survey, the vertical distribution of pelagic pollock indicates the high density on the cold water layer of 50-200m (FAJ,1988). The area on where the density distribution is high in particular, is consistent with the area on where the warm waters prevails remarkably under the second thermocline (Fig.11,50).

The vertical distribution of the zooplanktons on the Basin in winter (Fig.51) indicates that the density is high on the layer under the thermocline (Kitani and Komaki,1984; FAJ,1984). It seems that the biomass of the zooplanktons on the Basin is relatively in abundance. And it is assumed that the reason why pelagic pollock in winter feeds a few of foods is not due to the lack of the foods avialable in the living layer but the physiological factors in connection with the reproduction.

On the relationship with the oceanographic circumstances, the transfer of the eggs and larvae spawned on the Basin is the most important subject. Based on the simulation of the current system in the Bering Sea (Fig.52), it was estimated that there was the anticlockwise circulation system on the Aleutian Basin, and the eddying current on the central region (Ohtani,1973). Based on the recent study, the circulation was identified (Kitani,1983;Royer and Emery,1984). The circulation which flows on the mid layer on the Basin, moves eastward along with the north side of the Aleutian Islands and changes the direction to the northwest around the edge of the continental shelf northwest of the Unimak Pass. The speed and flow of the return current is remarkably large in winter as compared with in summer, and the mean speed of 0.2-0.3 nautical miles per hour was recored on the depth of 300m (Kitani,1983).

Based on the observation on board during the winter survey in 1983, the fertilized eggs of pelagic pollock hatched in about 25 days with 3-4°C. Consequently, it is estimated that the fertilized eggs which are spawned on the southeast region of the Basin, are transferred to the point about 150 nautical miles away on the northeast direction (Okada, 1986). Further studies on the difference in the spawning season and period for the major spawning populations, the growth rate of larvae, and the current system is neccessary to make clear the route of the transportation of eggs and larvae to the nursery grounds from the major spawning grounds.

9. Further Research

Based on the review described above, the biological informations regarding pelagic pollock which lives in the Aleutian Basin, has been partially accumulated so far. The study on this stock concerned is deemed as a part of large scale study to clarify the biological production mechanism of pollock resource in the whole Bering Sea including the stock on the continental shelf.

Pelagic Pollock in the international waters has been exploited by the fishing vessels from Japan, South Korea, Poland, and People's Republic of China. And it is reported that USSR has started fishing there. The survey conducted by the each nation on the stock in the international waters is necessary, however it is important that the comprehensive survey and study on the pollock stocks in the whole Bering Sea should be conducted in cooperation with the fisheries nations and coastal nations concerned. For this reason, it is necessary to establish the cooperative regime. In the future, in order to achieve the objective of the study described above, it is necessary to establish the subjects of the study as follows;

(1) Analysis of Stock Structure

It is generally known that there are several spawning grouds (spawning populations) of pollock including on the Aleutian Basin, however it is necessary to clarify that those spawning populations are independent each other in terms of lineage.

i. Confirmation of the spawning grounds and the scale of spawning populations, in particular in the Asian side.

ii. Comparison of the biological parameters of the each spawning populations. (abundance, age compositon, growth, condition factor, fecundity, mature at age, recruitment, mortality,etc.).

iii. Comparison of the meristics and morphometrics of the each spawning populations.

iv. Comparison of the shape or the formation patterns of the growth ring on the age materials (in general otolith or scale) of the spawning populations.

v. Comparison of the variations of the gene by the biochemical method in each spawning populations.

vi. Explication of the movement and migration, in paticular the movement from the spawning ground to the feeding ground, and the migration from the feeding ground to the spawning ground, and the movement from the continental shelf to the Basin or from the Basin to the continental shelf.

vii. The transfer of larva from the each spawning ground.

viii. Based on the surveys regarding the items of ii to v, if the existence of the subpopulations and the valid characteristics to identify those were disclosed, the geographical mixture of the individual subpopulations will be explicated quantitatively by the samples collected from the broad area in the summer feeding season.

(2) <u>Biomass estimate</u>

The biomass is one of basic factors to determine the scale of the biological production of living resource. The informations regarding the biomass by age and its annual fluctuation are inevitable to estimate the harvest level available from the resource. Among those informations, the abundance trend of juvenile fish before recruitment and the mature fish are the most important to predict the future trend of the resource.

i. Direct estimation by the research vessel; The biomass is estimated by the survey in combination of the quantitative echo sounder system and the midwater or onbottom trawl nets. The biomass estimate is varied by the values of the back scattering strength and the target strength as a base of the biomass estimate. Therefore, the acoustic survey should be carefully conducted, and hopefully the experts concerned participate in the survey. And it is appropriate to conduct the survey in summer and winter.

ii. Based on the catch data of the commercial fishing vessels, the biomass is estimated with the resource analysis models such as the Cohort model. As the basic informations, the number of fish by age is necessary. In case that there is no data or the data are not available from the certain fishery, the biomass estimate will be incomplete.

(3) Explication of commercial fishing

The informations from the commercial fishing vessels are extremely important to evaluate the biomass estimates from the models and surveys and the impacts of accuracy of the commercial catch on the resource.

i. Fishing efforts and catch; If the both of them are not reported accurately, it is meaningless on the study of the resource. Therefore, the individual nations should establish the system to obtain the accurate data from their commercial fishing vessels, and exchange those data after completion of the analysis in detail.

ii. Collection of the catch data of the size composition.

iii. Collection of the age materials.

iv. Collection of the frozen samples.

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Table 1. Frequency of occurrence and weight of food organisms in pelagic pollock stomachs from the Aleutian Basin in the summer of 1978 and 1979, and the winter of 1983 (Okada, 1986).

	1978		1979		1983	
	Occurrence	Weight (g)	Occurrence	Weight (g)	Occurrence	Weight (g)
Euphausiacea	541	1,475.7	252	474.8	365	312.4
Copepoda	2,069	15,969.4	1,477	5,390.7	245	139.4
Amphipoda	206	248.1	140	135.1	9	6.8
Gastropoda	86	334.8	72	223.7	-	-
<u>Oikopleura</u>	146	537.6	202	399.0	-	-
Pisces	42	199.0	9	85.6	408	135.1
Shrimps	-	-	-	-	15	20.5
Squids	-	-	6	54.1	78	173.3
Others	21	58.8	3	3.8	-	-
Unknown	11	12.1	-	-	-	-
Total	3,122	18,835.5	2,161	6,766.8	1,120	787.5
Empty	54		66		1,515	
Number of specimens	2,353		1,739		2,630	

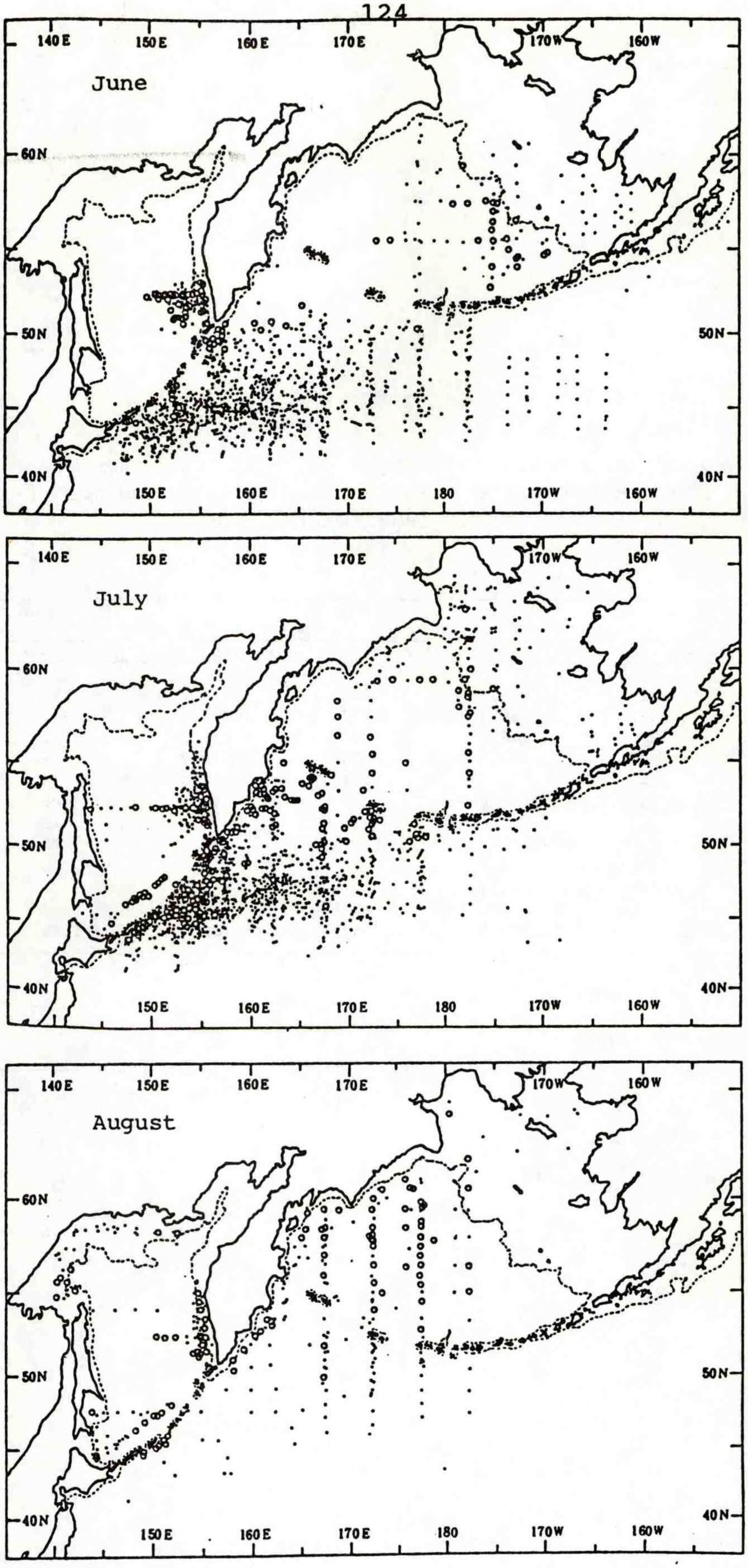


Fig. 1. Survey stations (•) and occurrences (O) of pelagic pollock incidentally caught from Japanese salmon driftnet surveys, 1965-1973 (Yamaguchi et al., 1979).

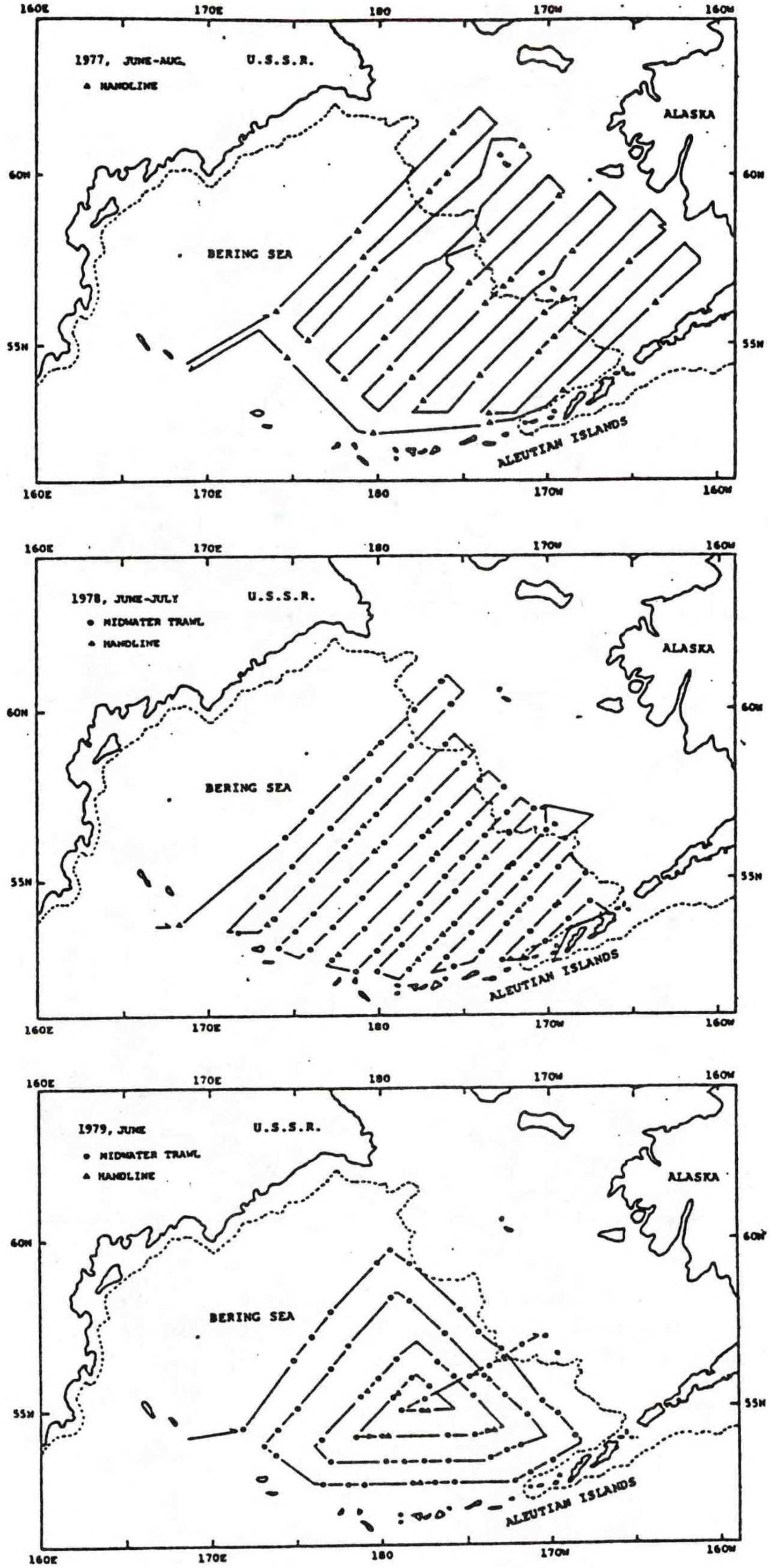


Fig. 2. Track line and positions of handline (▲) and midwater trawl (●) operations in Japanese pelagic pollock surveys in the Aleutian Basin in the summer of 1977-1979 (Okada, 1986).

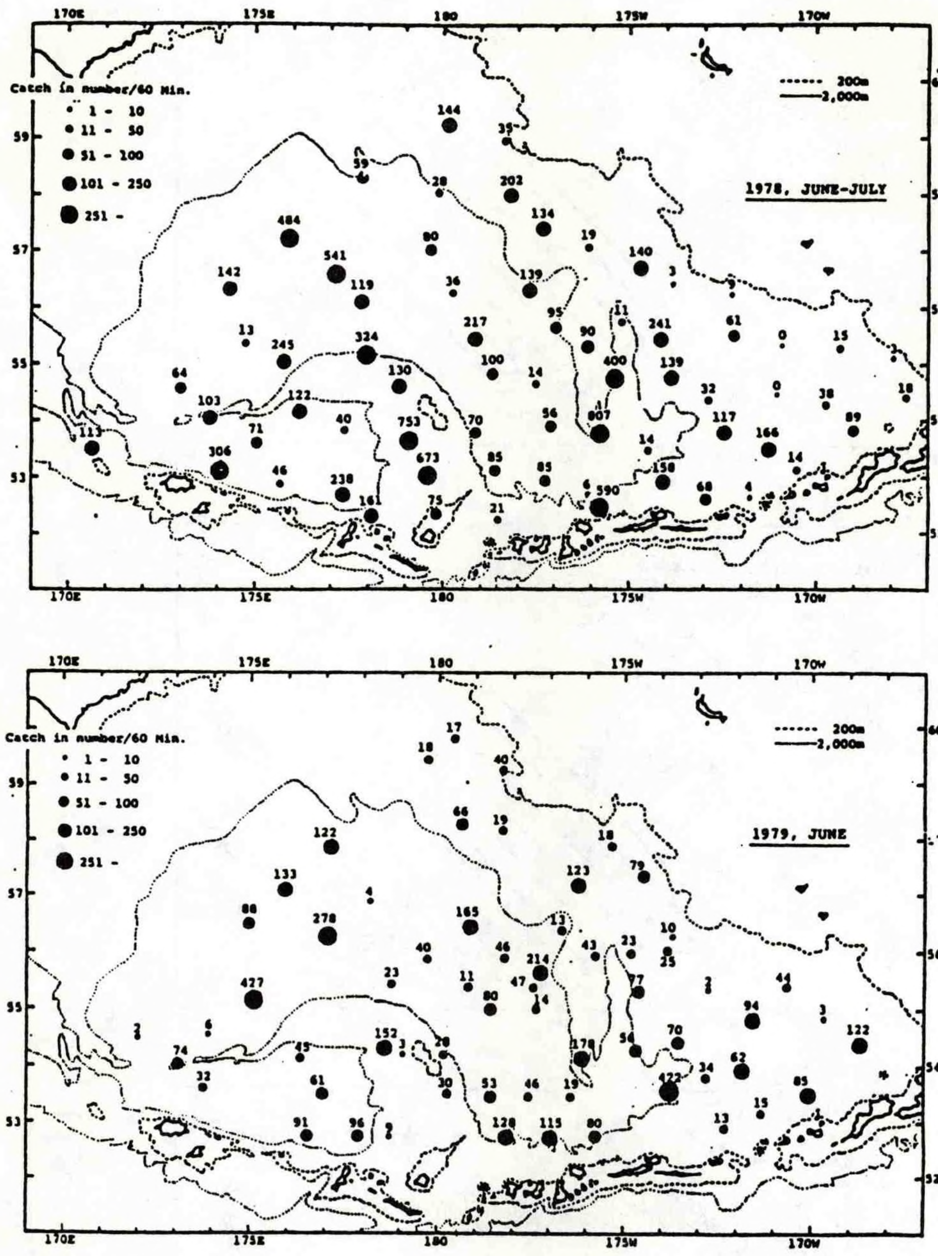


Fig. 3. CPUE distribution of pelagic pollock from Japanese midwater trawl surveys in the Aleutian Basin in the summer of 1978 and 1979 (Okada, 1986).

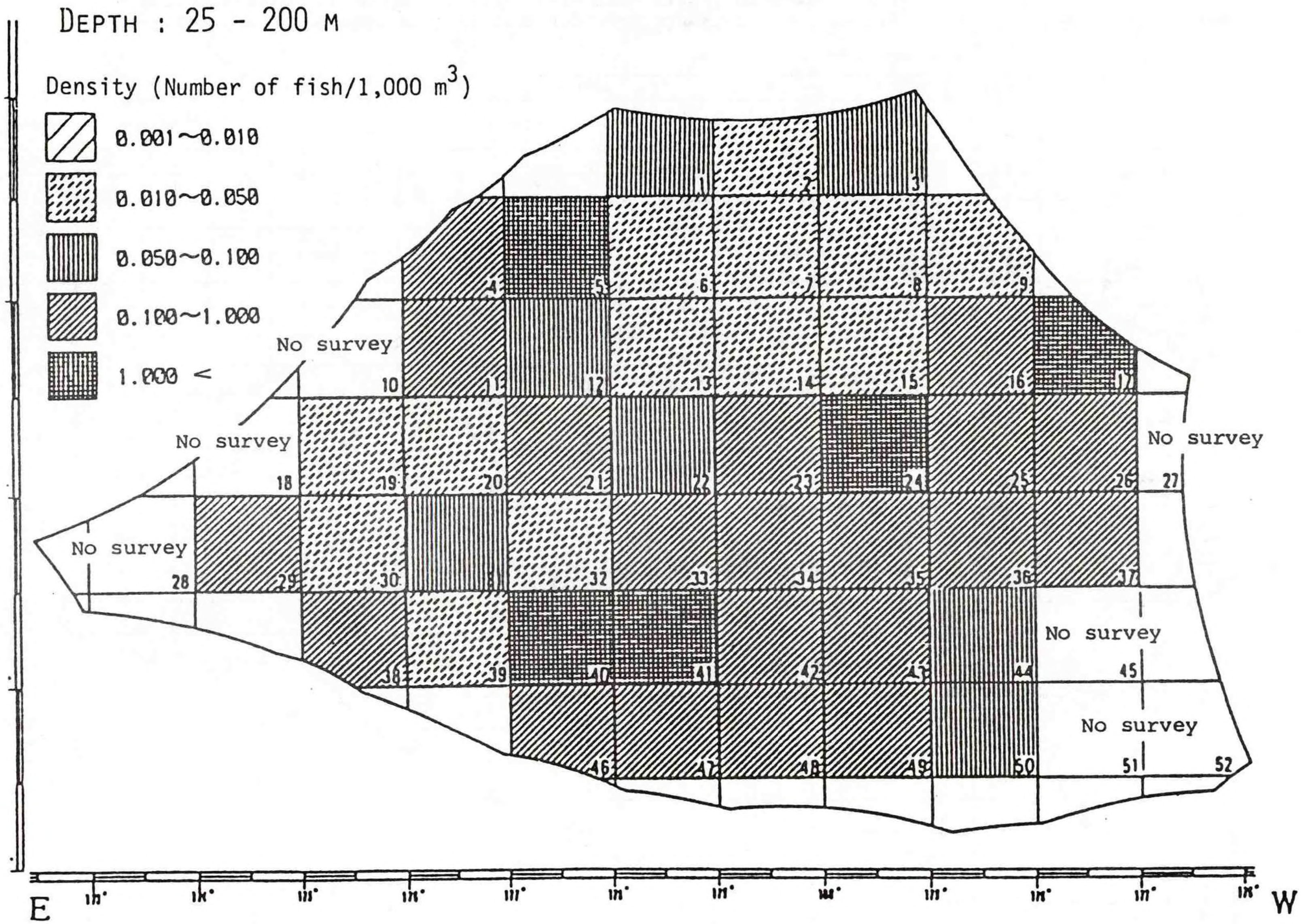


Fig. 4. Density distribution of pelagic pollock from Japanese acoustic survey in the international waters in the summer of 1987 (Fisheries Agency of Japan, 1988).

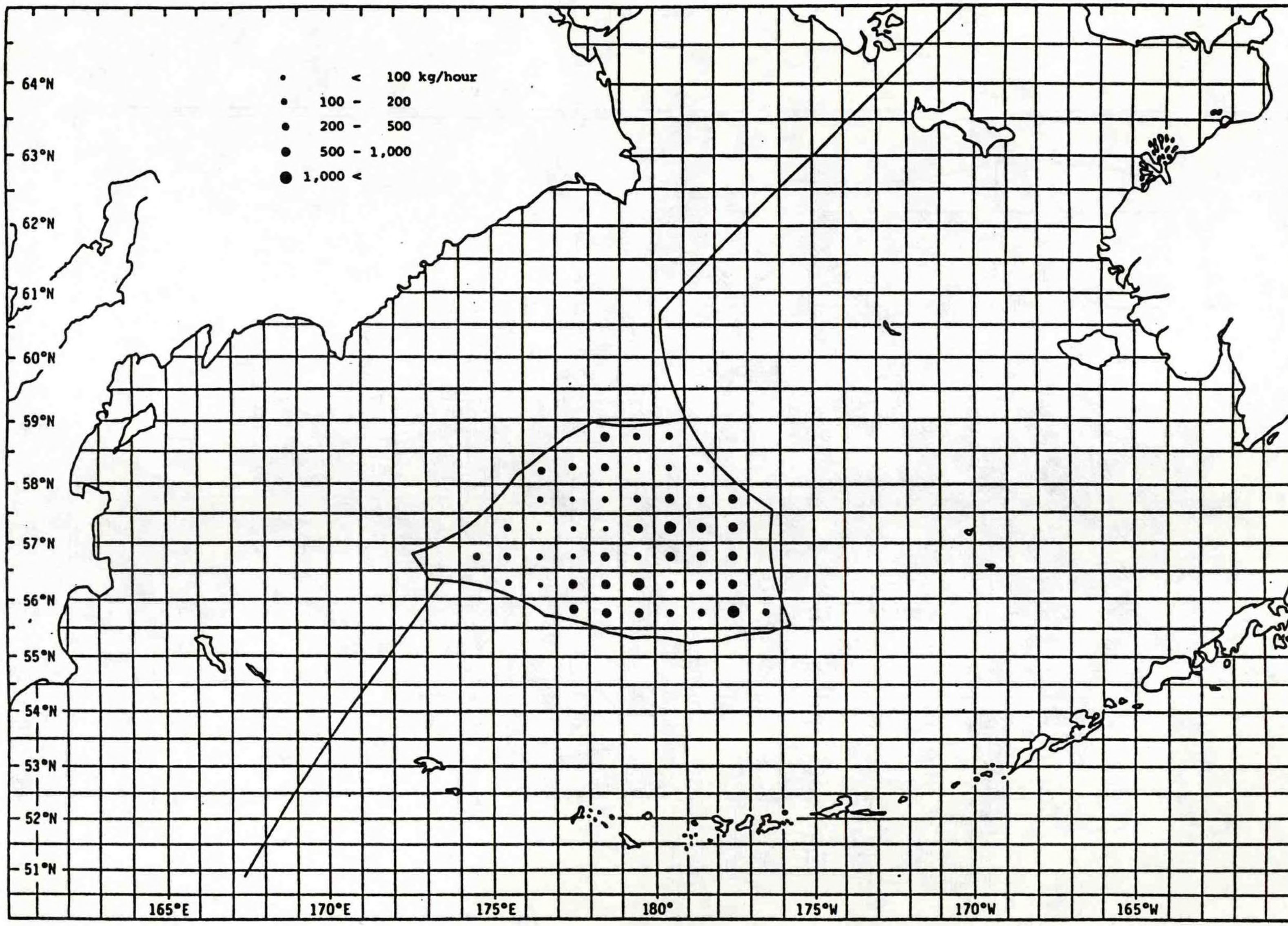


Fig. 5. CPUE distribution of pelagic pollock from Japanese midwater trawl survey in the international waters of the Bering Sea in the summer of 1987 (data from Fisheries Agency of Japan, 1988).

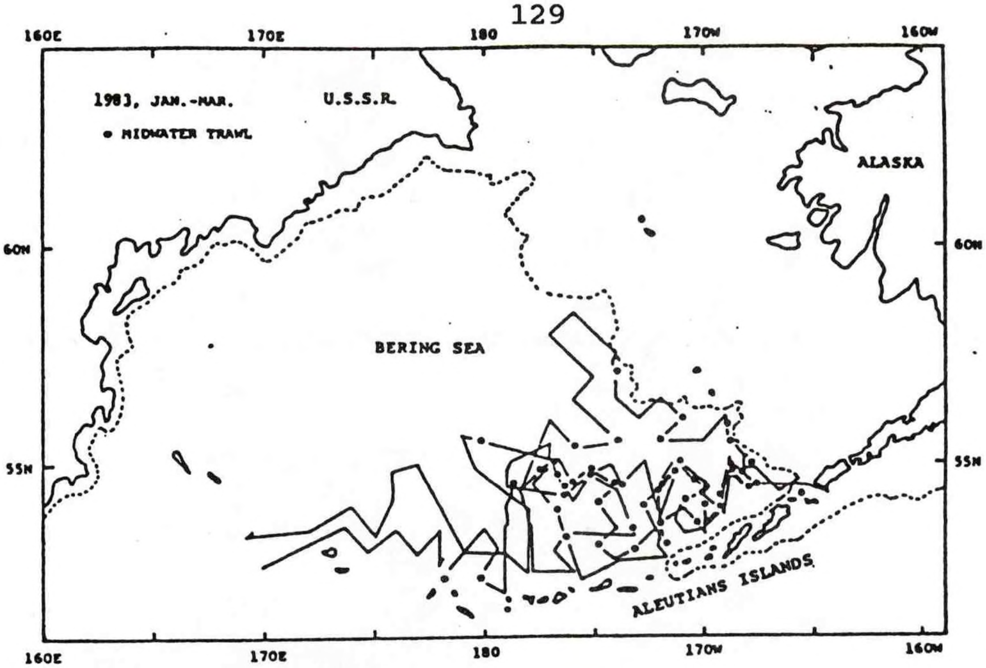


Fig. 6. Track line and positions of handline (▲) and midwater trawl (●) operations in Japanese pelagic pollock survey in the Aleutian Basin in the winter of 1983 (Okada, 1986).

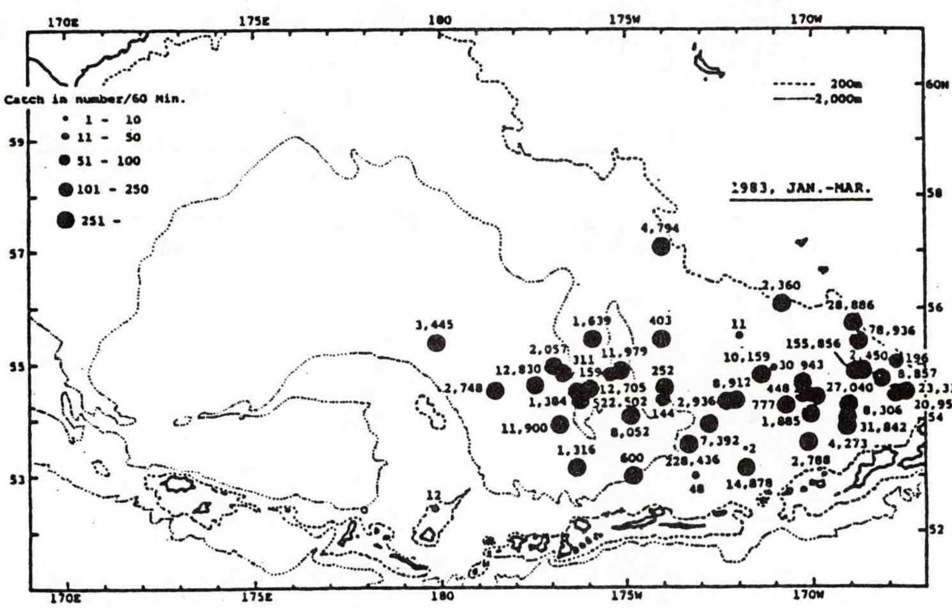


Fig. 7. CPUE distribution of pelagic pollock from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Okada, 1986).

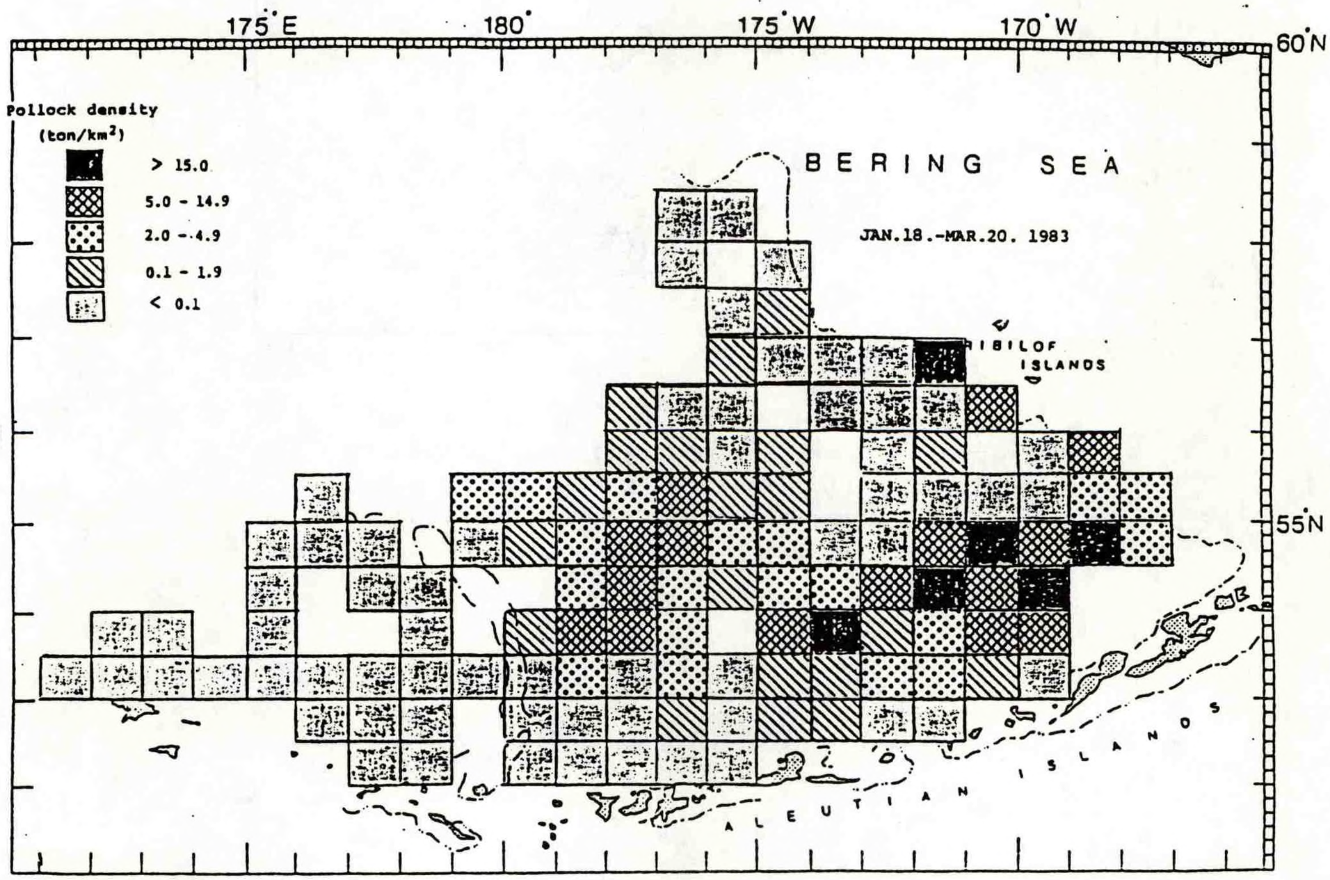


Fig. 8. Density distribution of pelagic pollock from Japanese acoustic survey in the Aleutian Basin in the winter of 1983 (Okada and Yamanaka, 1984).

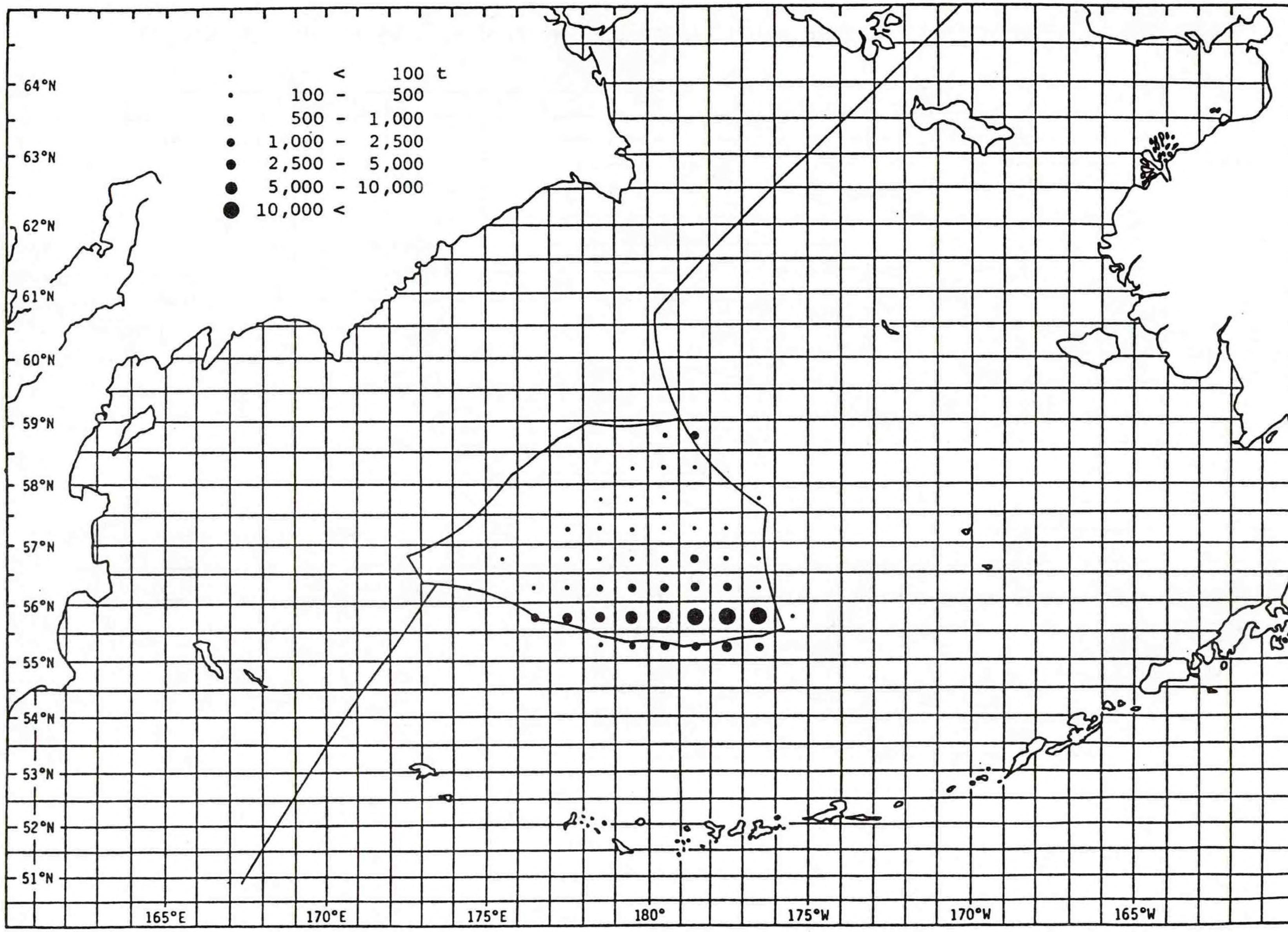


Fig. 9. Catch distribution of pelagic pollock by Japanese North Pacific Trawl Fishery in the international waters of the Bering Sea in 1985 (data file in Far Seas Fish. Res. Lab., Shimizu).

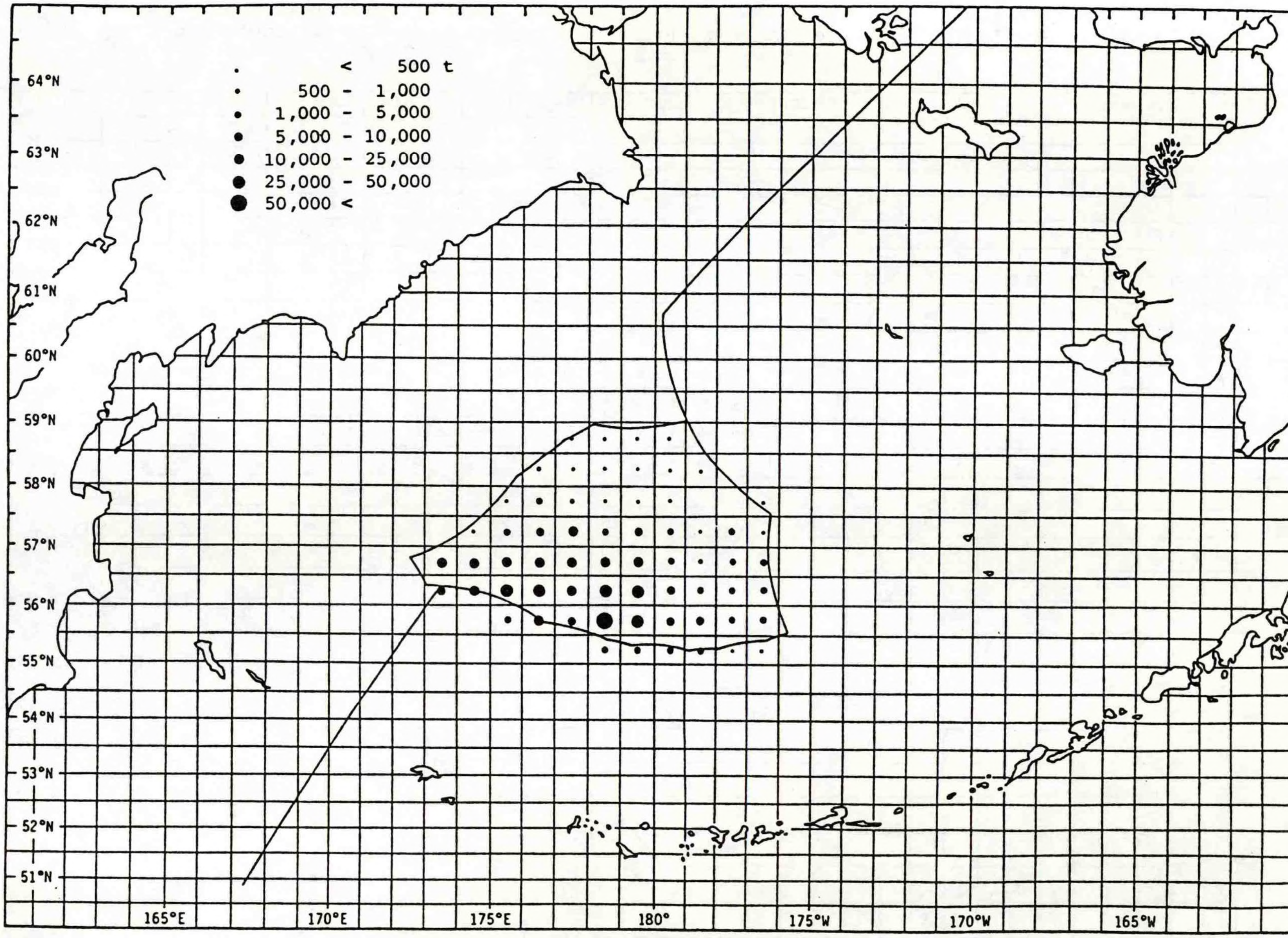


Fig. 10. Catch distribution of pelagic pollock by Japanese North Pacific Trawl Fishery in the international waters of the Bering Sea in 1987 (data file in Japan Deep Sea Trawlers Ass., Tokyo).

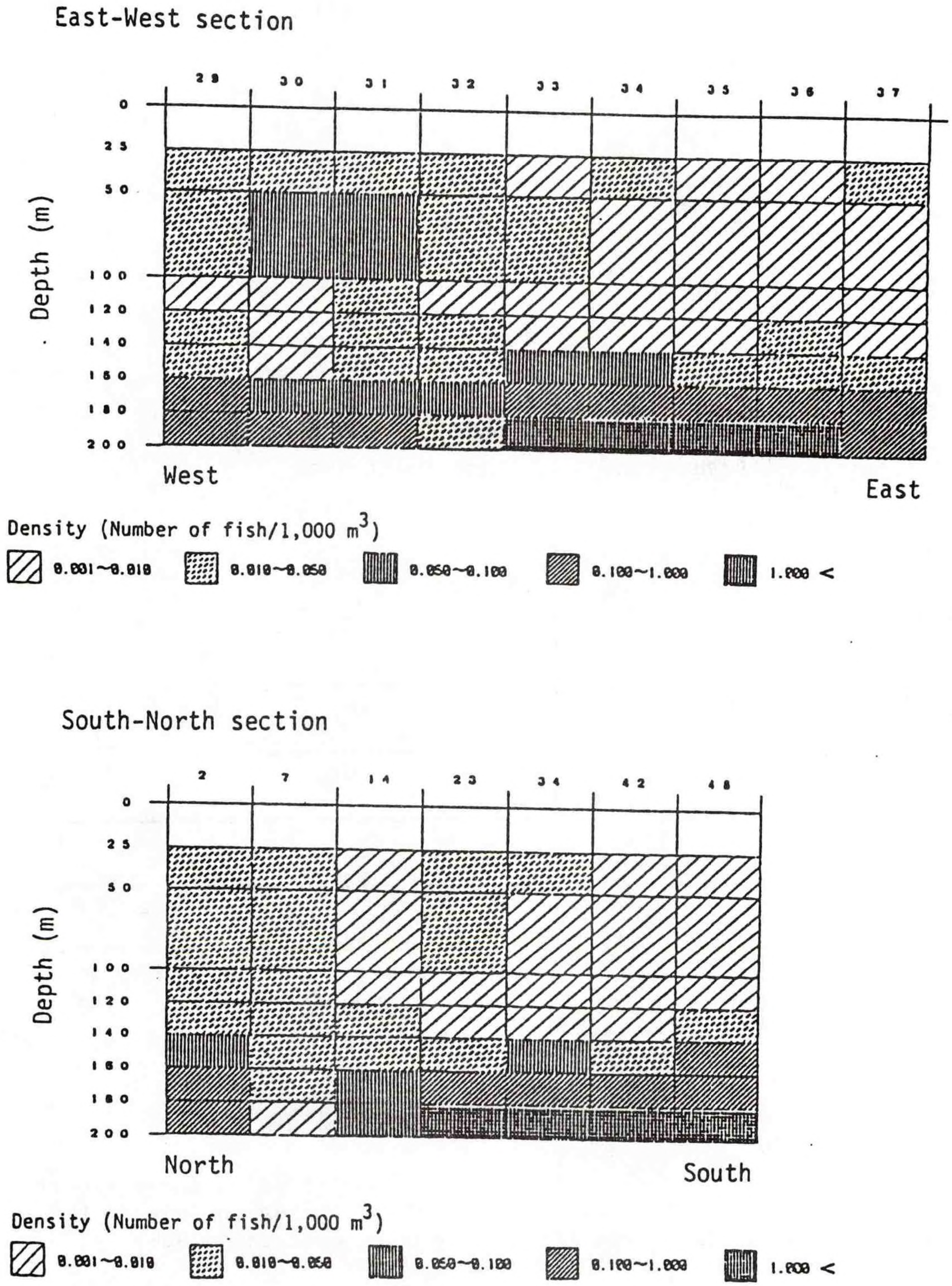


Fig. 11. Vertical density distribution of pelagic pollock along the east-west section (57°N) and south-north section (180°) from Japanese acoustic survey in the international waters of the Bering Sea in the summer of 1987 (Fisheries Agency of Japan, 1988).

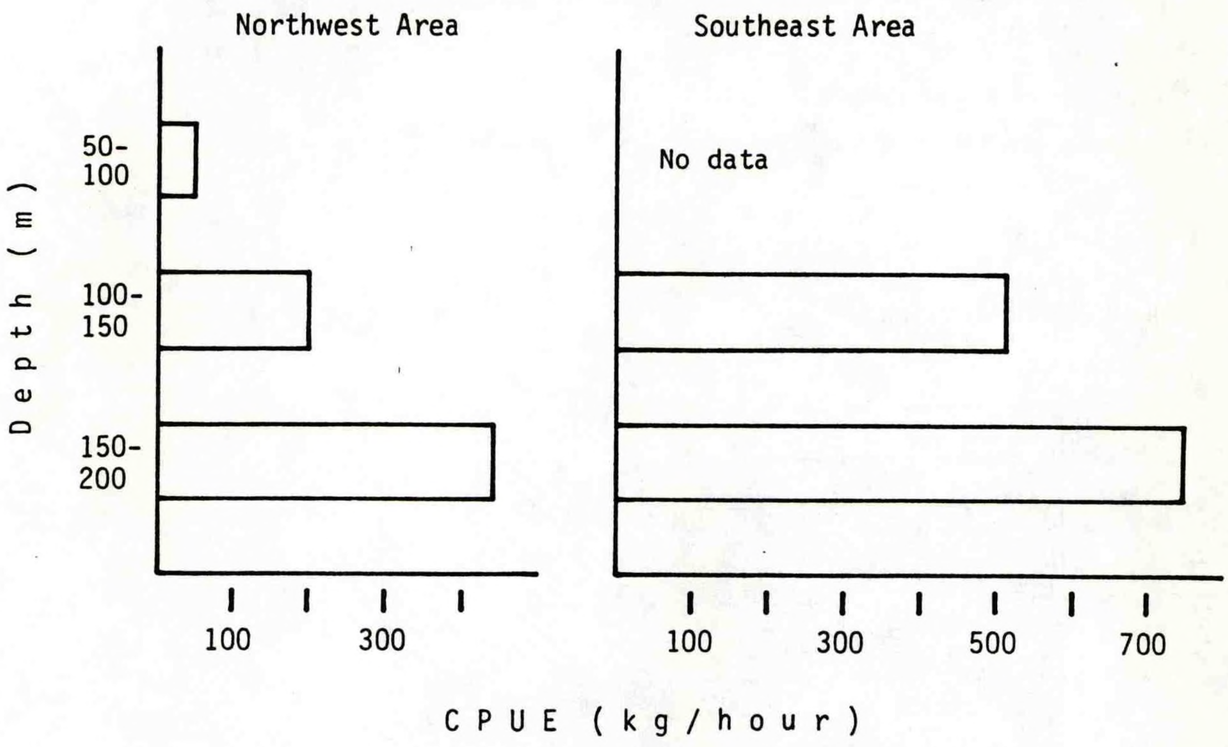


Fig. 12. Vertical CPUE distribution of pelagic pollock from Japanese midwater trawl survey in the international waters of the Bering Sea in the summer of 1987. Data from Fisheries Agency of Japan (1988).

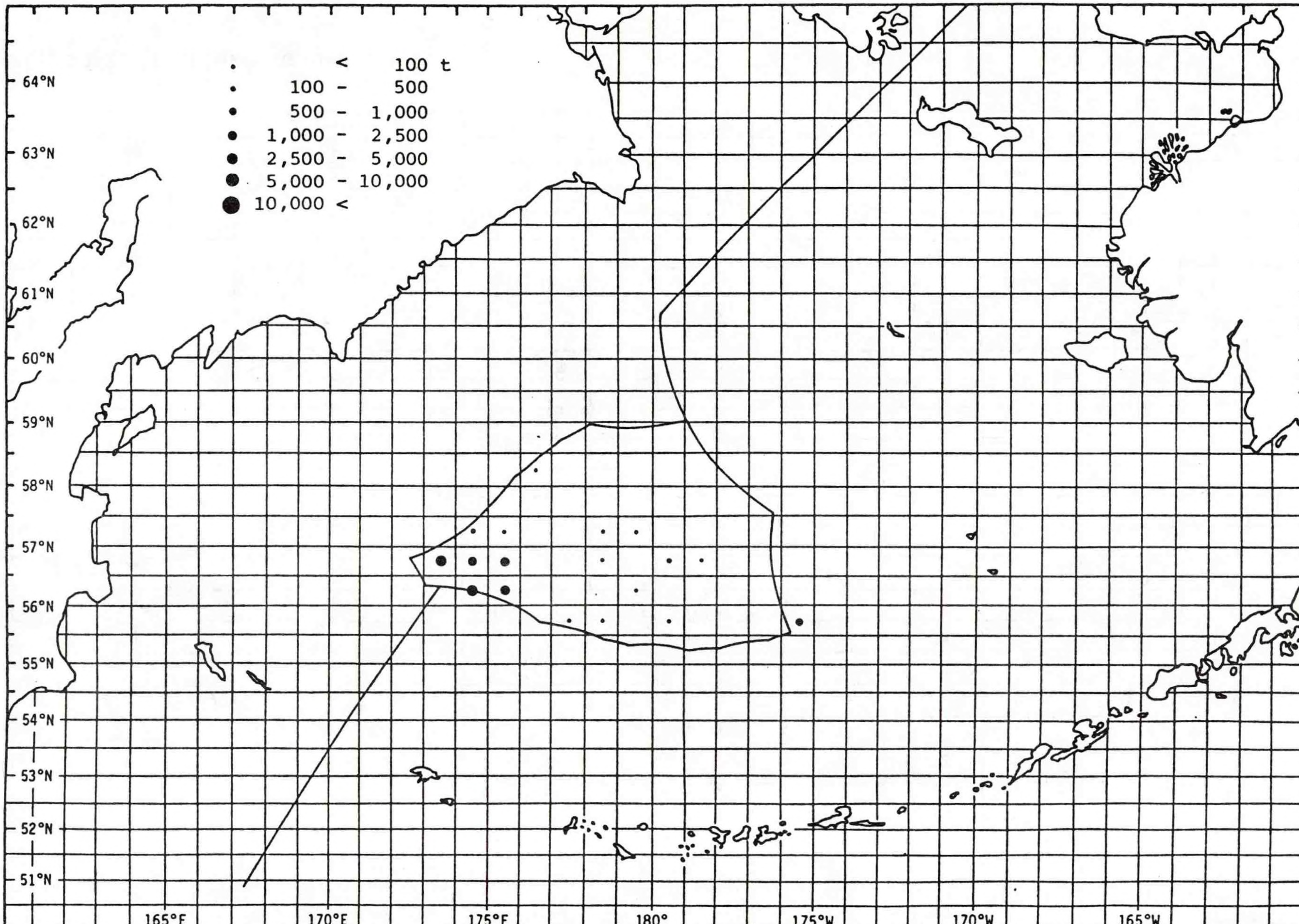


Fig. 13-1. Catch distribution of pelagic pollock by Japanese North Pacific Trawl Fishery in the international waters of the Bering Sea in October 1986.

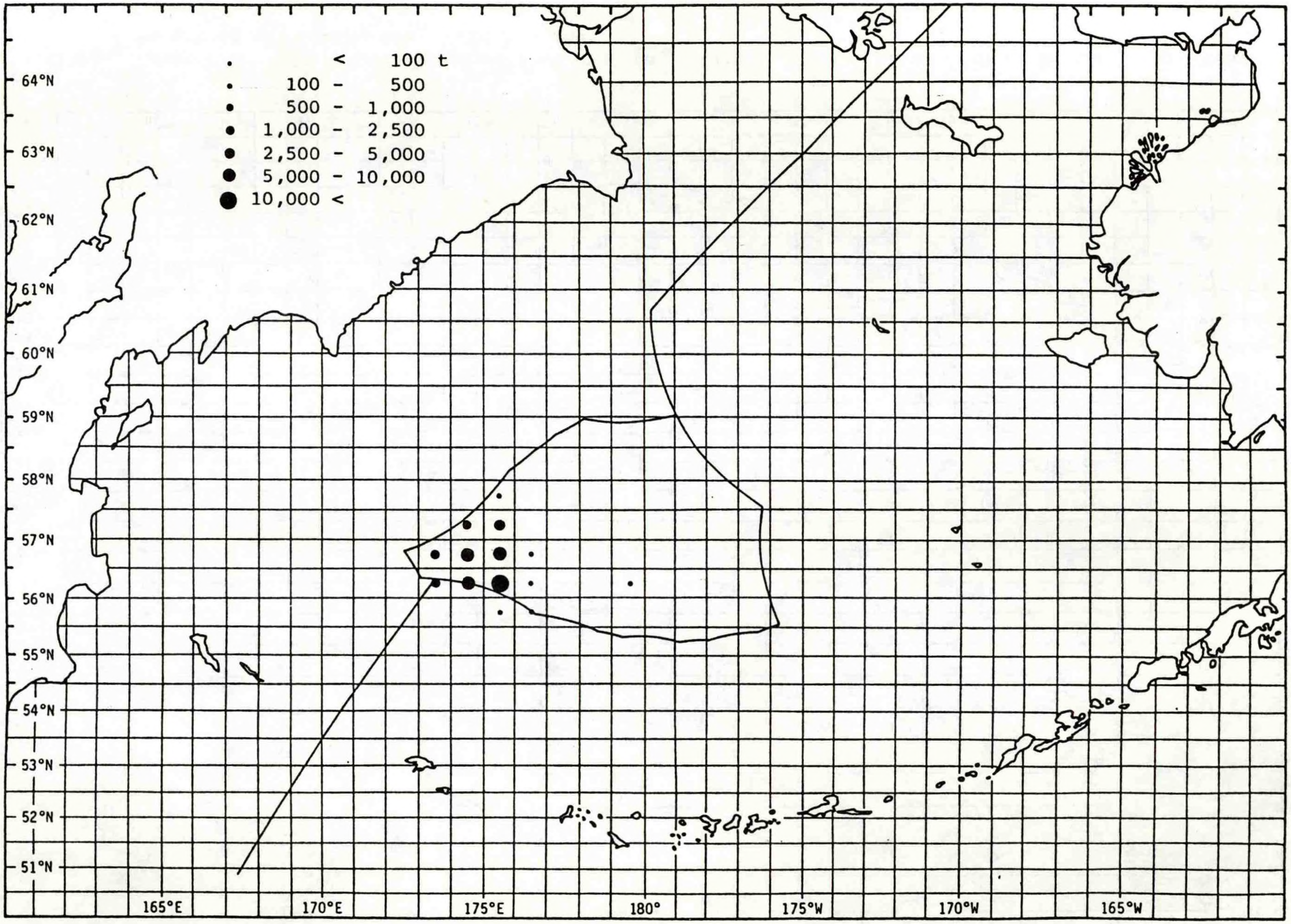


Fig. 13-2. Continued (November 1986).

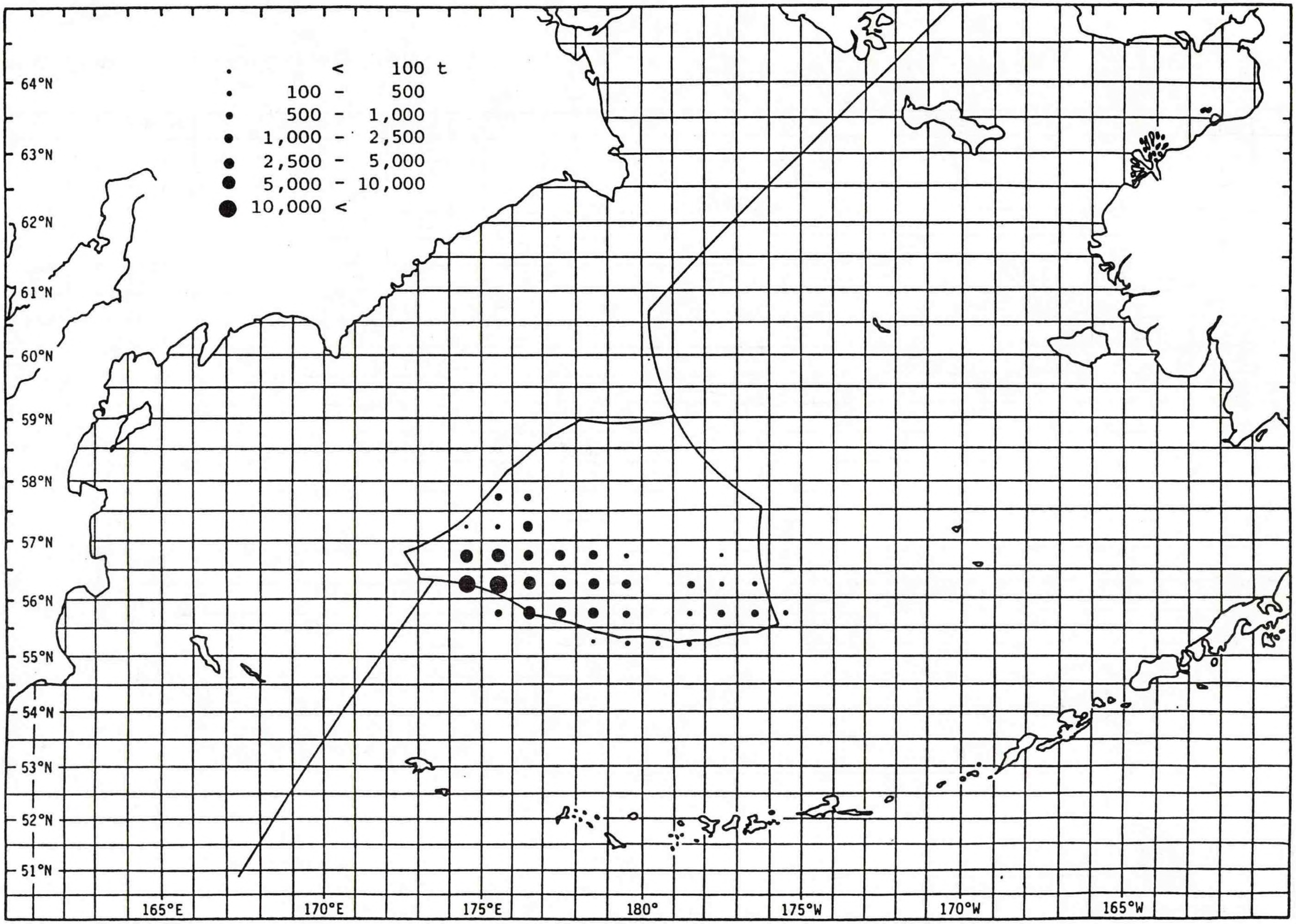


Fig. 13-3. Continued (December 1986).

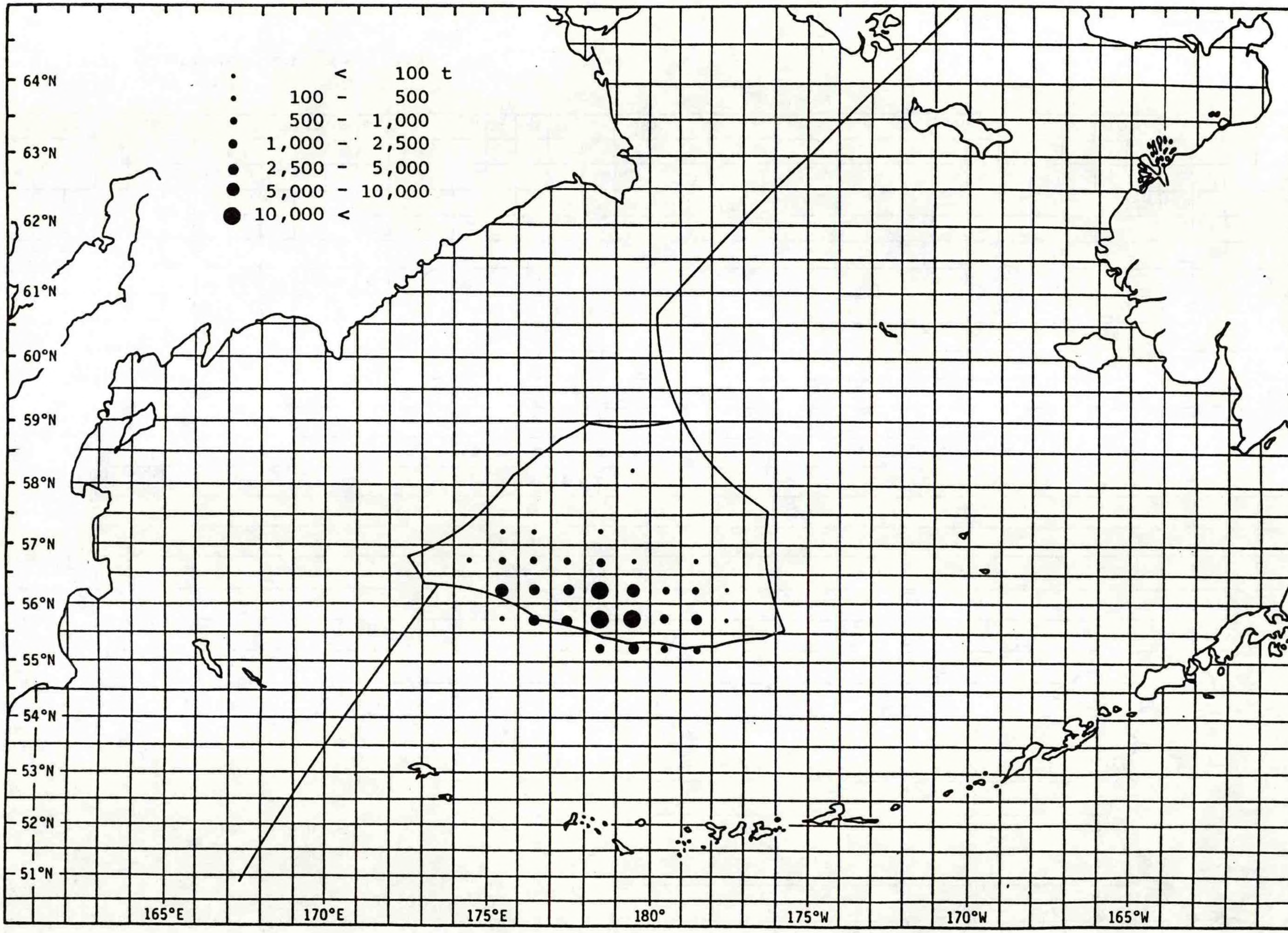


Fig. 13-4. Continued (January 1987).

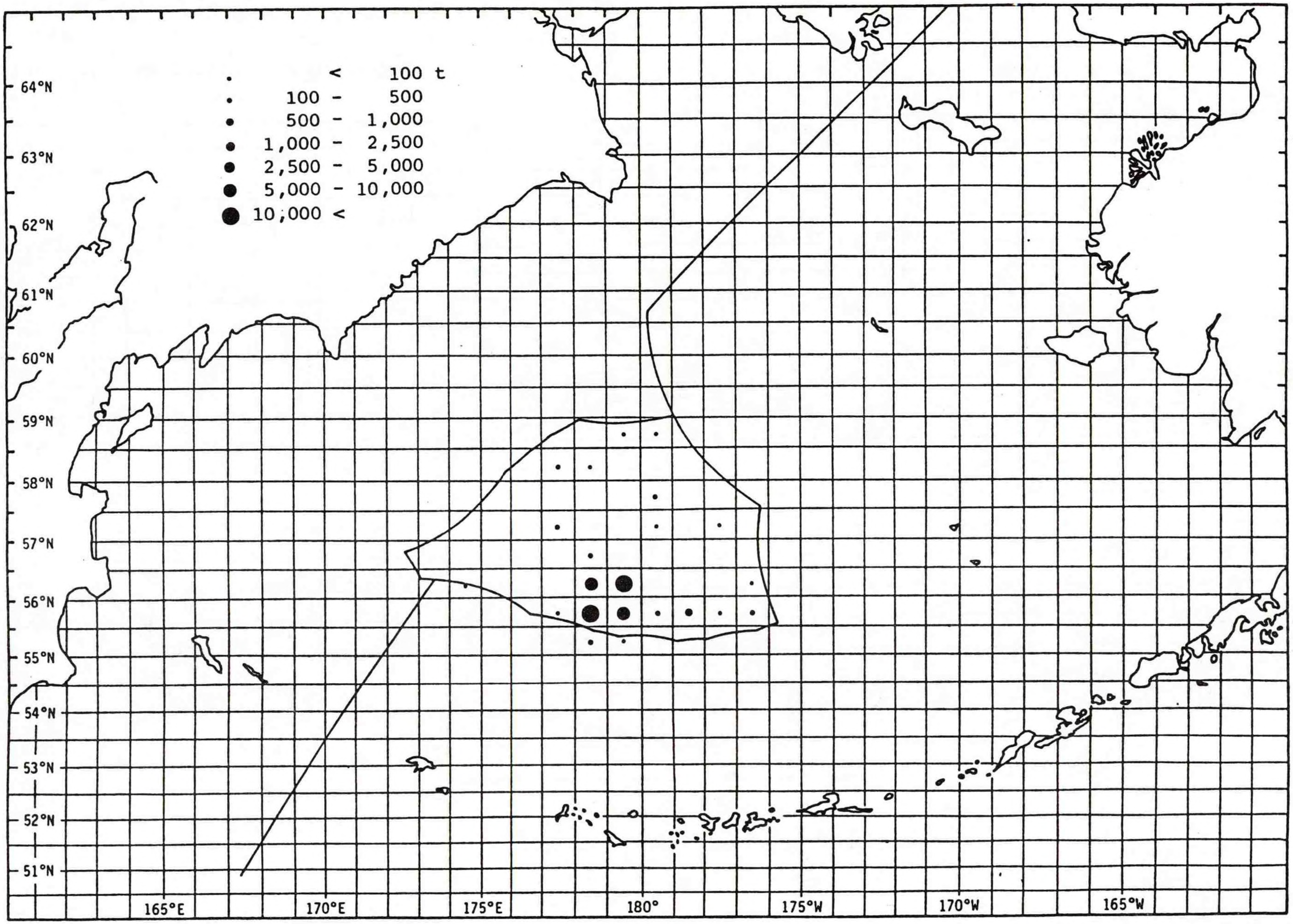


Fig. 13-5. Continued (February 1987).

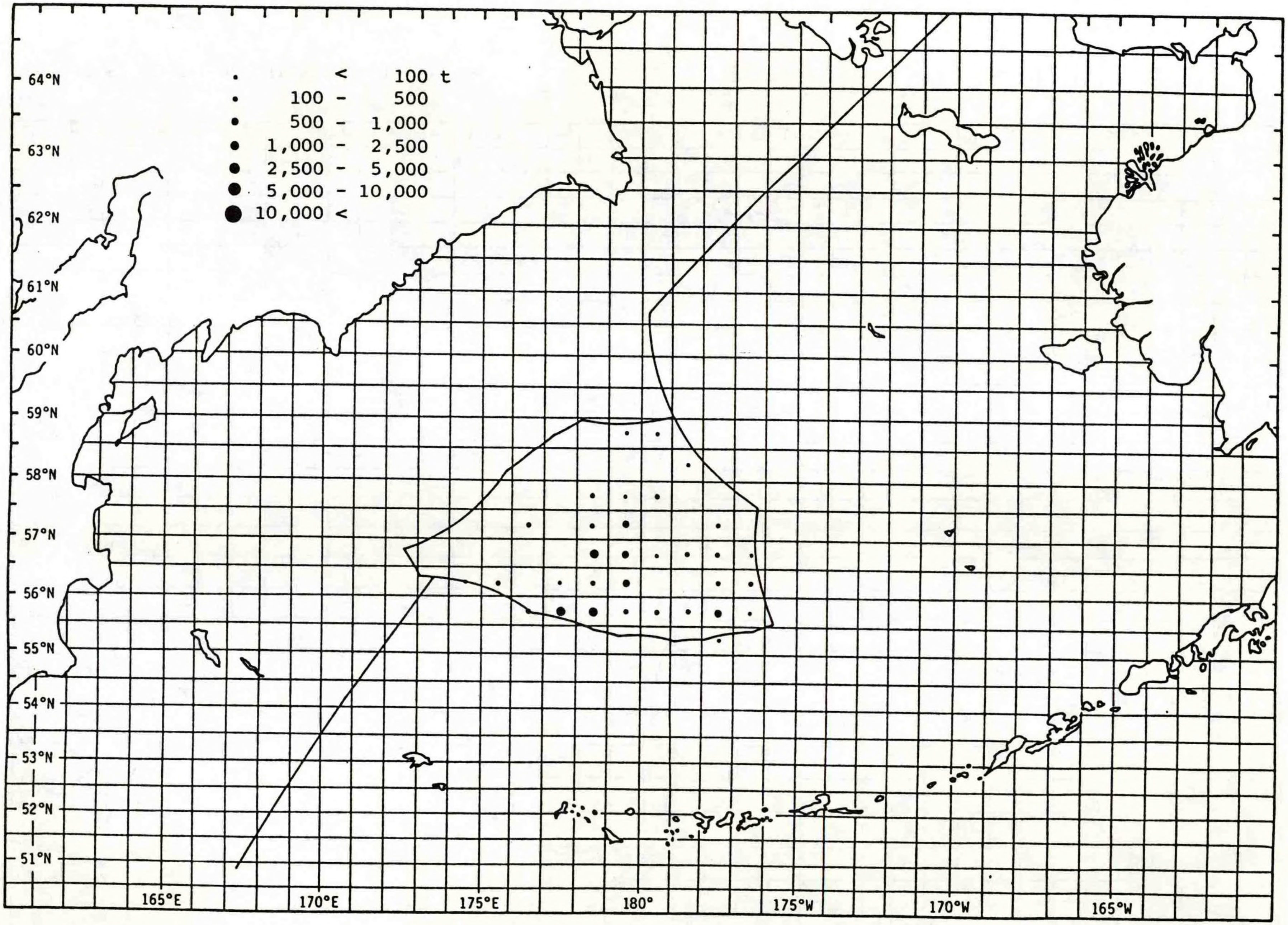


Fig. 13-6. Continued (March 1987).

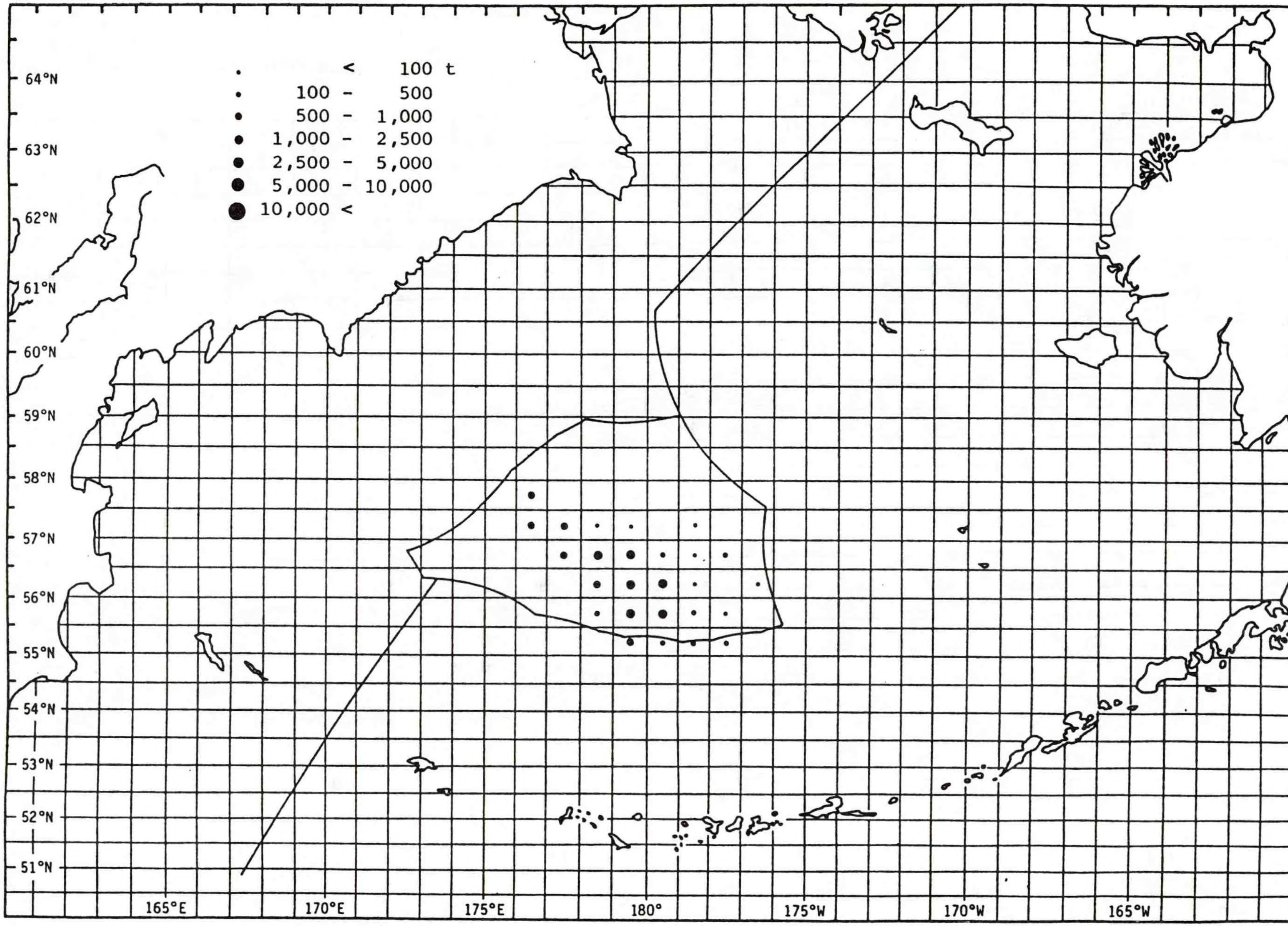


Fig. 13-7. Continued (April 1987).

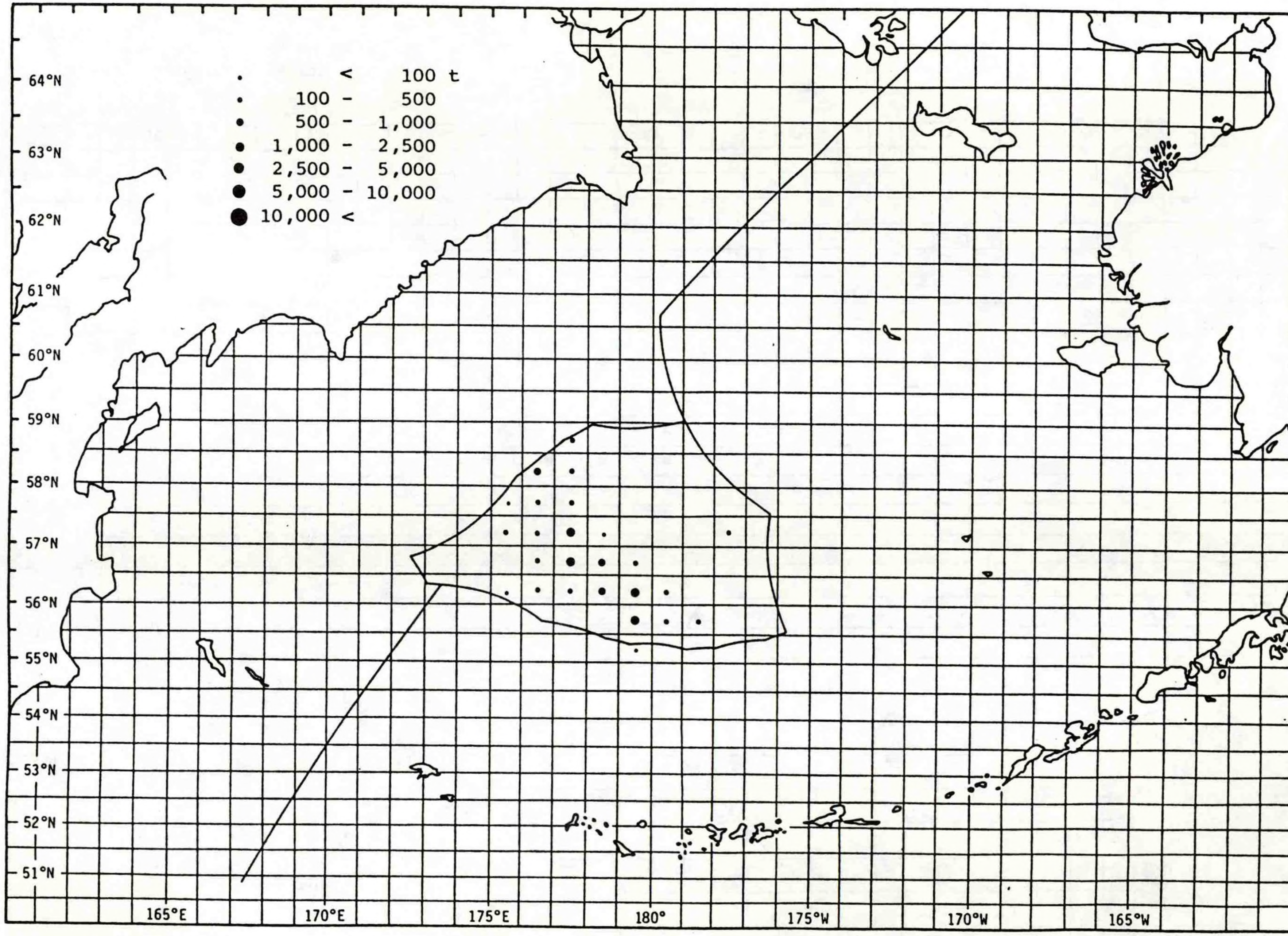


Fig. 13-8. Continued (May 1987).

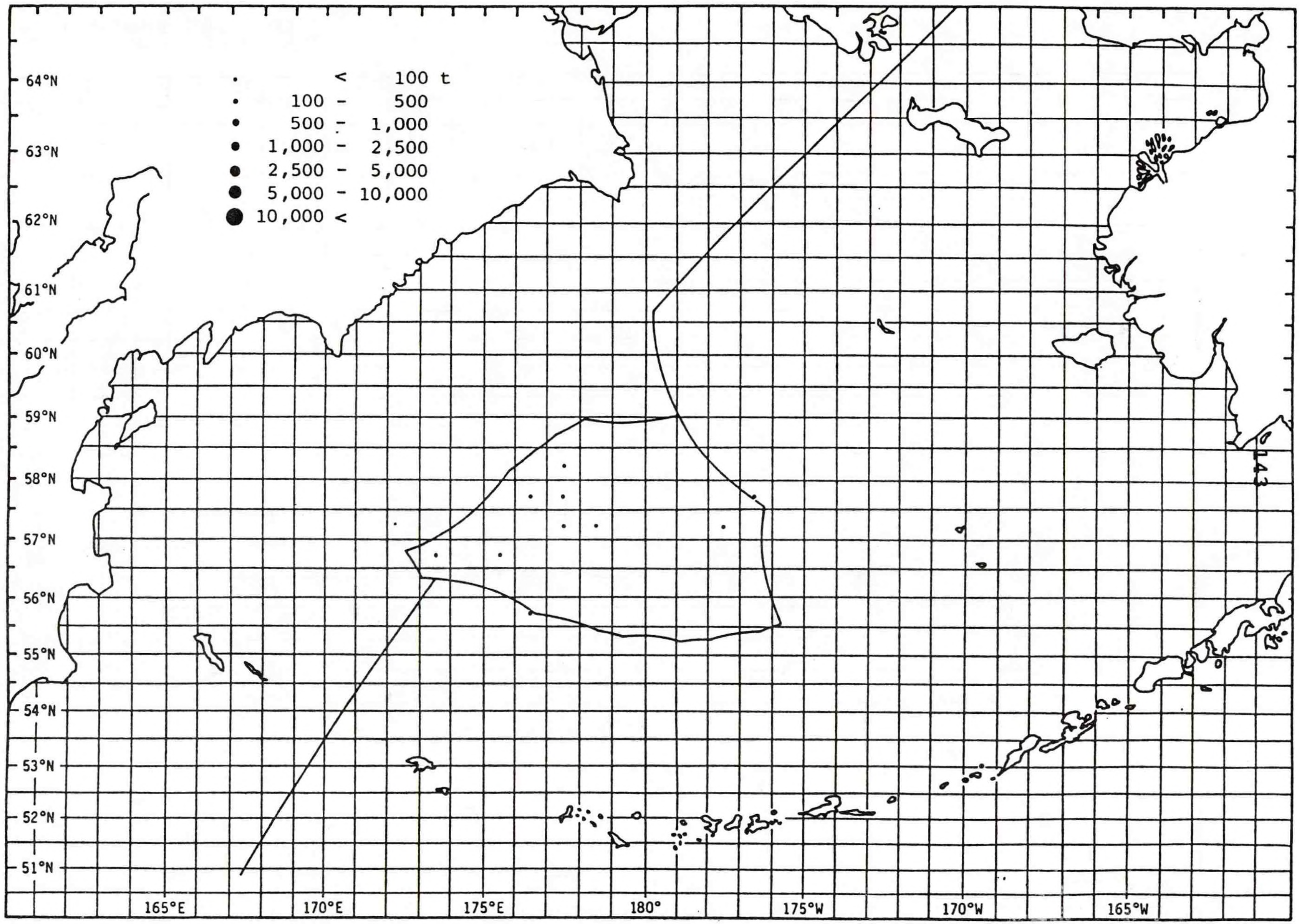


Fig. 13-9. Continued (June 1987).

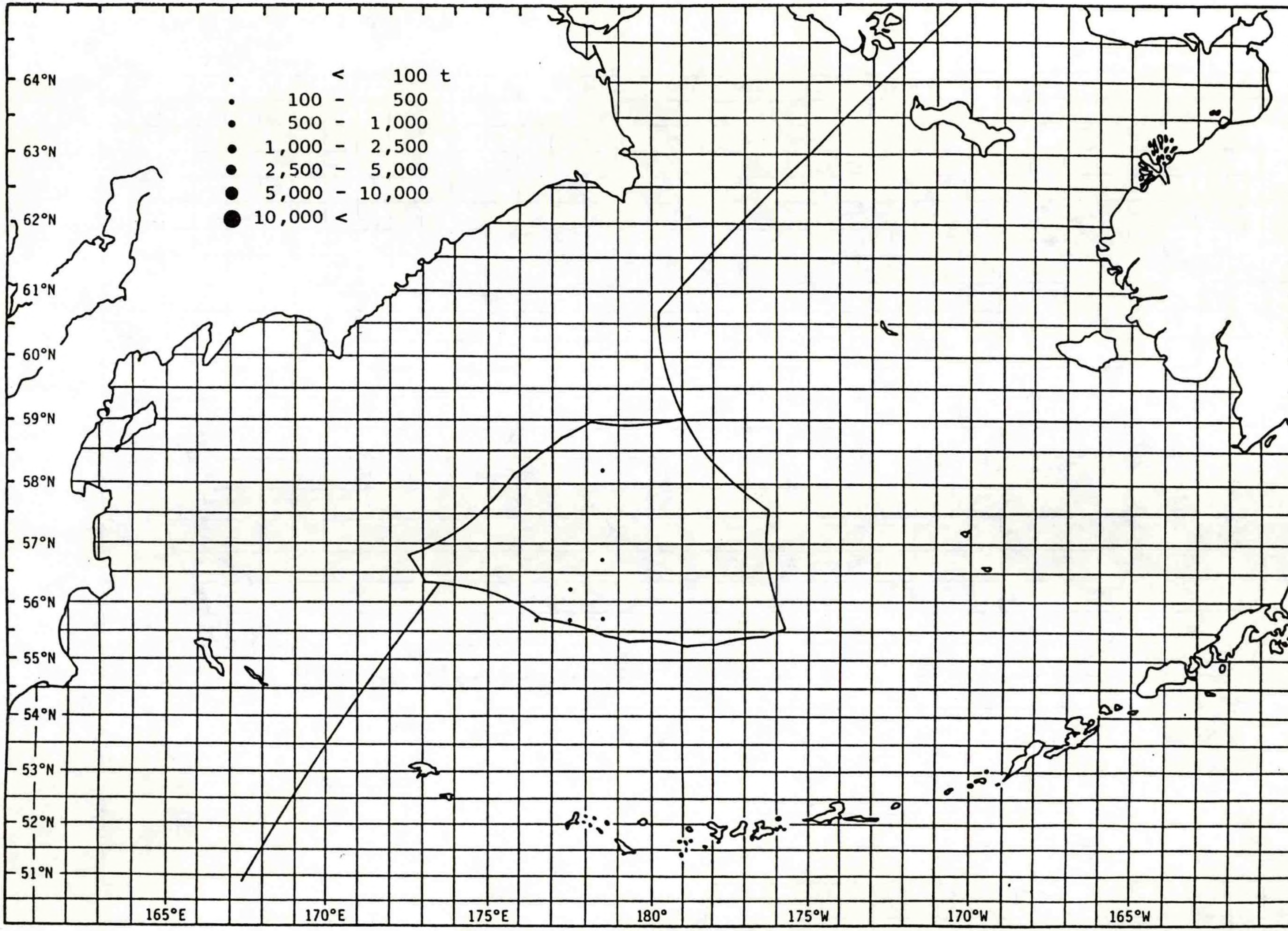


Fig. 13-10. Continued (July 1987).

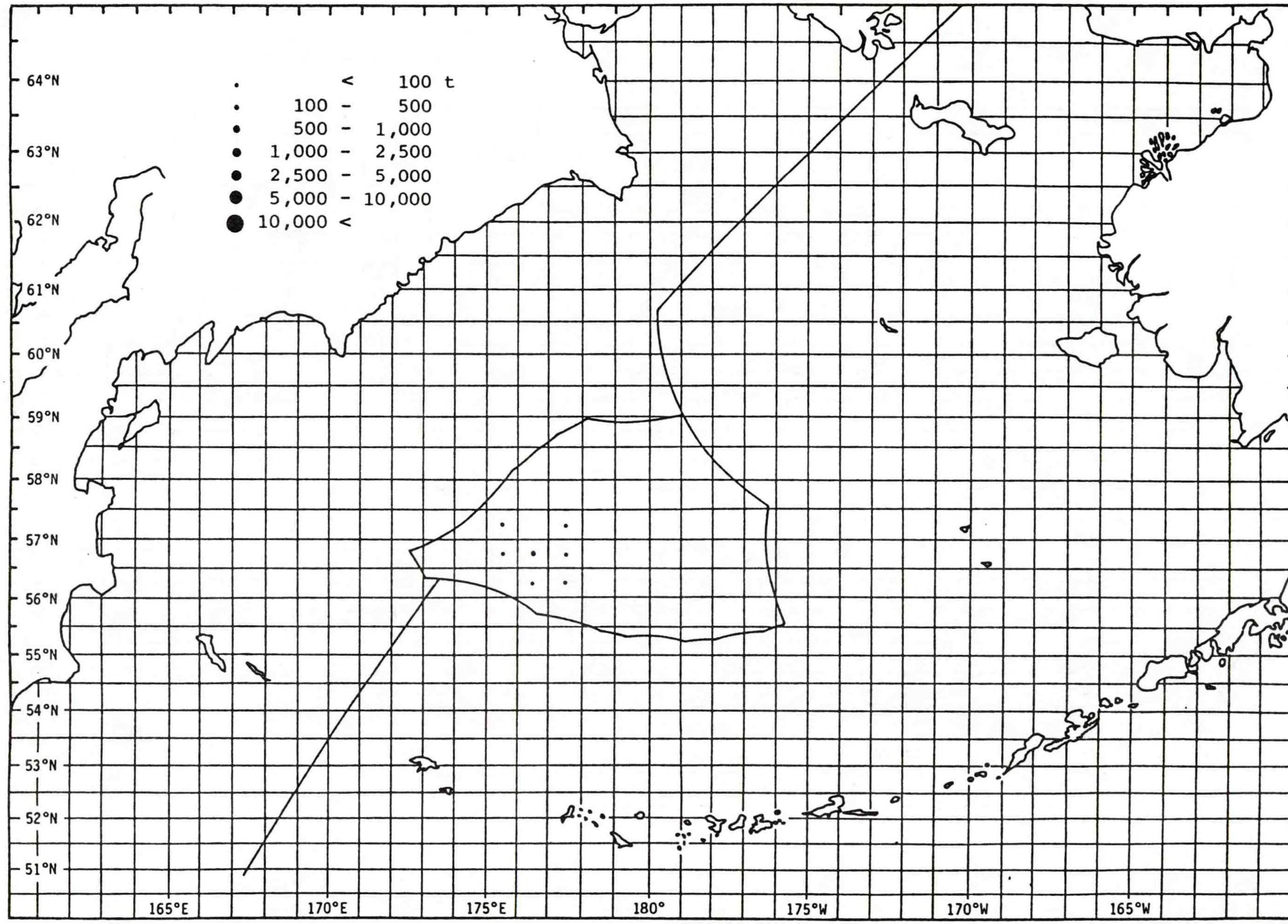
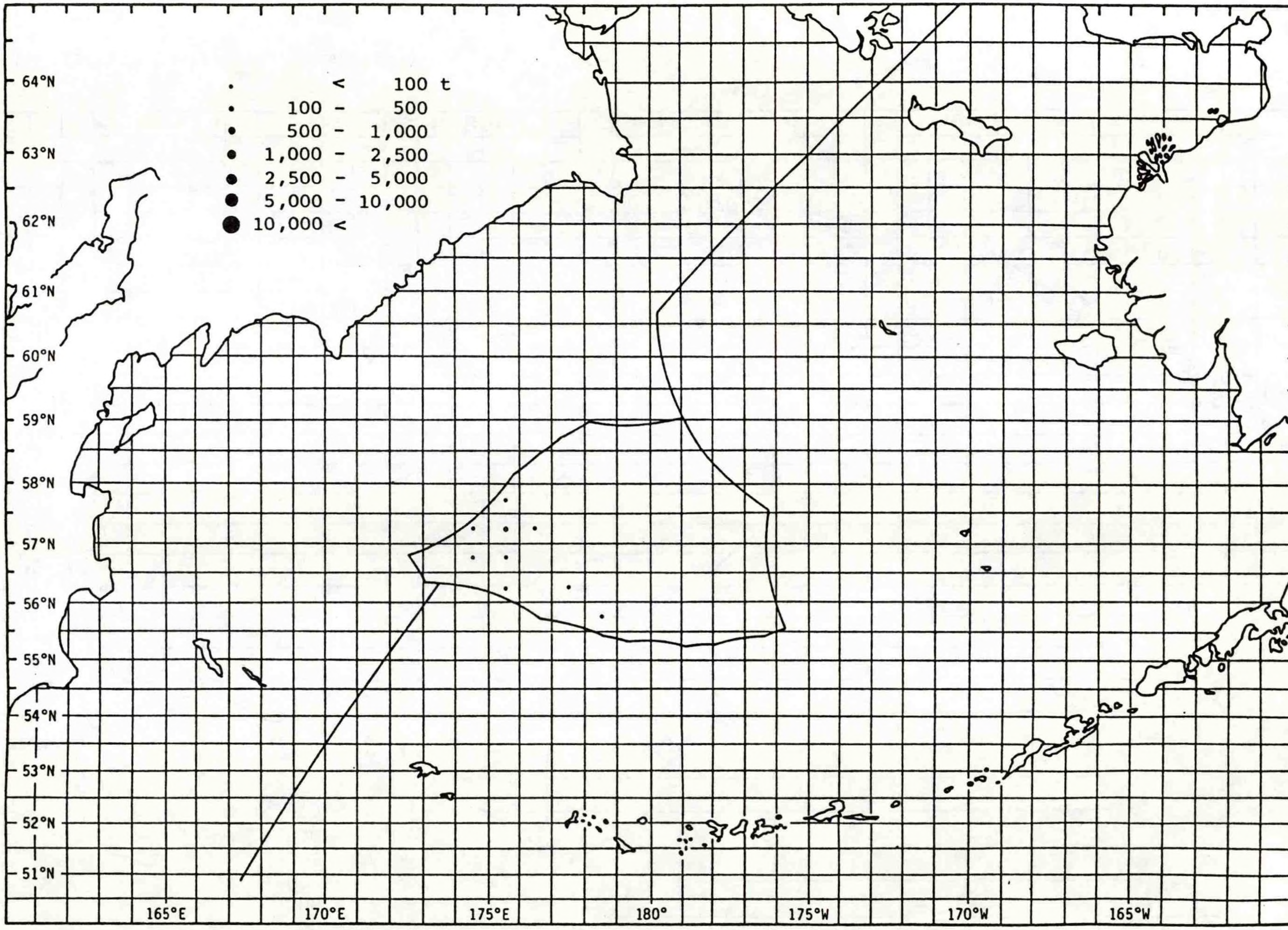


Fig. 13-11. Continued (August 1987).



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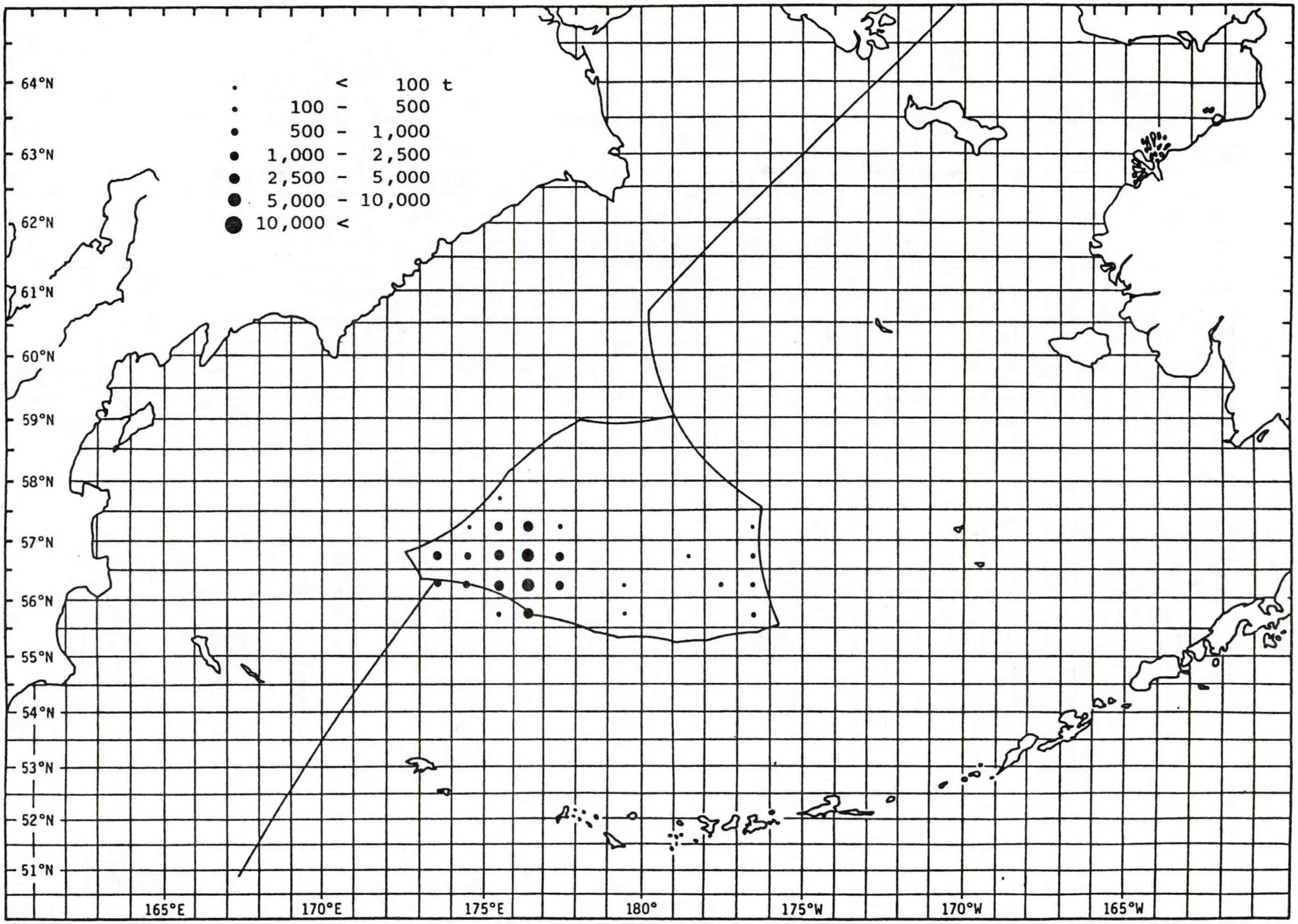

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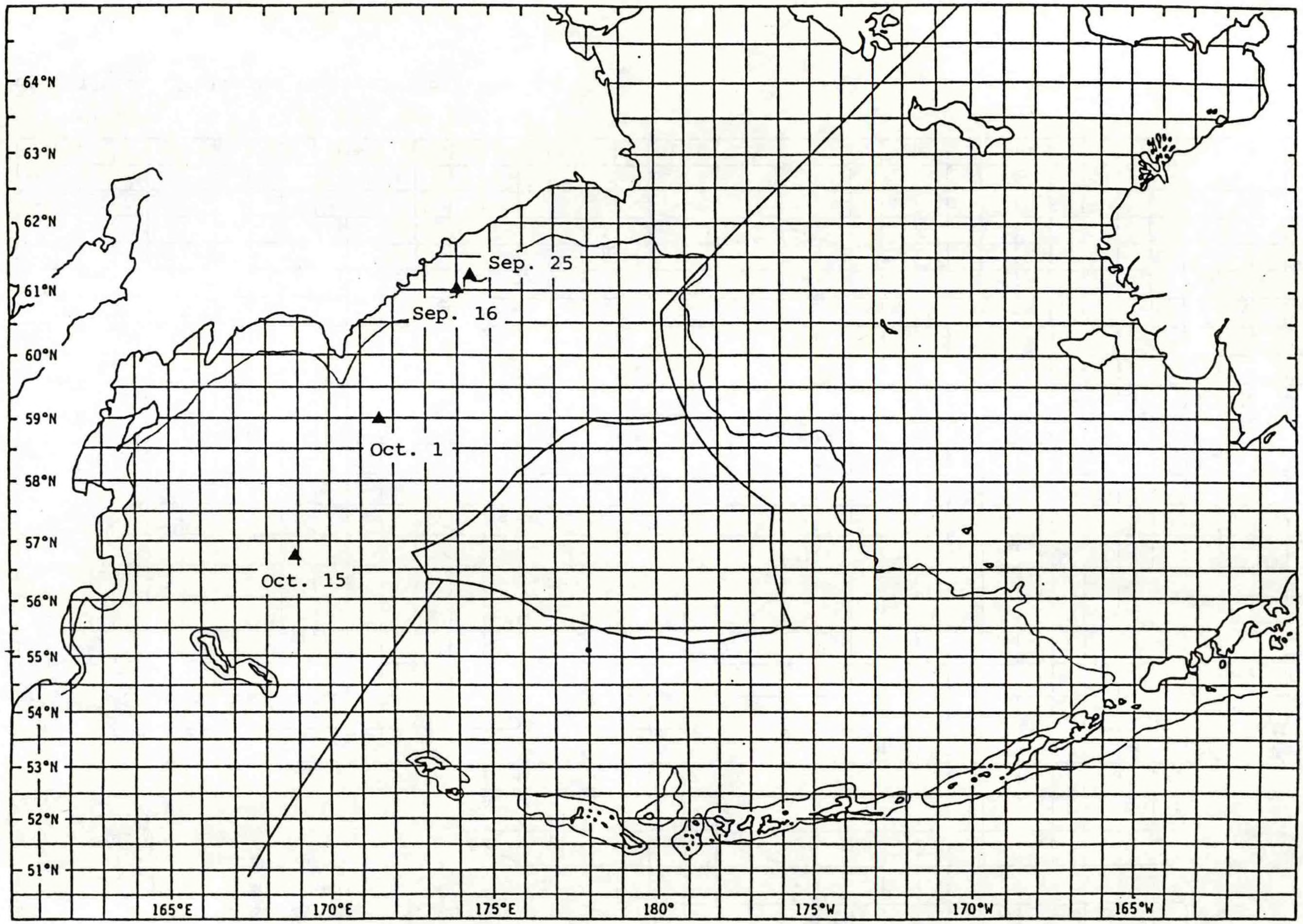
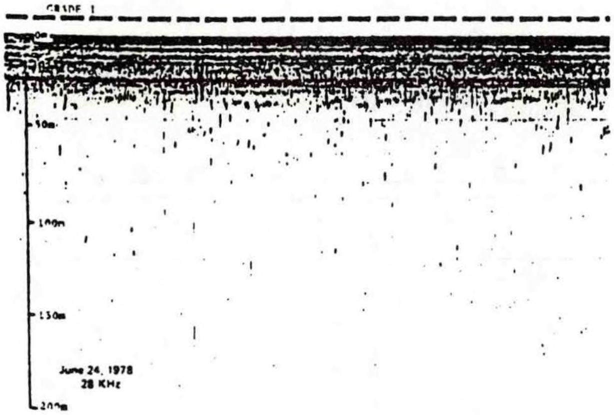
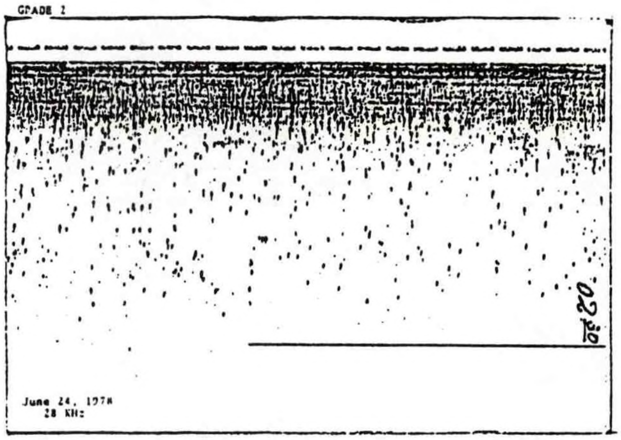


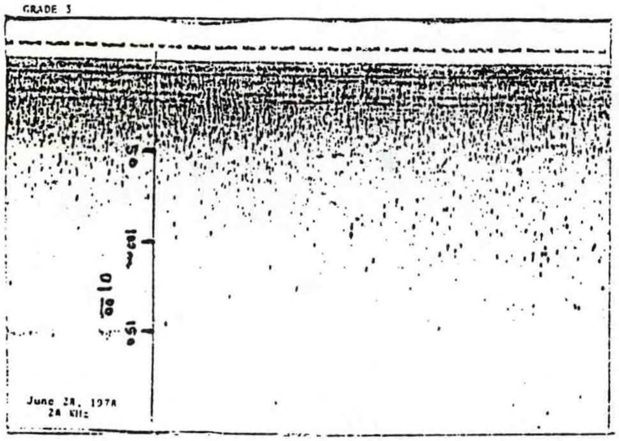
Fig. 14. Sampling positions of pollock from the western Bering Sea obtained from Japan-U.S.S.R. joint venture fishery in 1987.



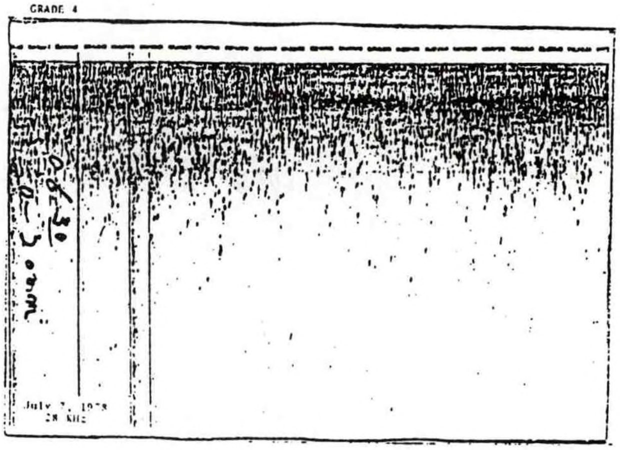
Grade 1



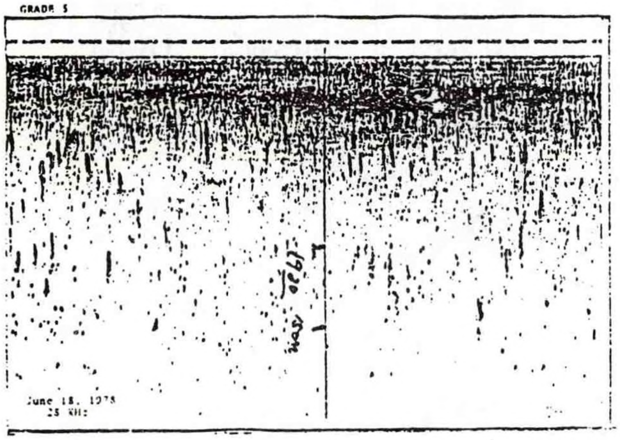
Grade 2.



Grade 3.



Grade 4.



Grade 5.

Fig. 15. Spotted echo observed during Japanese acoustic survey of pelagic pollock in the Aleutian Basin in the summer of 1978 (Okada, 1985).

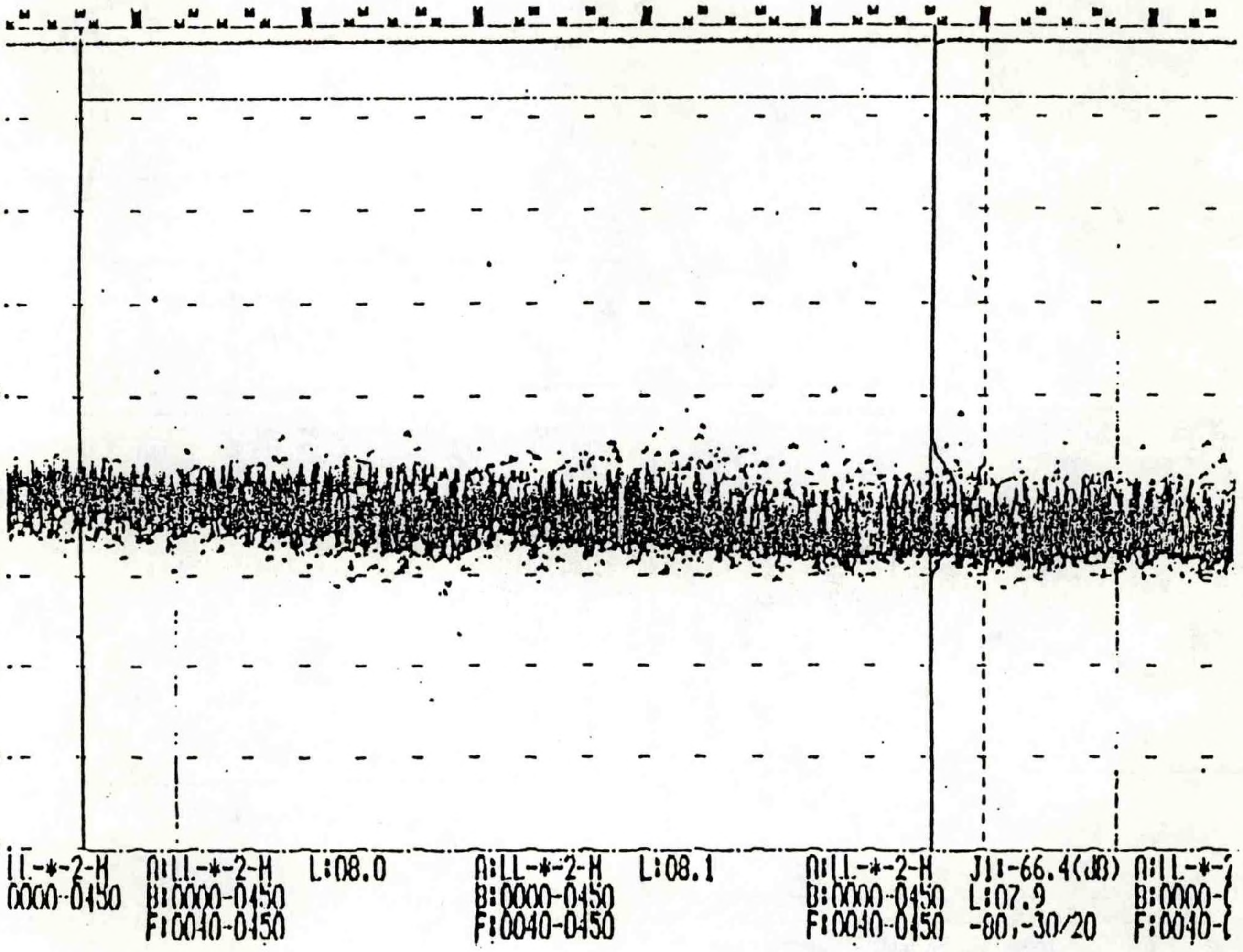


Fig. 16. Belt shape echo observed during Japanese acoustic survey of pelagic pollock in the Aleutian Basin in the winter of 1983 (Fisheries Agency of Japan, 1984).

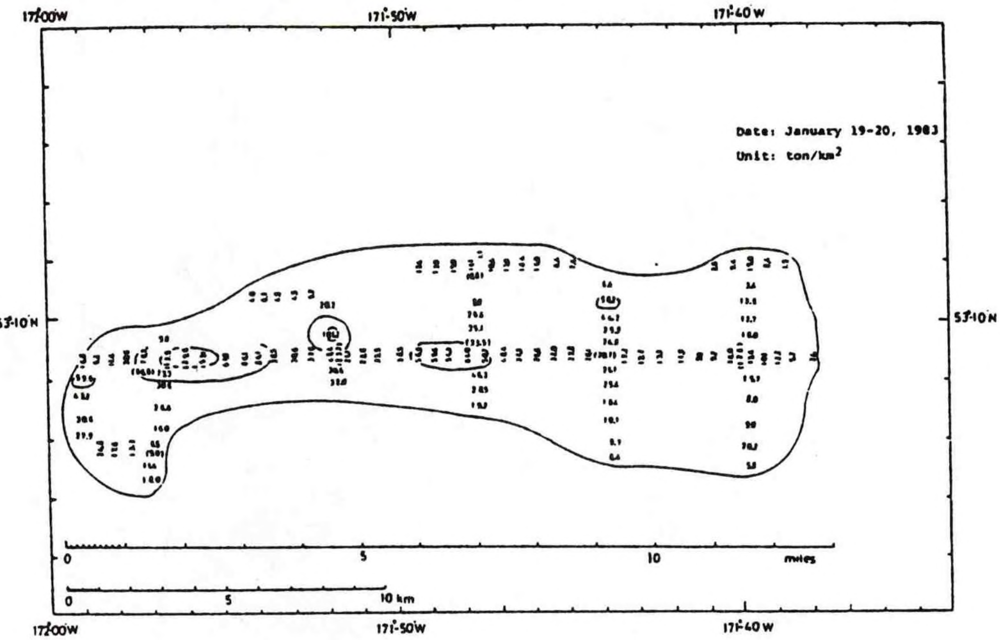


Fig. 17. Horizontal density distribution of pelagic pollock showing patch shape echo observed during Japanese acoustic survey in the Aleutian Basin in the winter of 1983 (Fisheries Agency of Japan, 1984).

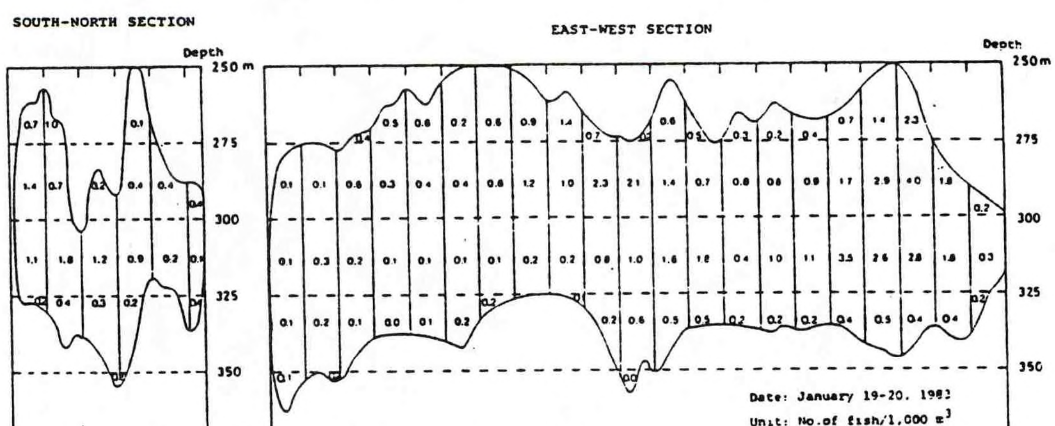


Fig. 18. Vertical density distribution of pelagic pollock showing patch shape echo observed during Japanese acoustic survey in the Aleutian Basin in the winter of 1983 (Fisheries Agency of Japan, 1983).

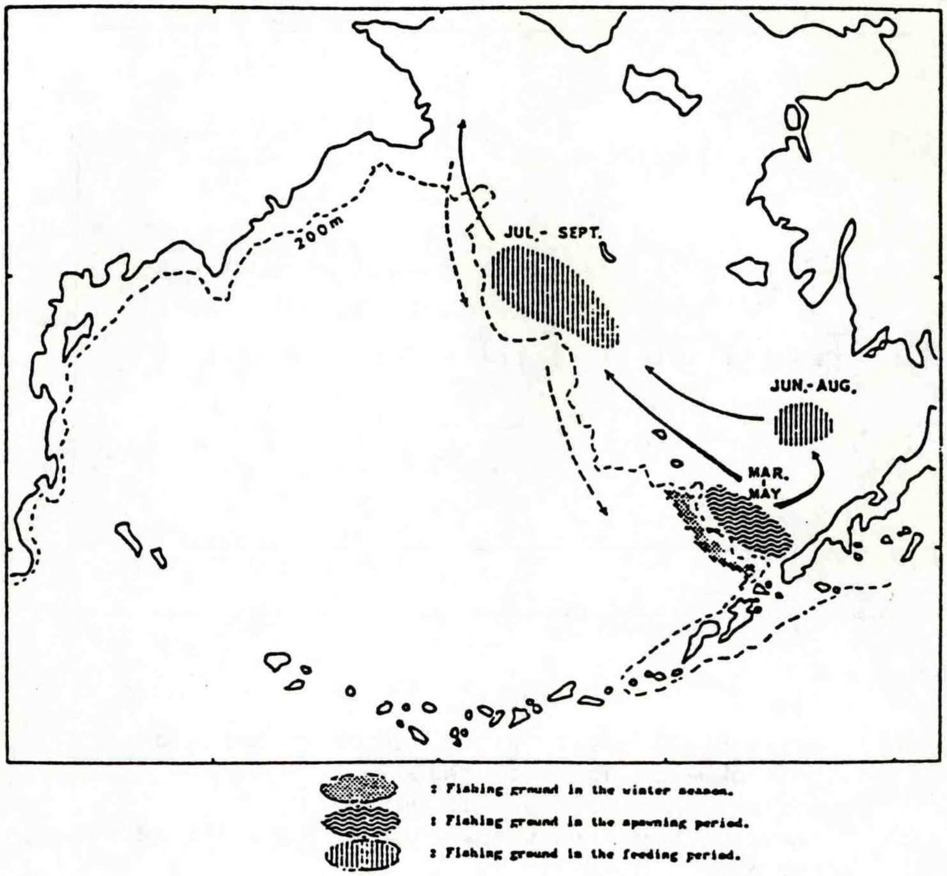


Fig. 19. Estimated seasonal migration and the fishing grounds of pollock in the eastern Bering Sea (Takahashi and Yamaguchi, 1972).

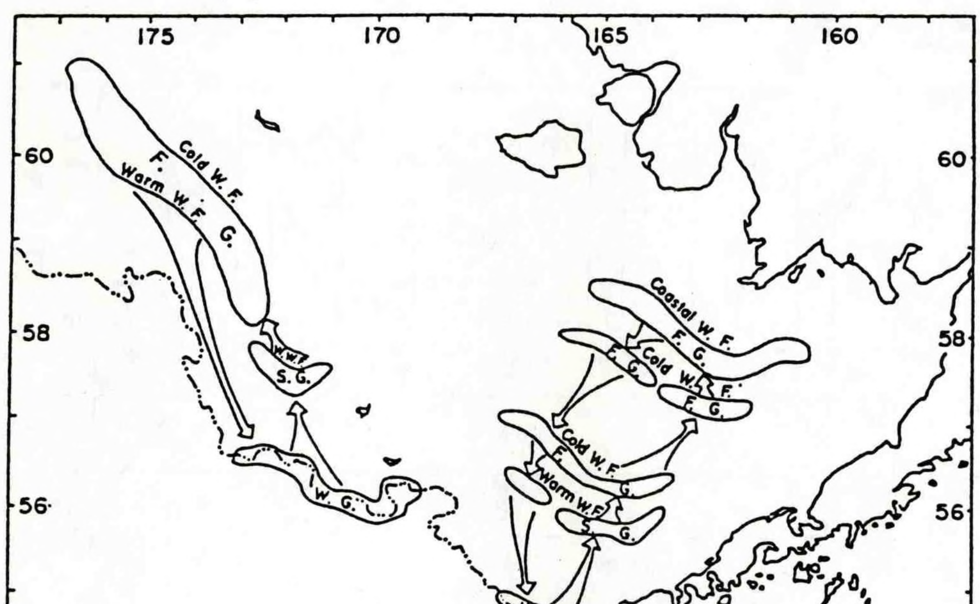


Fig. 20. Migration of mature pollock in the eastern Bering Sea (Maeda, 1972). W.G. : Wintering grounds
S.G. : Spawning grounds
F.G. : Feeding grounds
W.F. : Water front

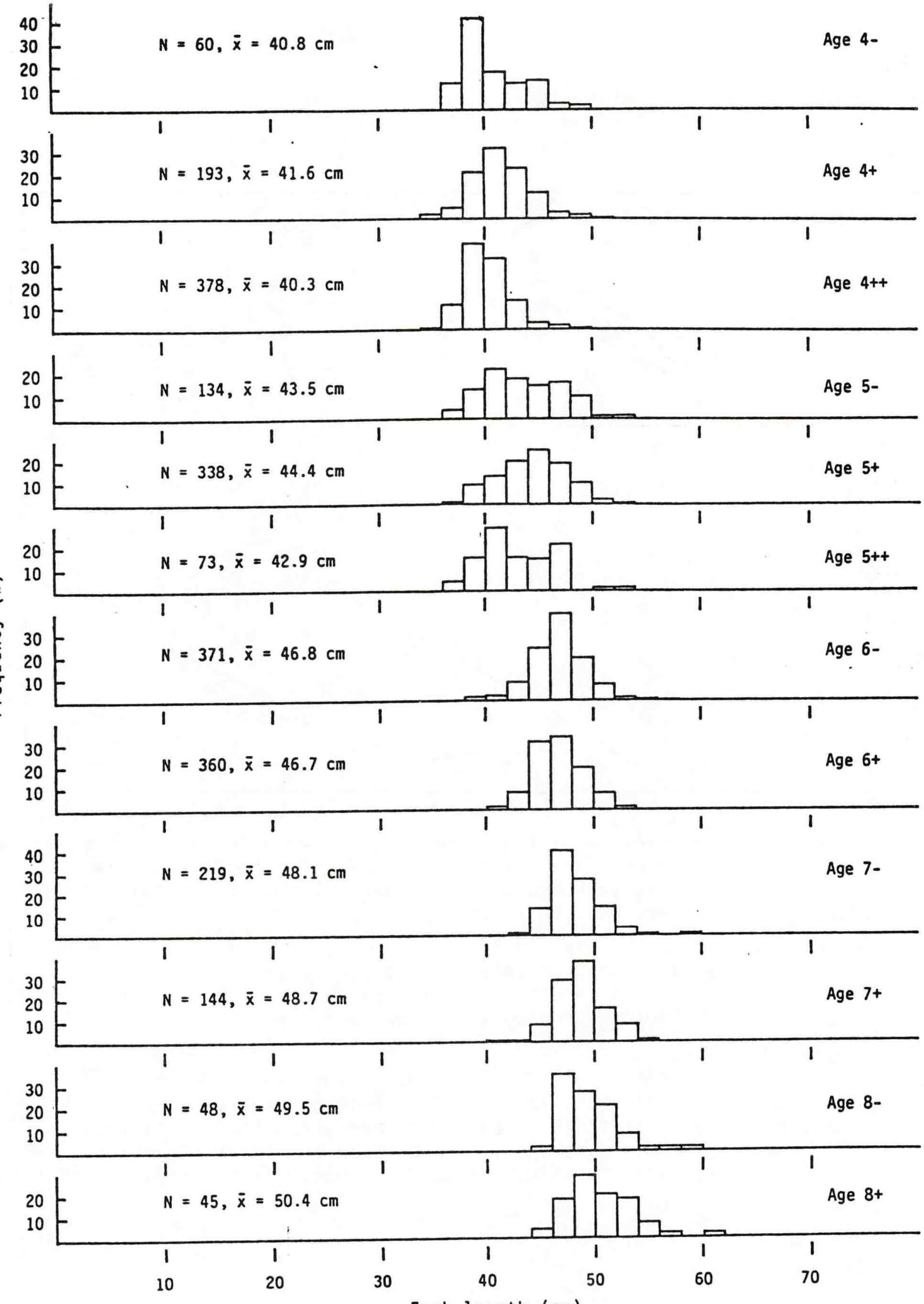


Fig. 21. Size composition at age of pelagic pollock in the Aleutian Basin in the winter of 1983 (Sasaki and Yoshimura, 1988).

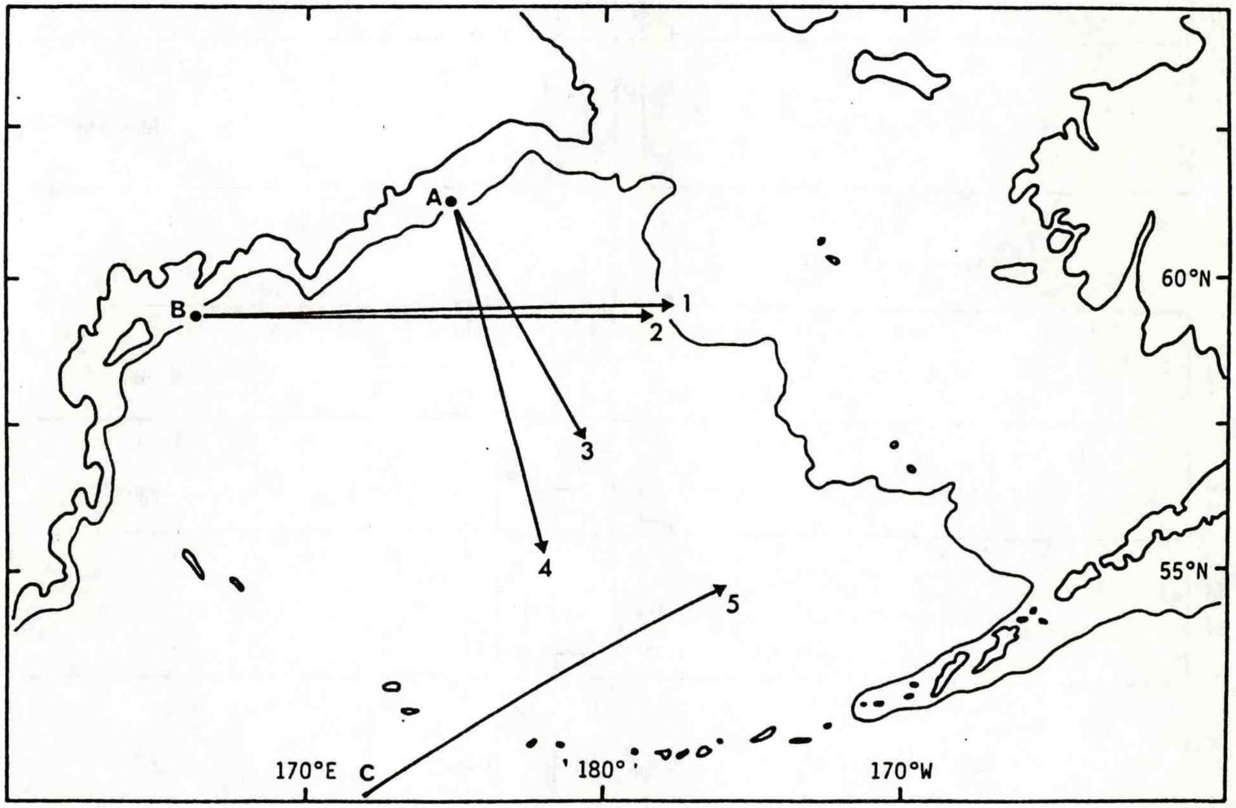


Fig. 22. Locations of recoveries of tagged pollock released in the western Bering Sea (Hokkaido Regional Fish. Res. Lab., 1974; Far Seas Fish. Res. Lab., 1977; and data file in Hokkaido Regional Fish. Res. Lab., Kushiro and in Far Seas Fish. Res. Lab., Shimizu).

Release data :

A : June 26, 27, 1973; 61°18'N, 174°52'E; Handline
B : October 17, 1972; 59°18'N, 166°20'E; Handline
C : April 27, 1979; 42°48'N, 145°05'E; Handline

Recovery data :

1 : Jan. 24, 1974; 59°30'N, 177°50'W; Bottom trawl (Japan)
2 : Apr. 15, 1975; 59°19'N, 178°26'W; Bottom trawl (Japan)
3 : Jul. 19, 1977; 57°15'N, 179°10'E; Surface driftnet (Japan)
4 : Feb. 10, 1981; 55°10'N, 177°55'E; Midwater trawl (Japan)
5 : Oct. 7, 1981; 54°35'N, 176°05'W; Midwater trawl (Republic of Korea)

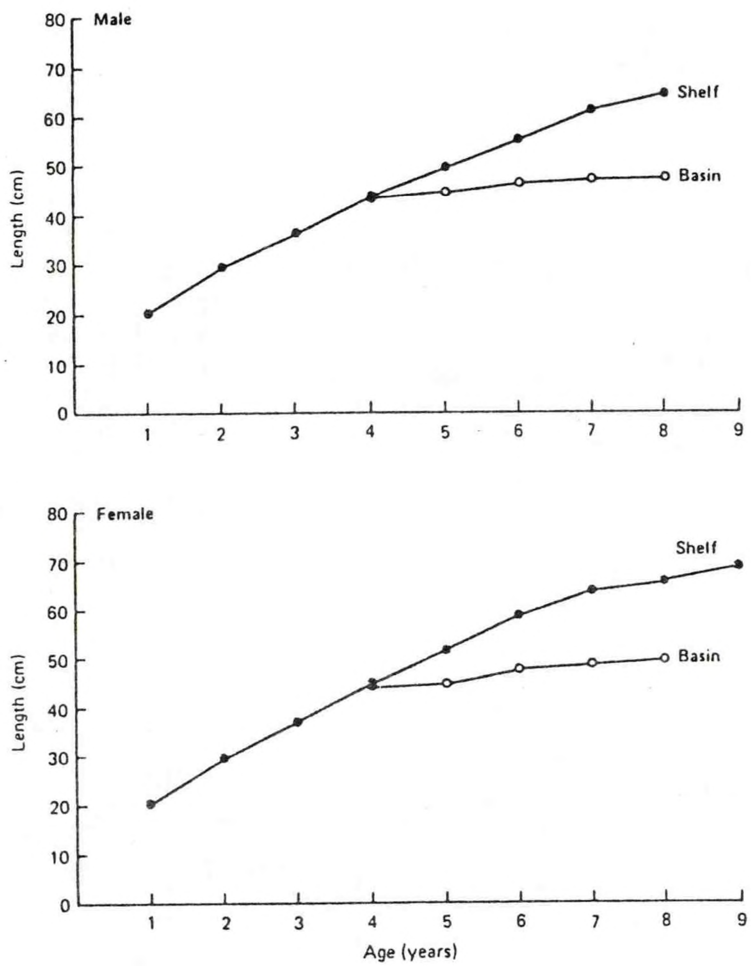


Fig. 23. Mean length at age of pollock captured by midwater trawl in the Aleutian Basin and by demersal trawls in the eastern Bering Sea in the summer of 1979 by Japanese research vessels and aged by scales (Okada and Yamaguchi, 1985).

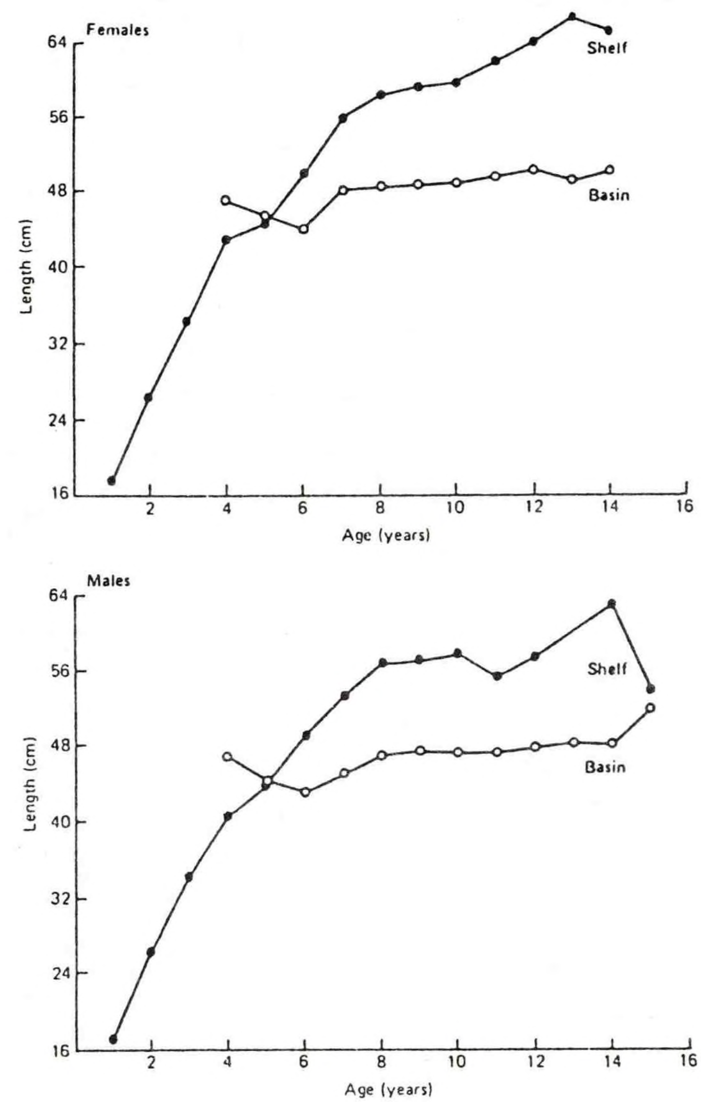


Fig. 24. Mean length at age of pollock captured by midwater trawls in the Aleutian Basin and over the continental shelf in the eastern Bering Sea during the U.S. hydroacoustic survey in the summer of 1979 and aged by otoliths (Traynor and Nelson, 1985).

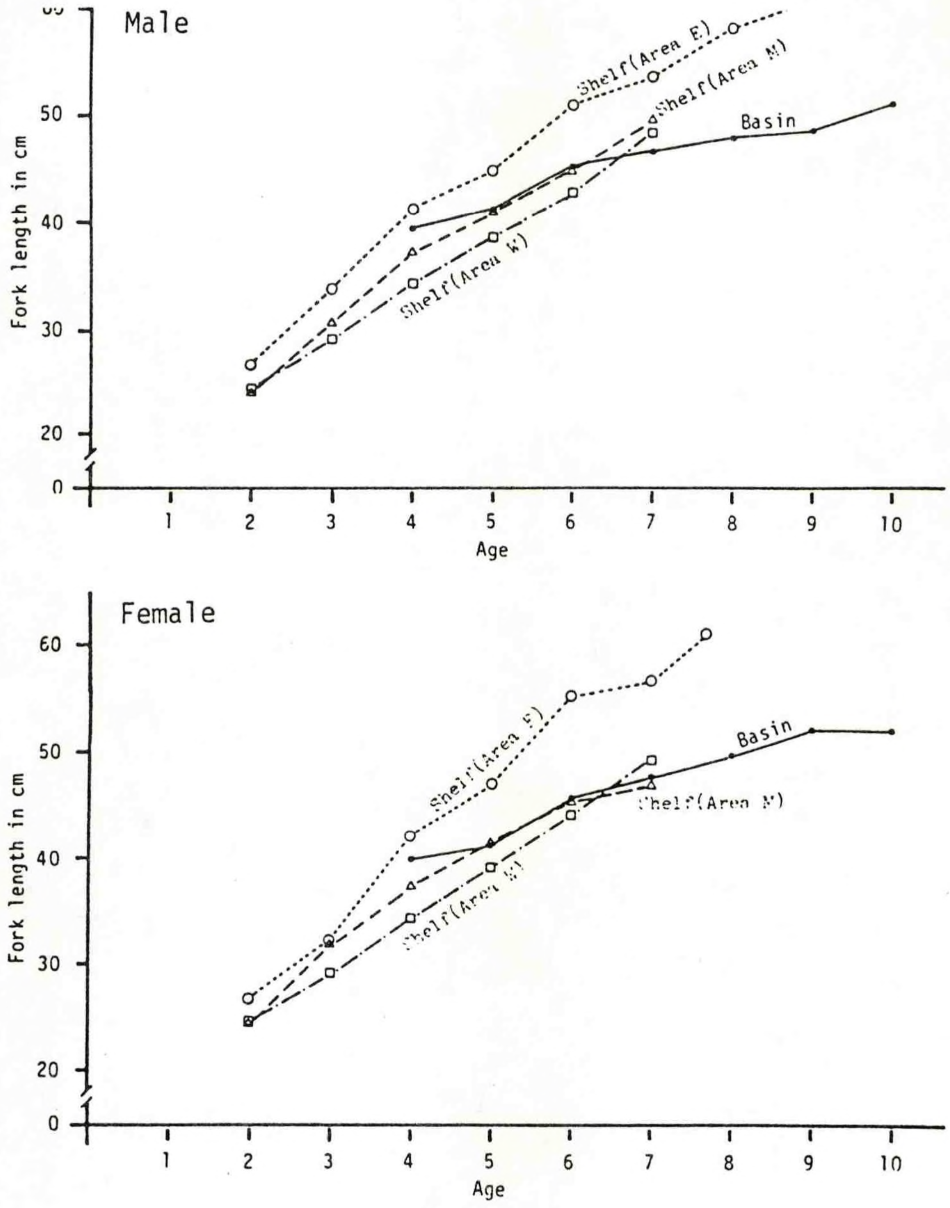


Fig. 25. Mean length at age of pelagic pollock caught in Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 and caught by bottom trawls in the continental shelf of the eastern Bering Sea in the summer (Yamaguchi, 1984).

Area E : Southeastern area
Area M : Middle area
Area W : Northwestern area

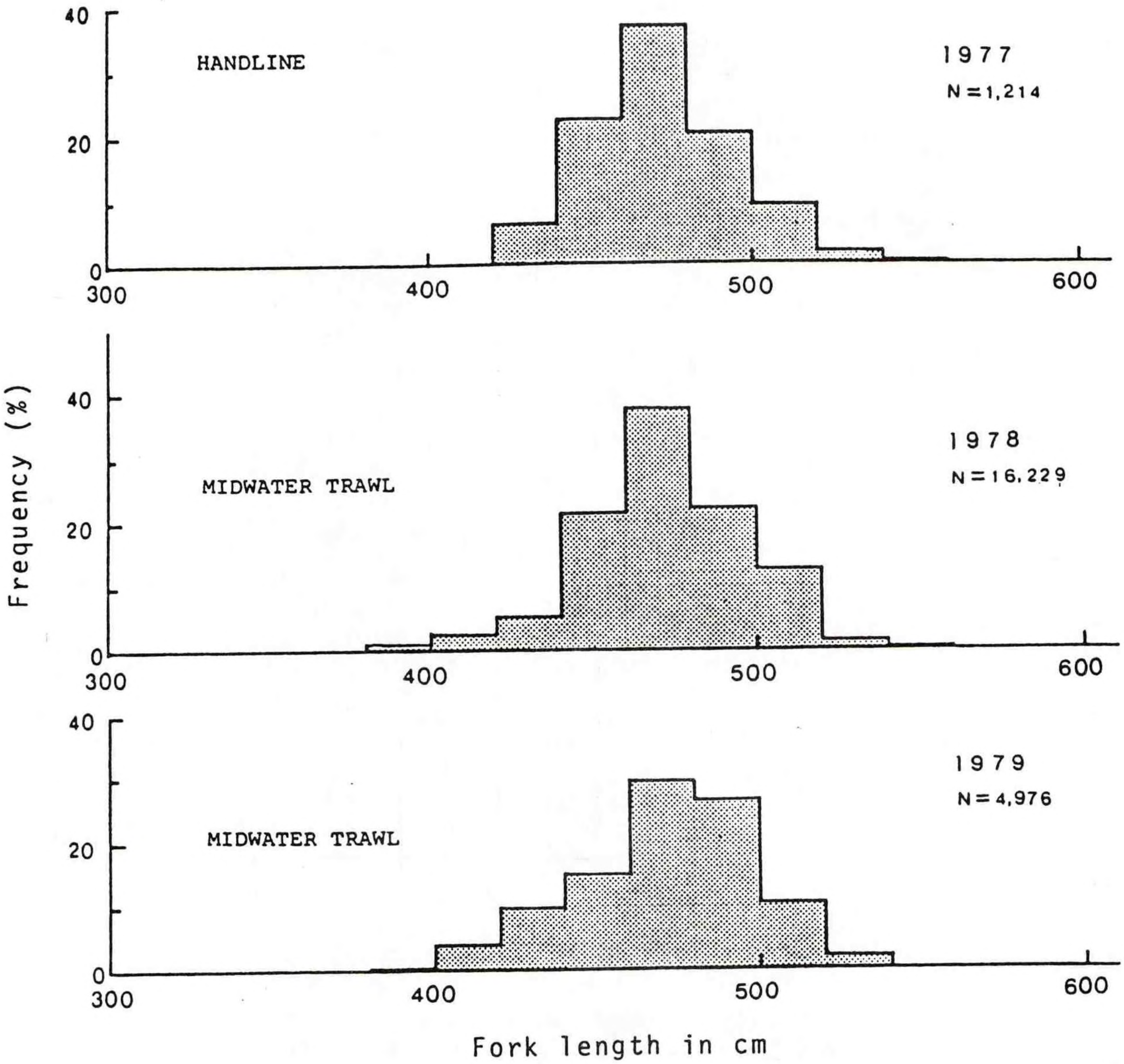


Fig. 26. Size frequency distribution of pelagic pollock from Japanese handline and midwater trawl surveys in the Aleutian Basin in the summer of 1977, 1978, and 1979 (Okada, 1986).

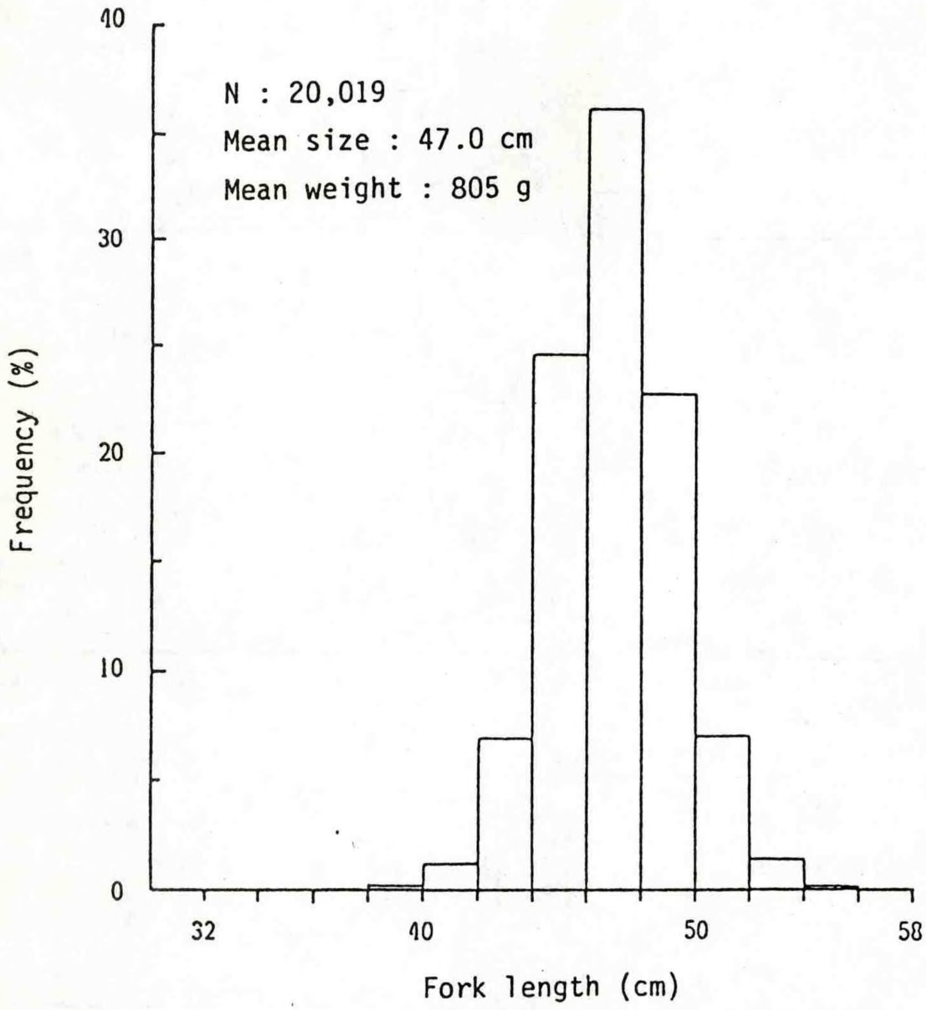


Fig. 27. Size frequency distribution of pelagic pollock from Japanese midwater tarwl survey in the international waters of the Bering Sea in the summer of 1987 (Fisheries Agency of Japan, 1988).

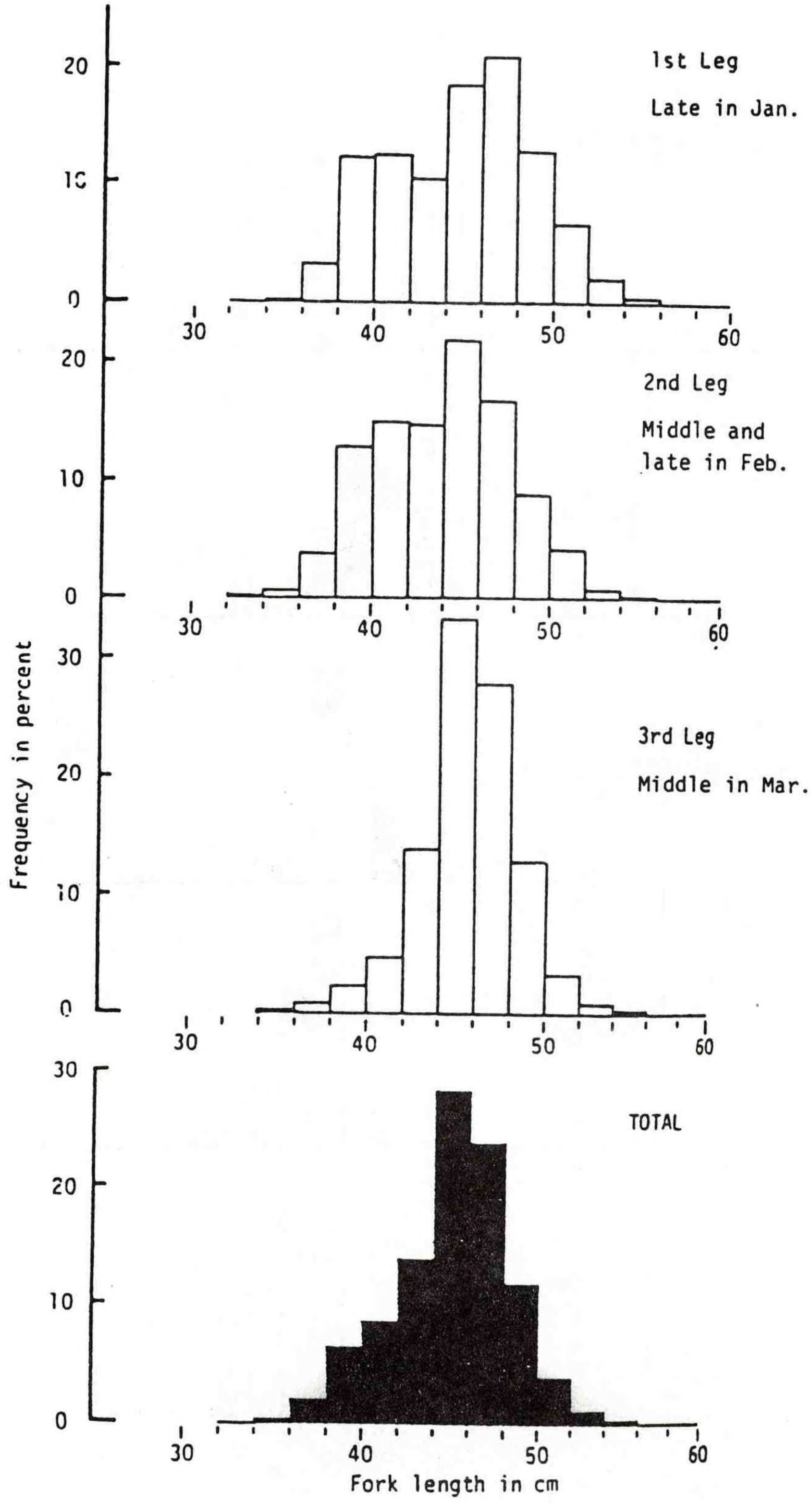


Fig. 28. Size frequency distribution of pelagic pollock from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

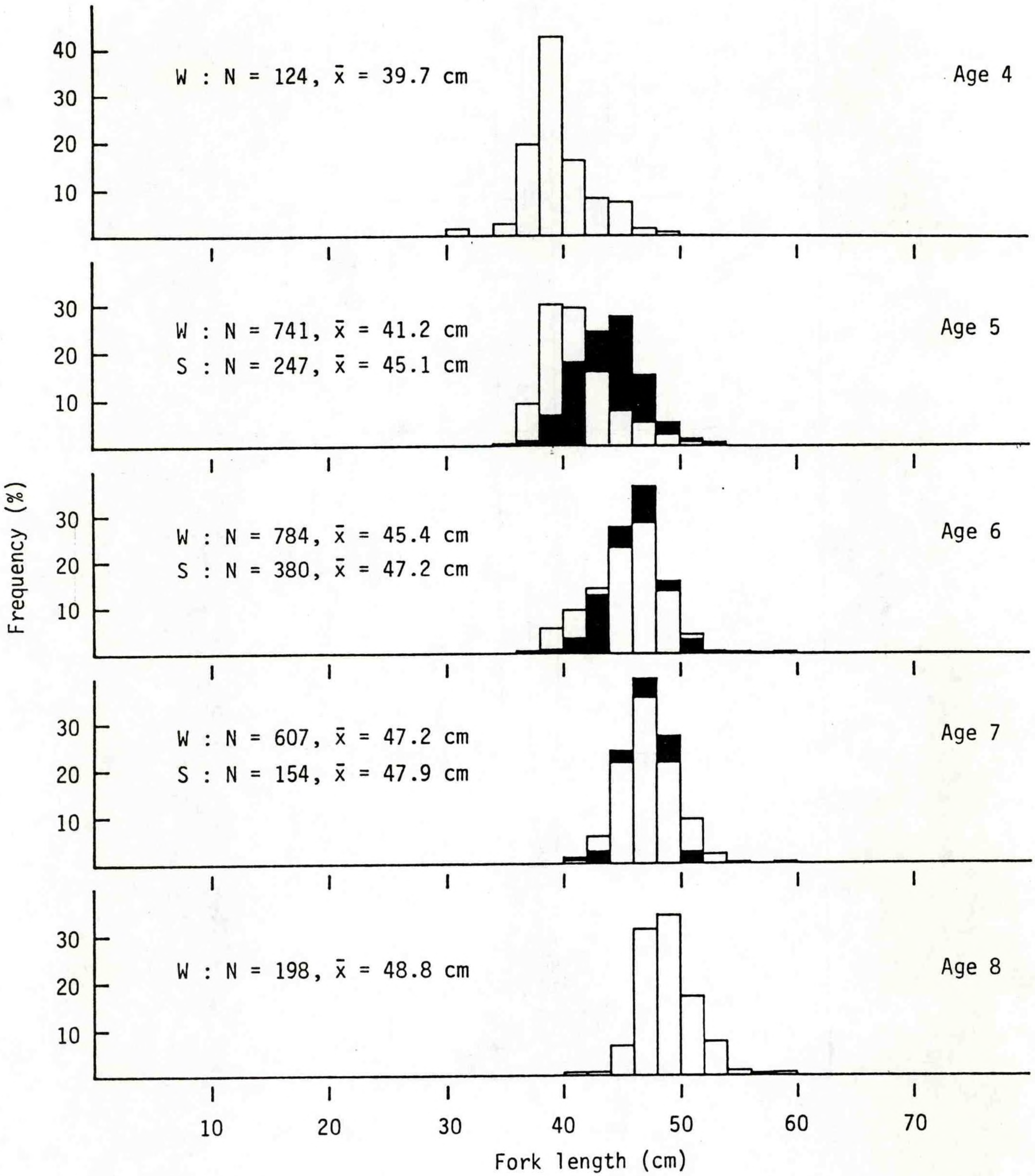


Fig. 29. Size composition at age of pelagic pollock from Japanese midwater tarwl surveys in the Aleutian Basin in the winter (Jan.-Mar.) of 1983 and the summer (Jun.) of 1979 (Sasaki and Yoshimura, 1988). Blank shows the winter (W) and black shows the summer (S).

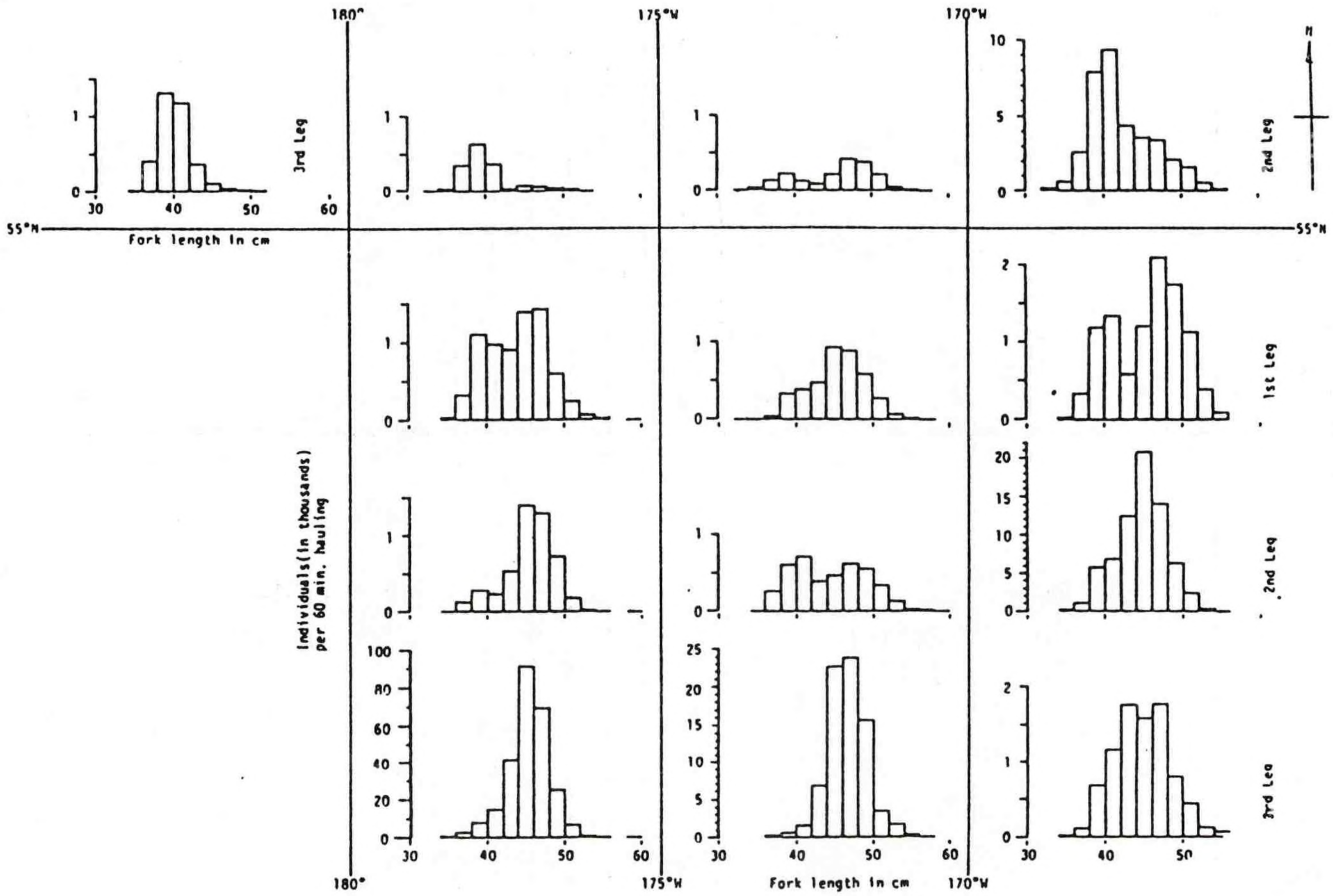


Fig. 30. Size frequency distribution of pelagic pollock by north and south of 55°N and by longitude 5 degrees from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

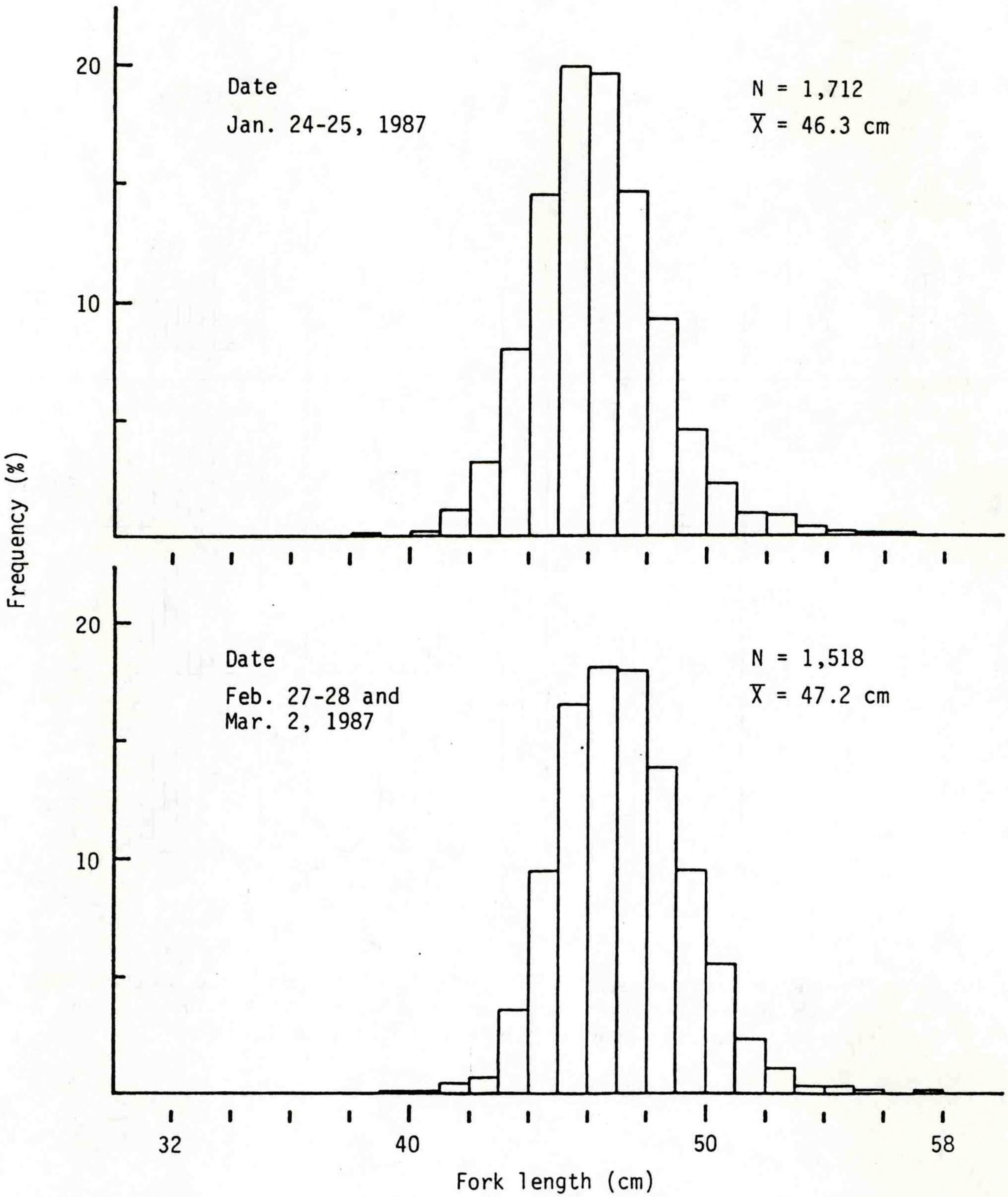


Fig. 31. Size frequency distribution of pelagic pollock caught by Japanese landbased dragnetters in the international waters of the Bering Sea in the winter of 1987 (Sasaki and Yoshimura, 1987).

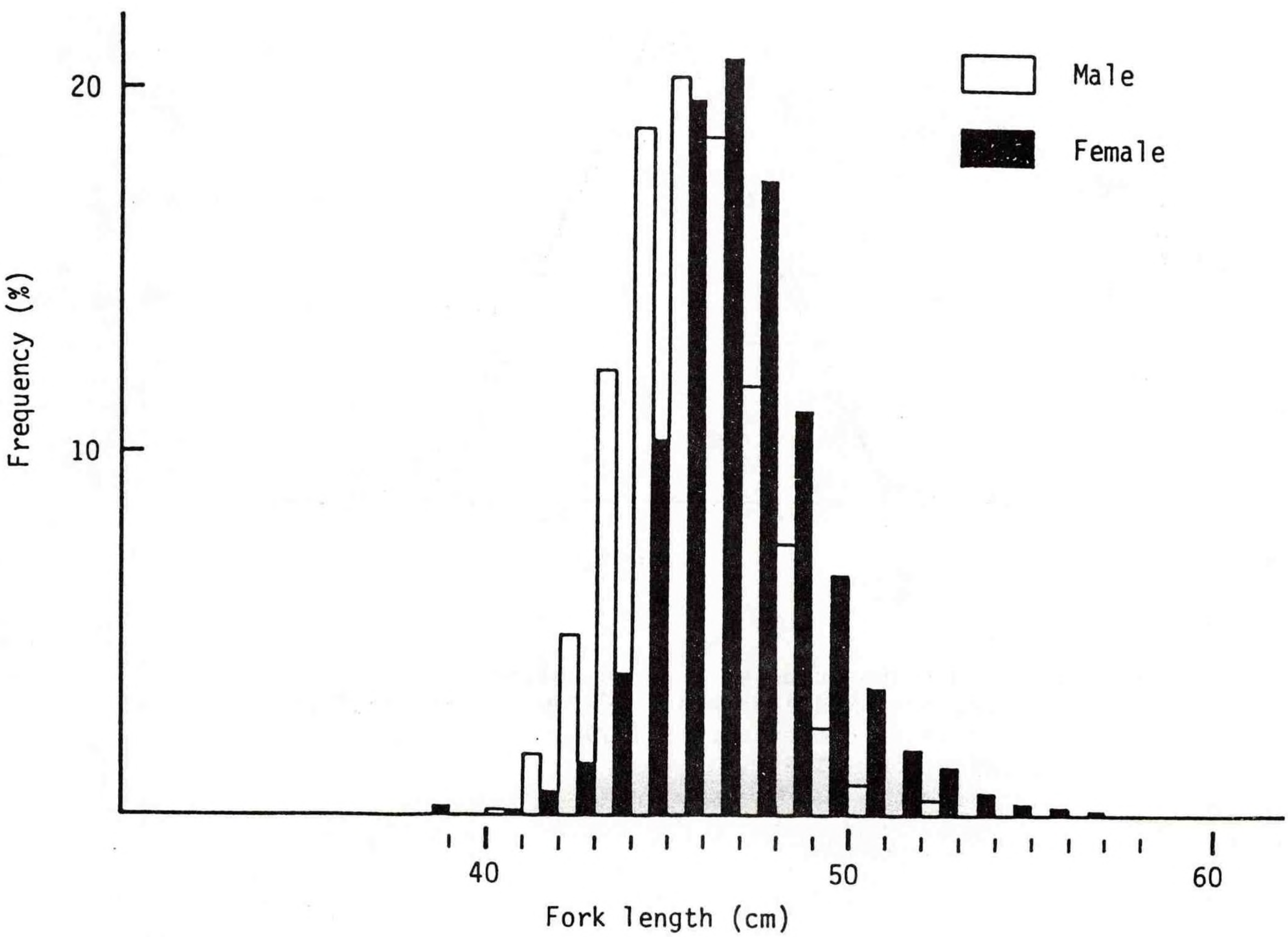


Fig. 32. Size frequency distribution of pelagic pollock by sex caught by Japanese landbased dragnetters in the international waters of the Bering Sea in the late January and the late February-early March of 1987 (Sasaki and Yoshimura, 1987).

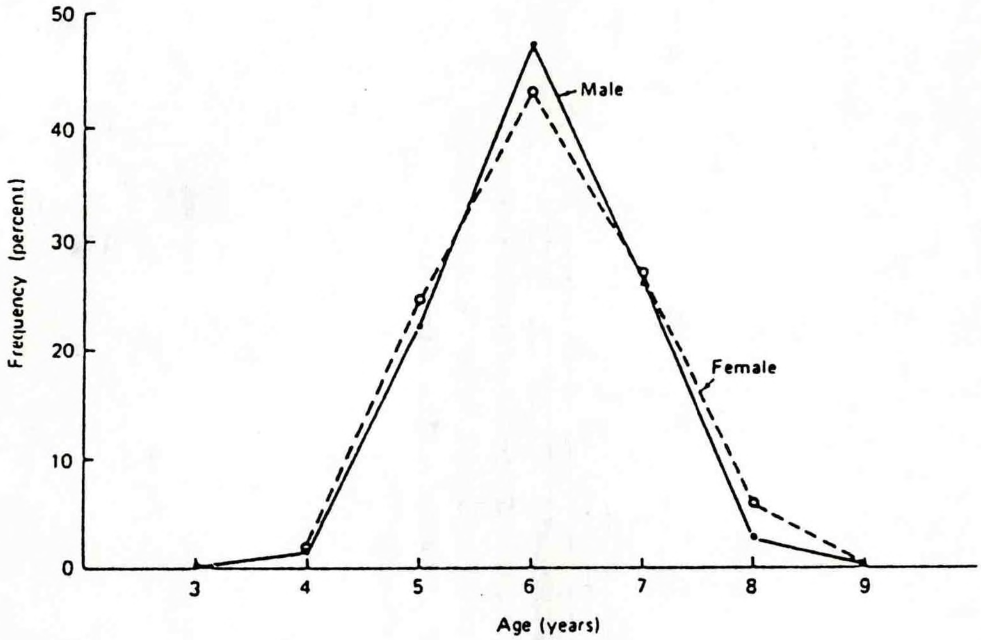


Fig. 33. Age composition of pelagic pollock by sex from Japanese midwater trawl survey in the Aleutian Basin in the summer of 1979 (Okada and Yamaguchi, 1985).

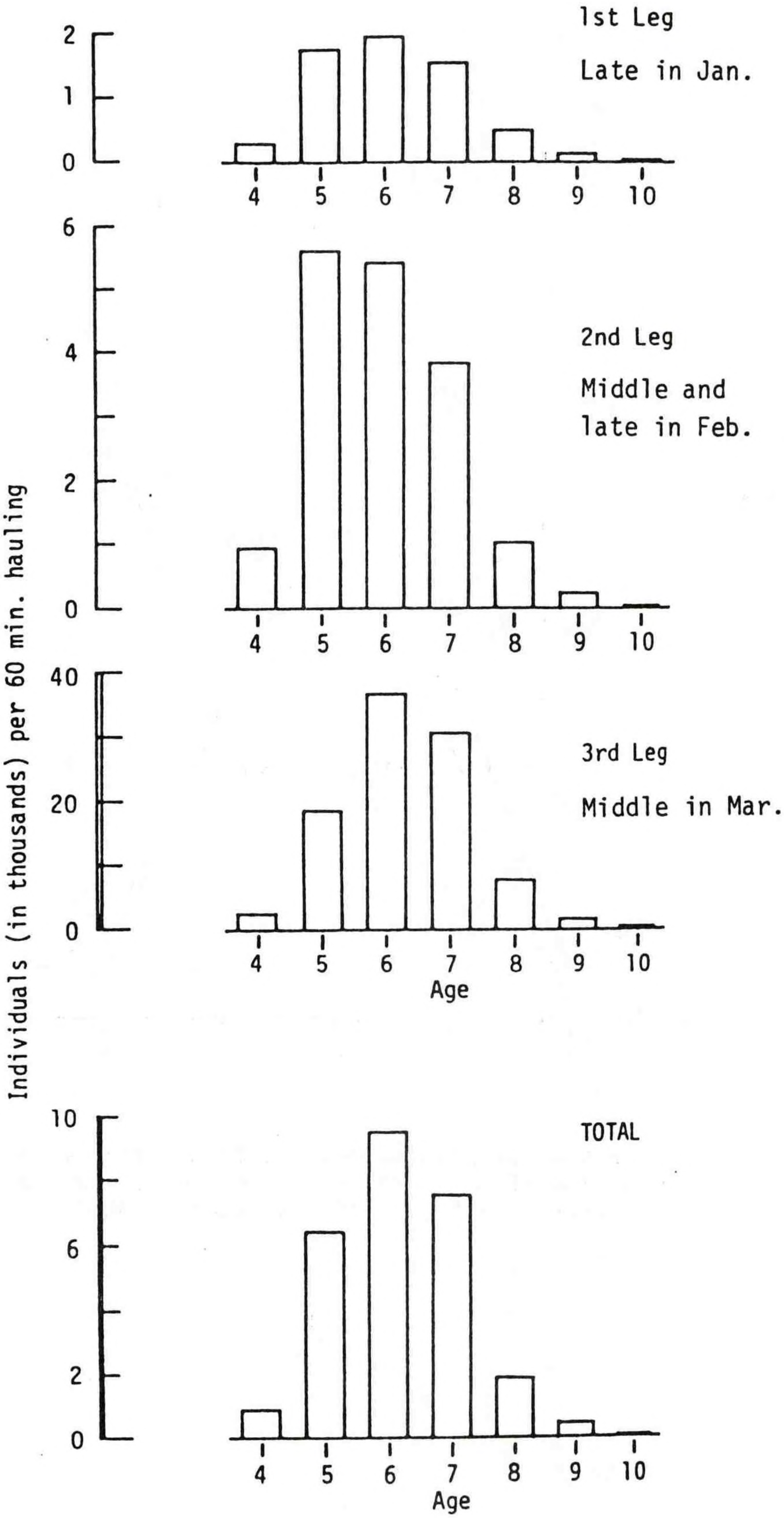


Fig. 34. Age composition of pelagic pollock from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

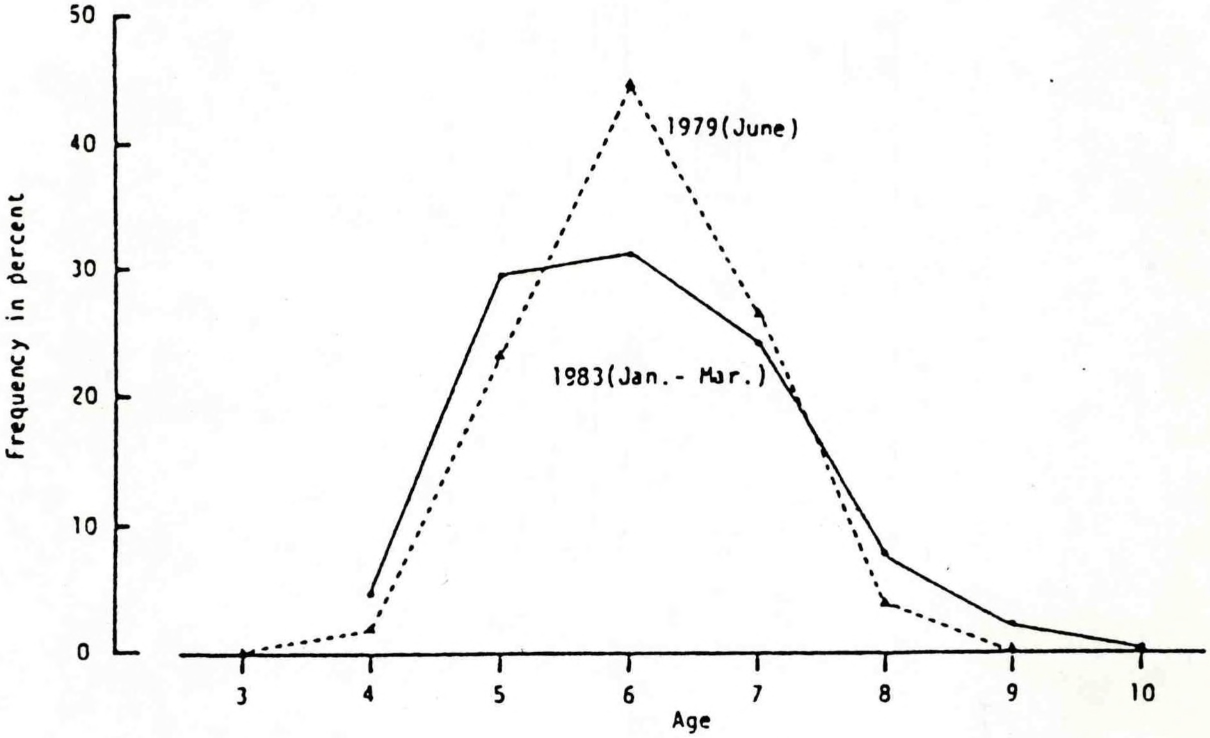


Fig. 35. Age composition of pelagic pollock from Japanese midwater trawl surveys in the Aleutian Basin in the winter (Jan.-Mar.) of 1983 and the summer (Jun.) of 1979 (Yamaguchi, 1984).

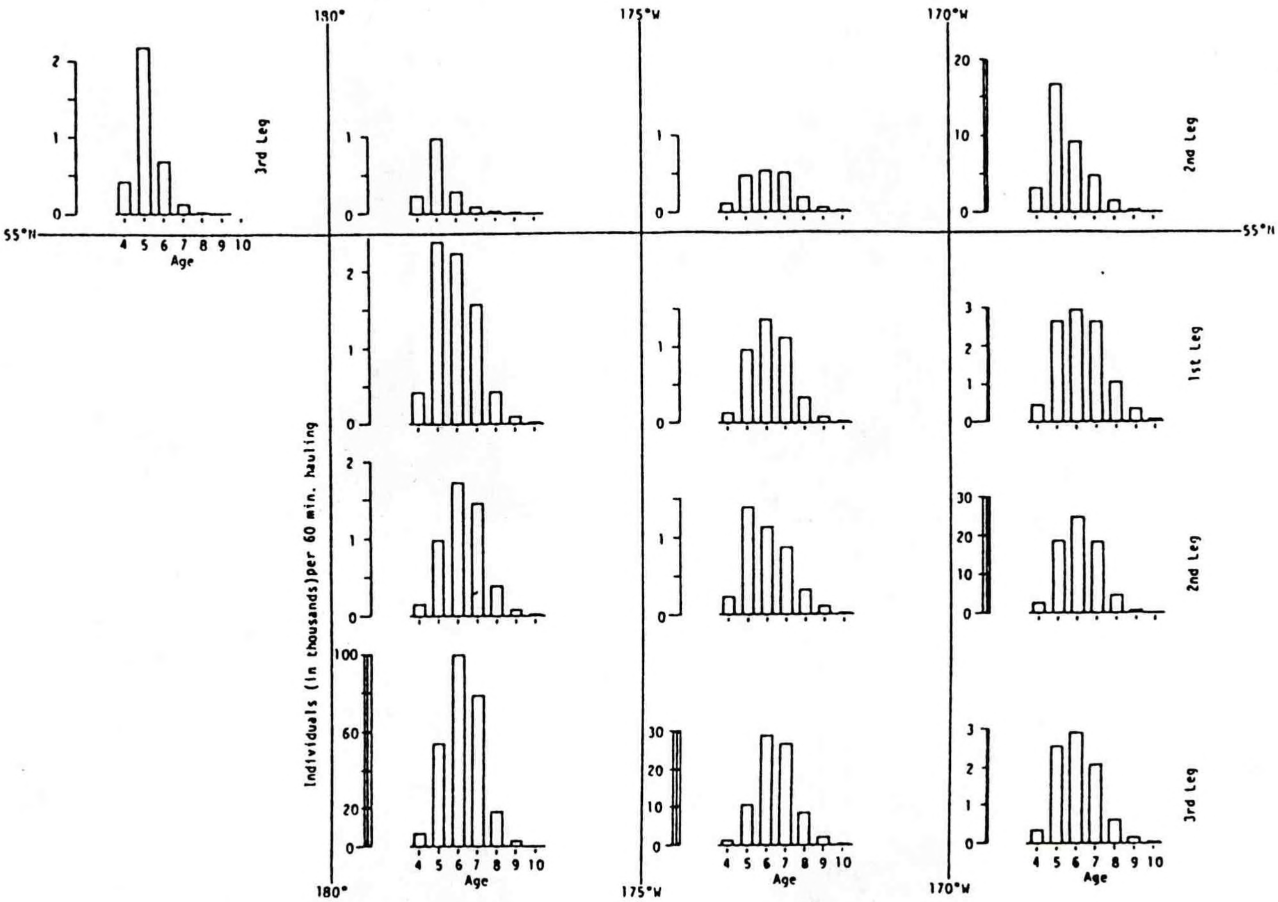


Fig. 36. Age composition of pelagic pollock by north and south of 55°N and by longitude 5 degrees from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

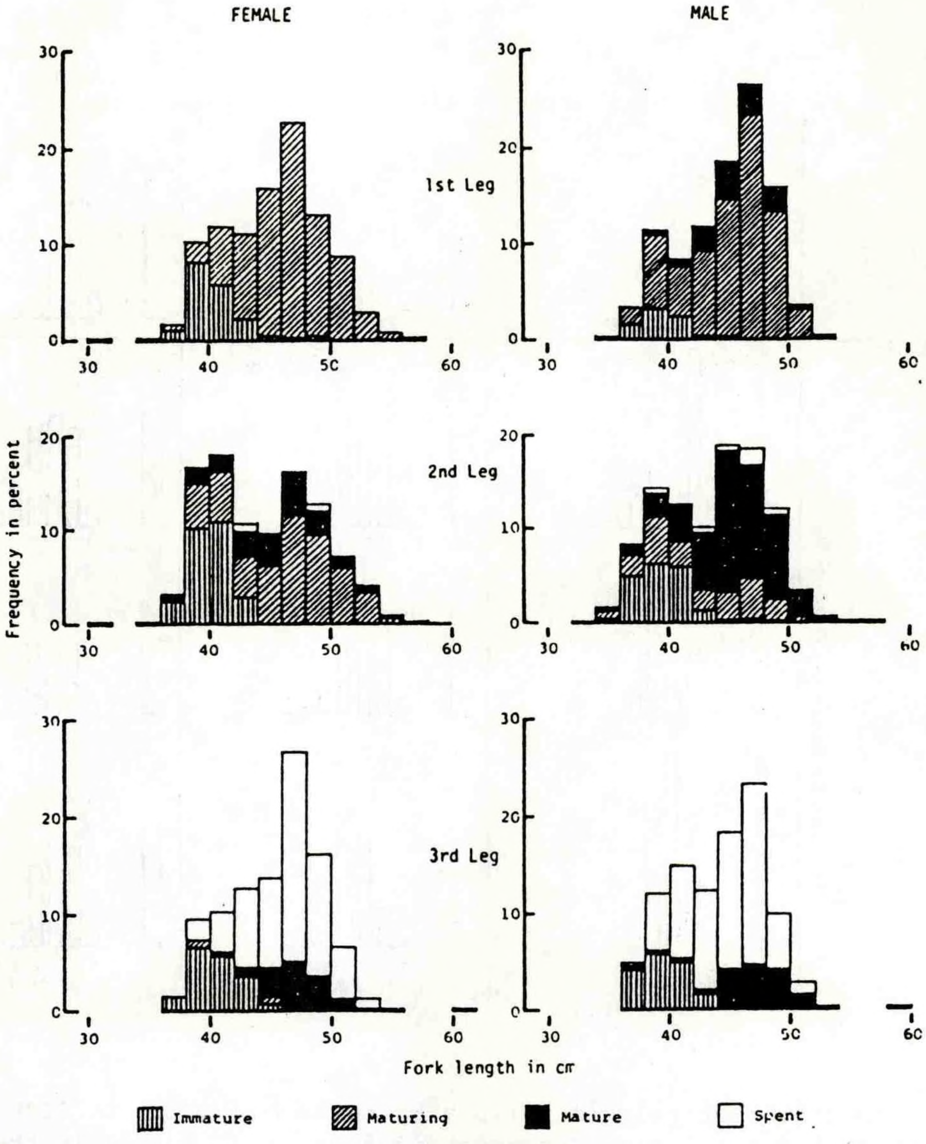


Fig. 37. Maturity composition of pelagic pollock by size class from Japanese midwater trawl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

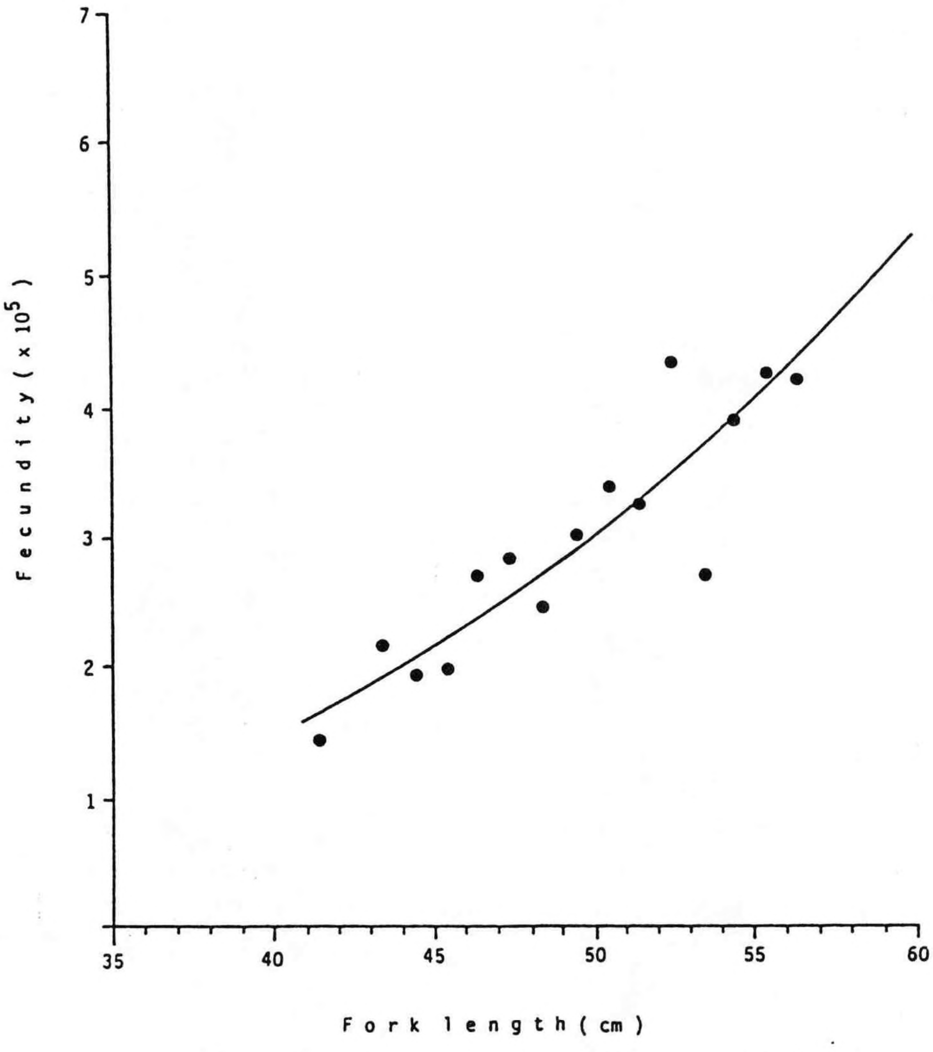


Fig. 38. A relationship between fecundity (estimated total number of oocytes within an ovary) and fork length of pelagic pollock sampled in the international waters of the Bering Sea late in January of 1987 (Teshima et al., 1988).

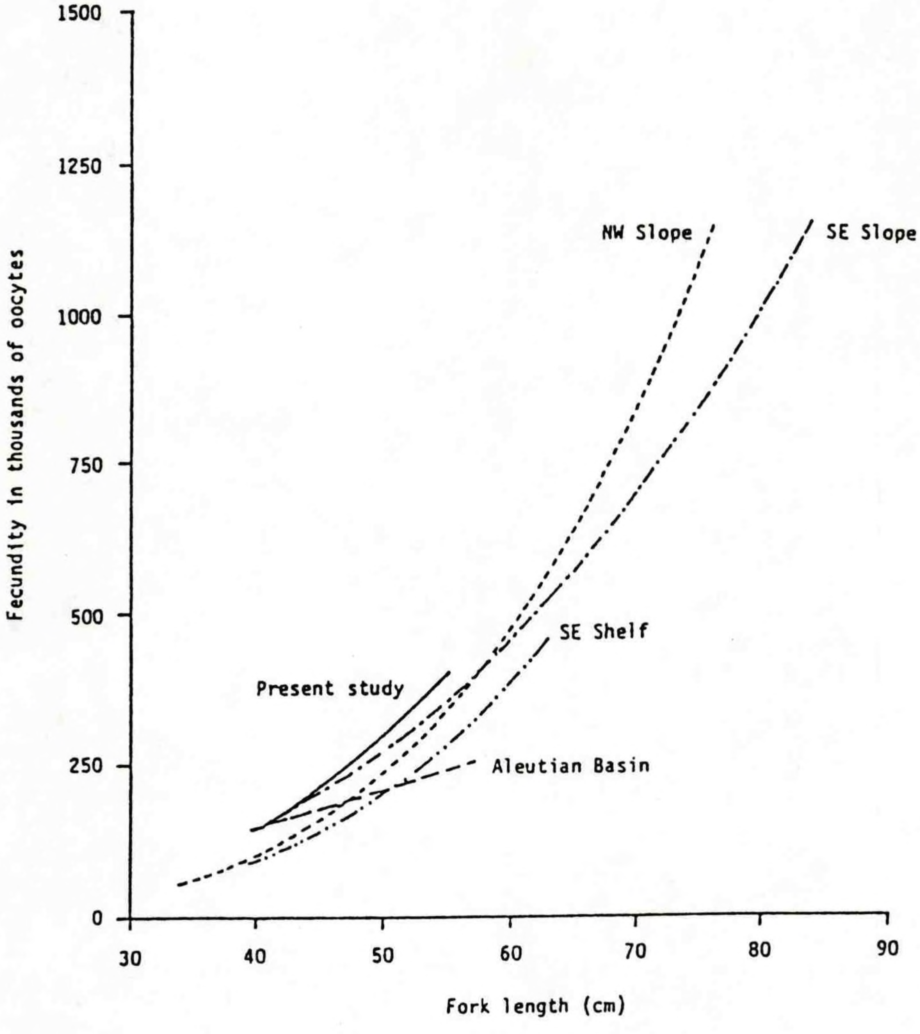


Fig. 39. Fecundity-fork length relationships of pollock in the five different seas areas (Teshima et al., 1988). Present study in the figure was obtained from pelagic pollock in the international waters of the Bering Sea by Teshima et al. (1988) and NW and SE slopes, SE shelf in the eastern Bering Sea, and Aleutian Basin are from Hinckley (1987).

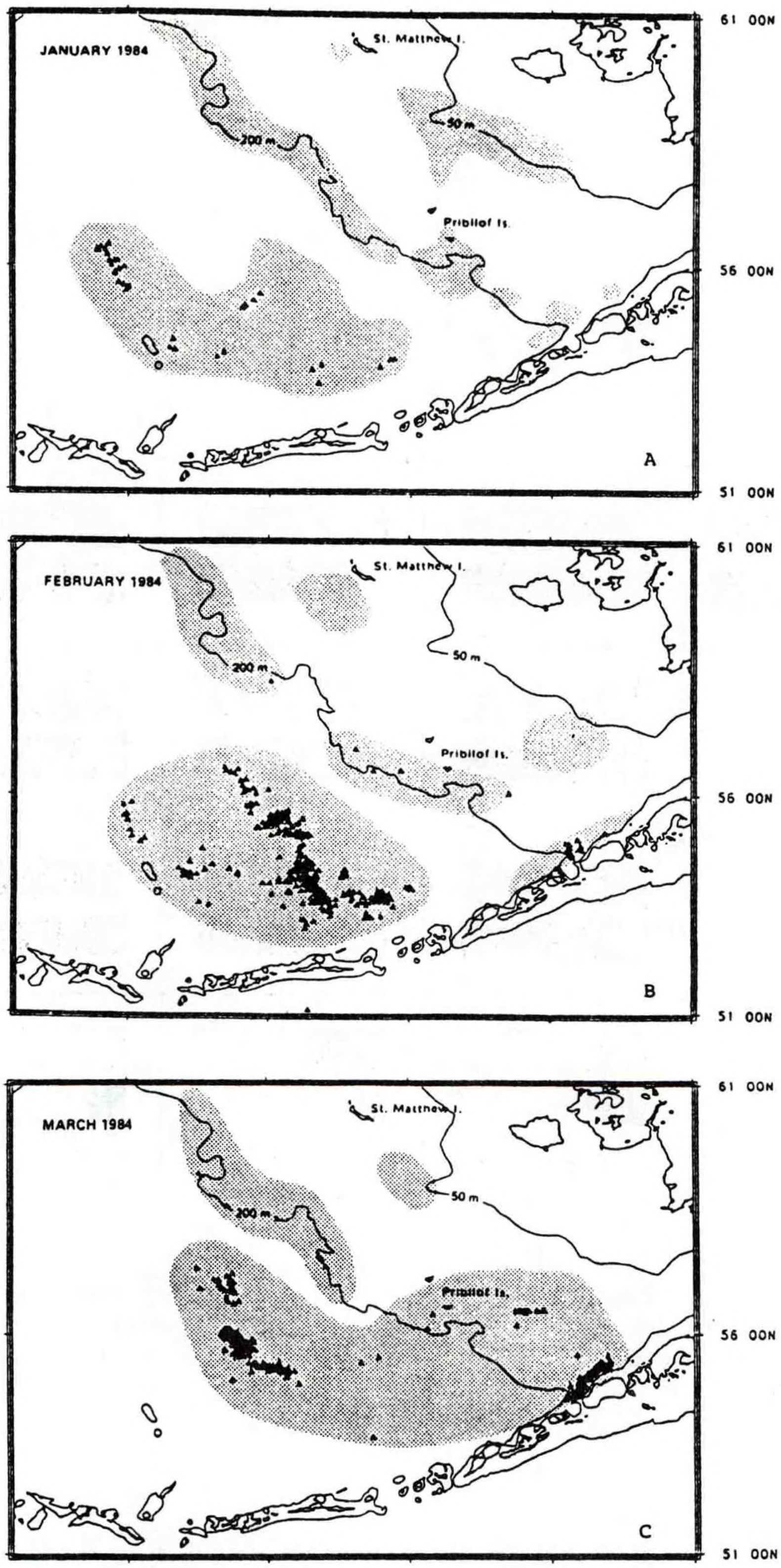


Fig. 40. Observed distribution of spawing pollock in 1984, by month (Hinckley, 1987). Shaded areas indicate distribution of the foreign or non-U.S. commercial fishing fleet. Triangles indicate hauls in which spawning pollock were caught.

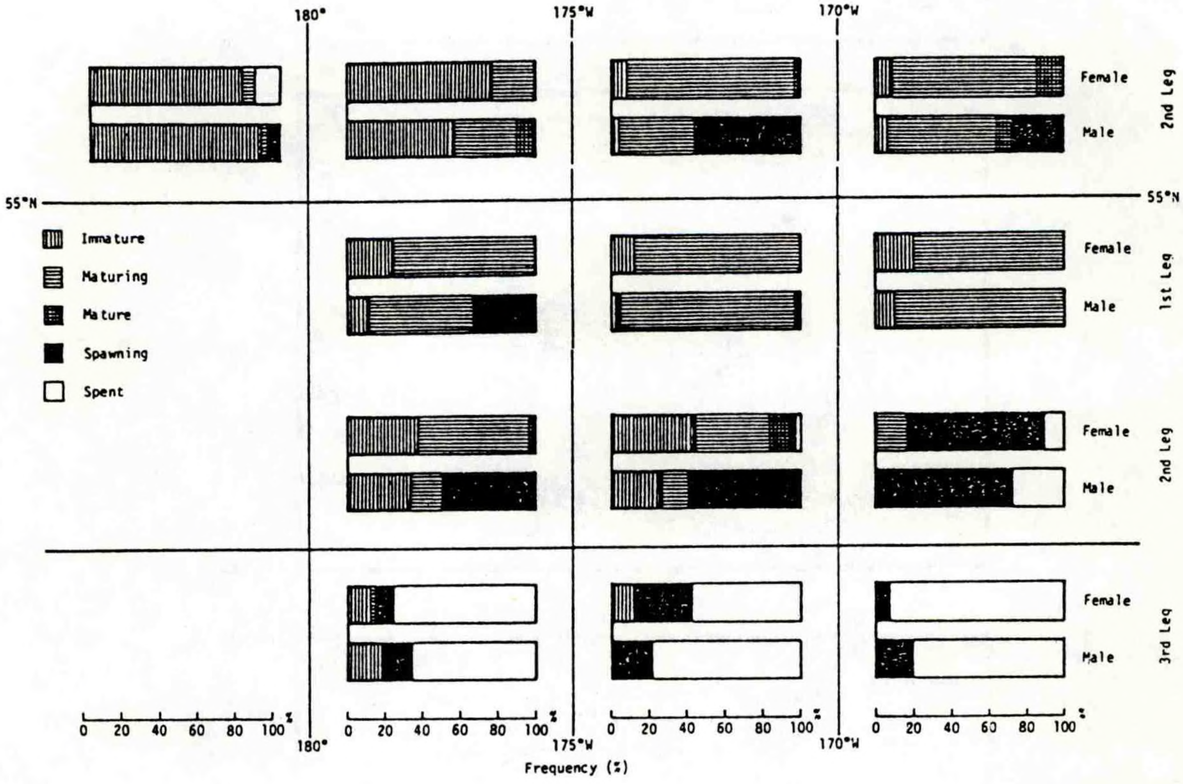


Fig. 41. Maturity composition of pelagic pollock by north and south of 55°N and by longitude 5 degrees from Japanese midwater tarwl survey in the Aleutian Basin in the winter of 1983 (Yamaguchi, 1984).

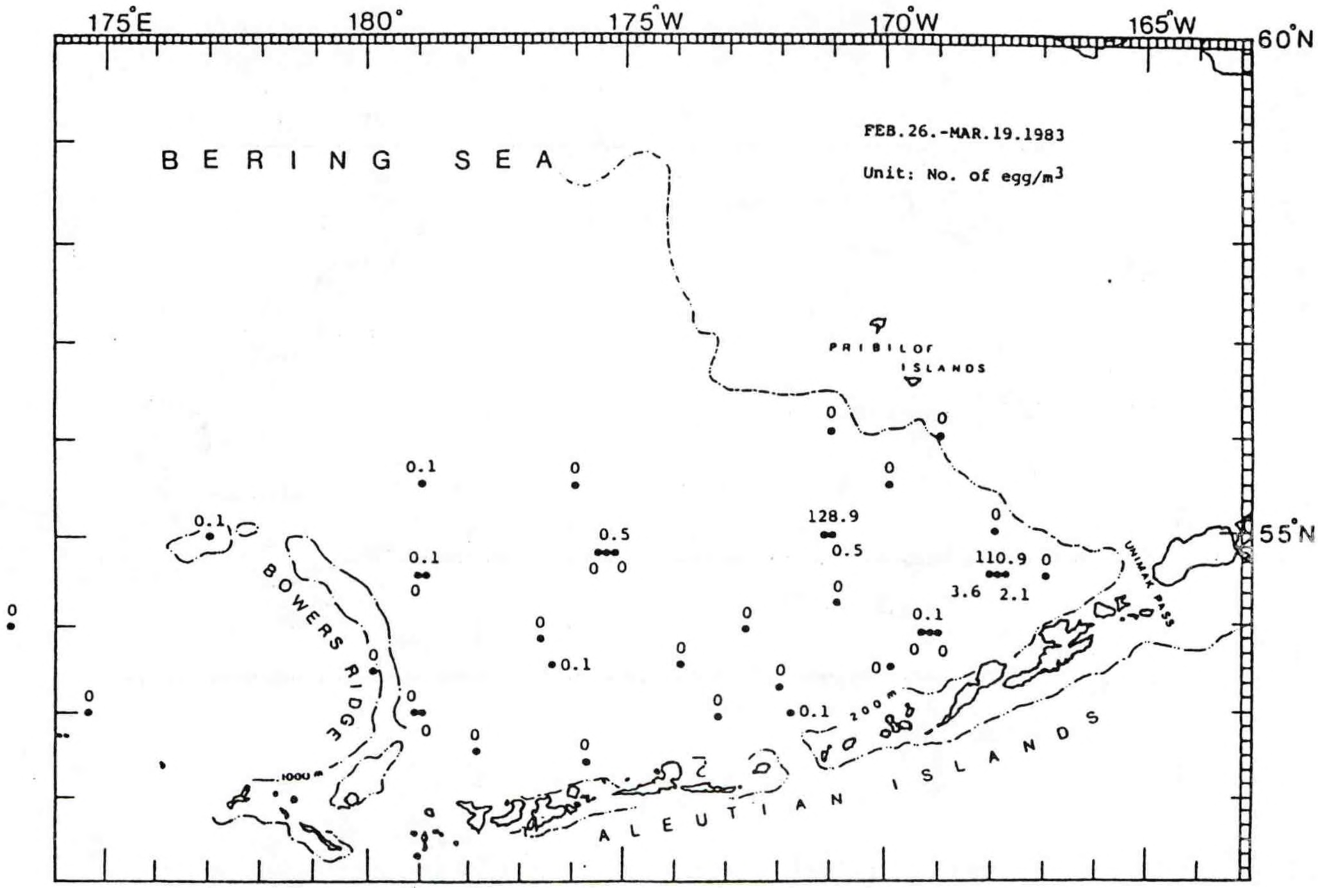


Fig. 42. Distribution of pelagic pollock eggs collected by NORPAC net during Japanese acoustic/midwater trawl survey in the Aleutian Basin in February and March of 1983 (Okada, 1986).

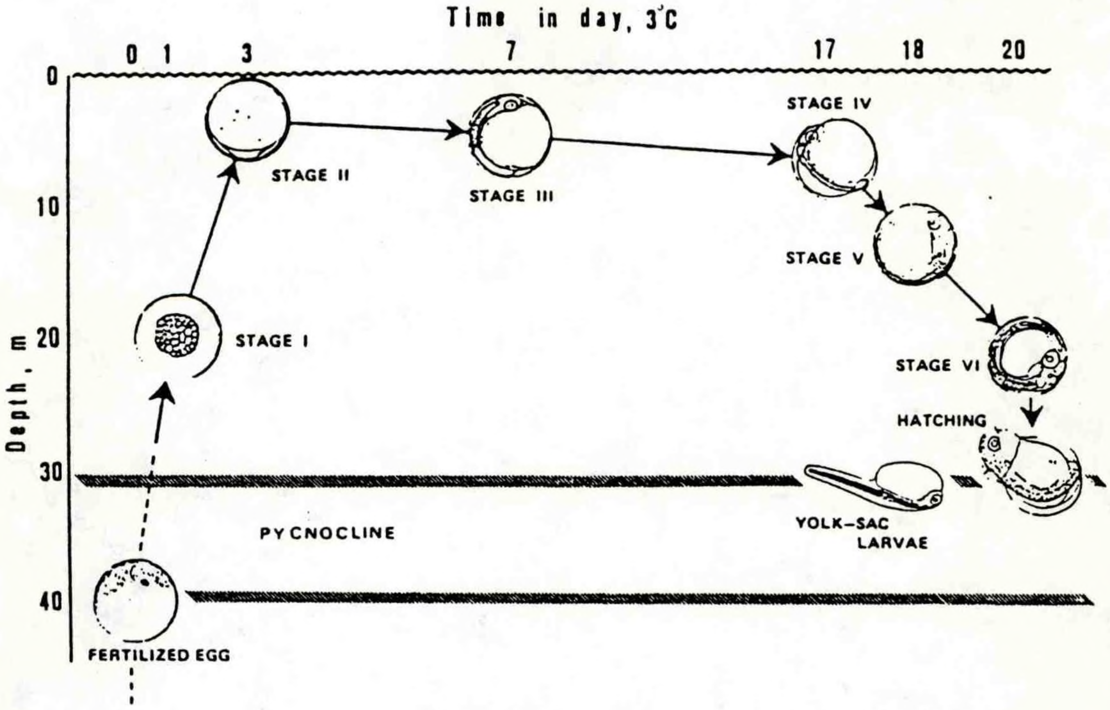


Fig. 43. Schematic illustration of vertical distribution of pollock eggs and larvae in the continental shelf of the eastern Bering Sea (Nishiyama et al., 1986).

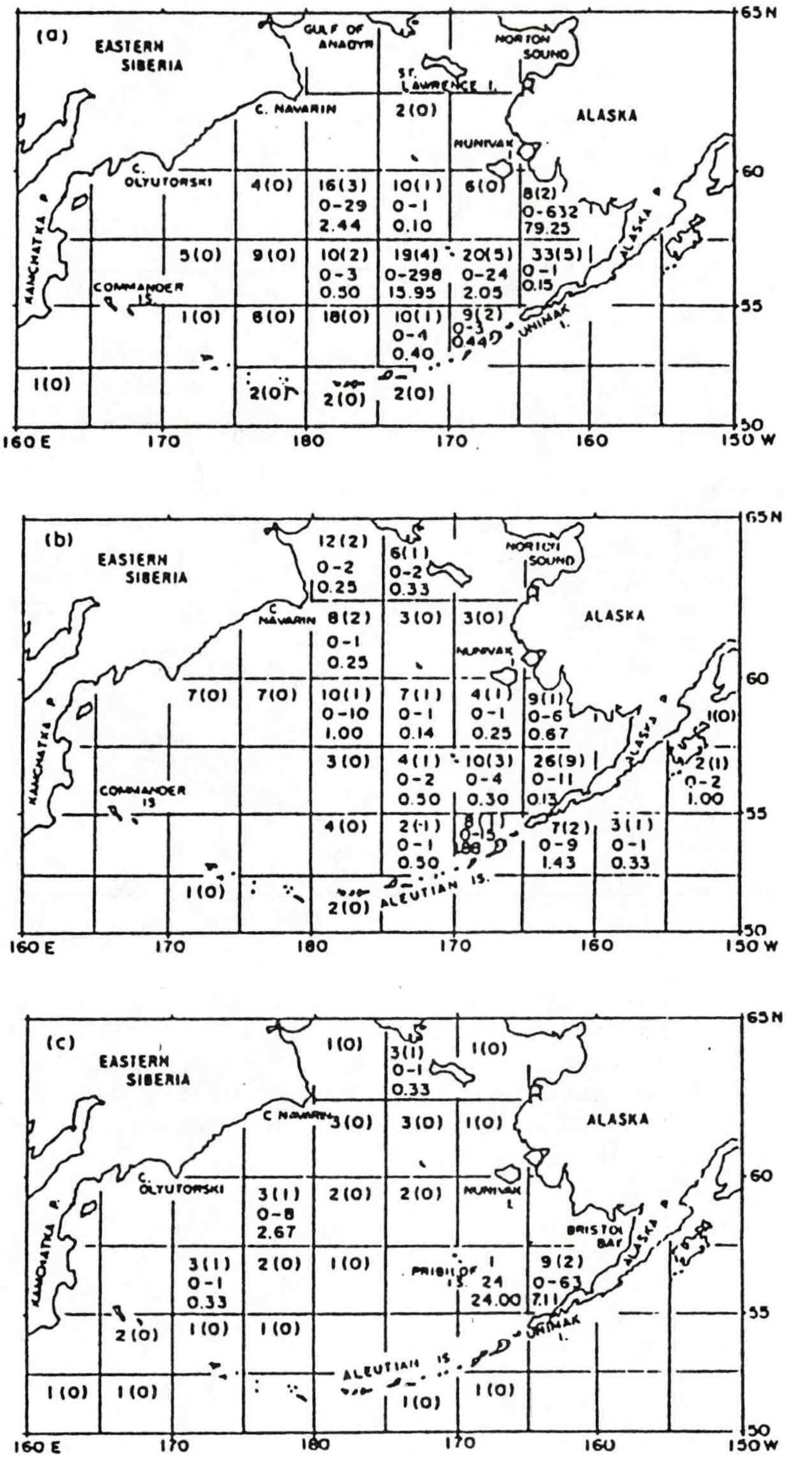


Fig. 44. Relative abundance of pollock larvae in the Bering Sea by 2.5°X5° quadrangles in 1963-1974 (Haryu, 1980). (a), (b), (c) is June, July, and August respectively. The figures in each quadrangle denote the number of hauls (the number of occurrence of pollock larvae), range of the number of pollock larvae collected and the number of pollock larvae per one haul from top to bottom, respectively.

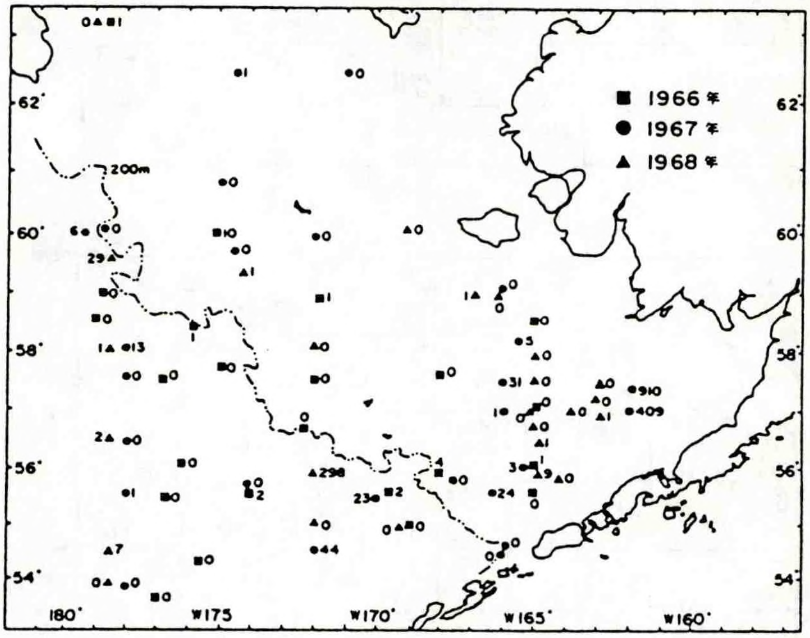


Fig. 45. Horizontal distribution of pollock larvae obtained with a larva net tow at the surface and at the 8-50 m layer from the sea surface in the eastern Bering Sea from June to August of 1966-1968 (Maeda and Hirakawa, 1977).

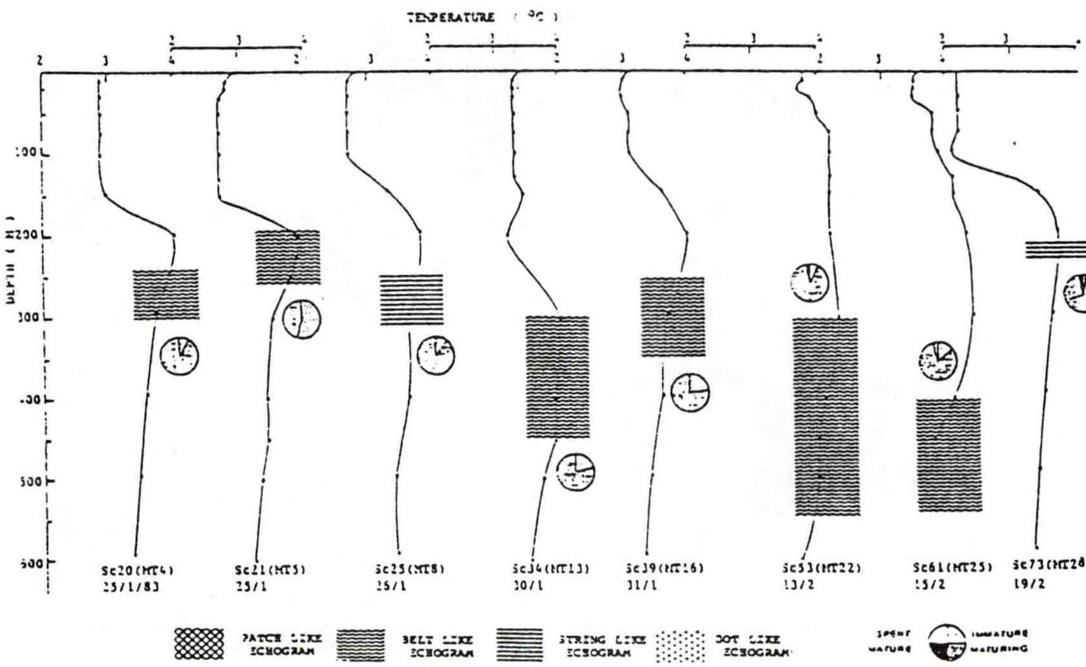


Fig. 46. Relationship between vertical distribution of water temperature and echogram patterns of pelagic pollock from Japanese acoustic survey in the Aleutian Basin in the winter of 1983 (Fisheries Agency of Japan, 1984).

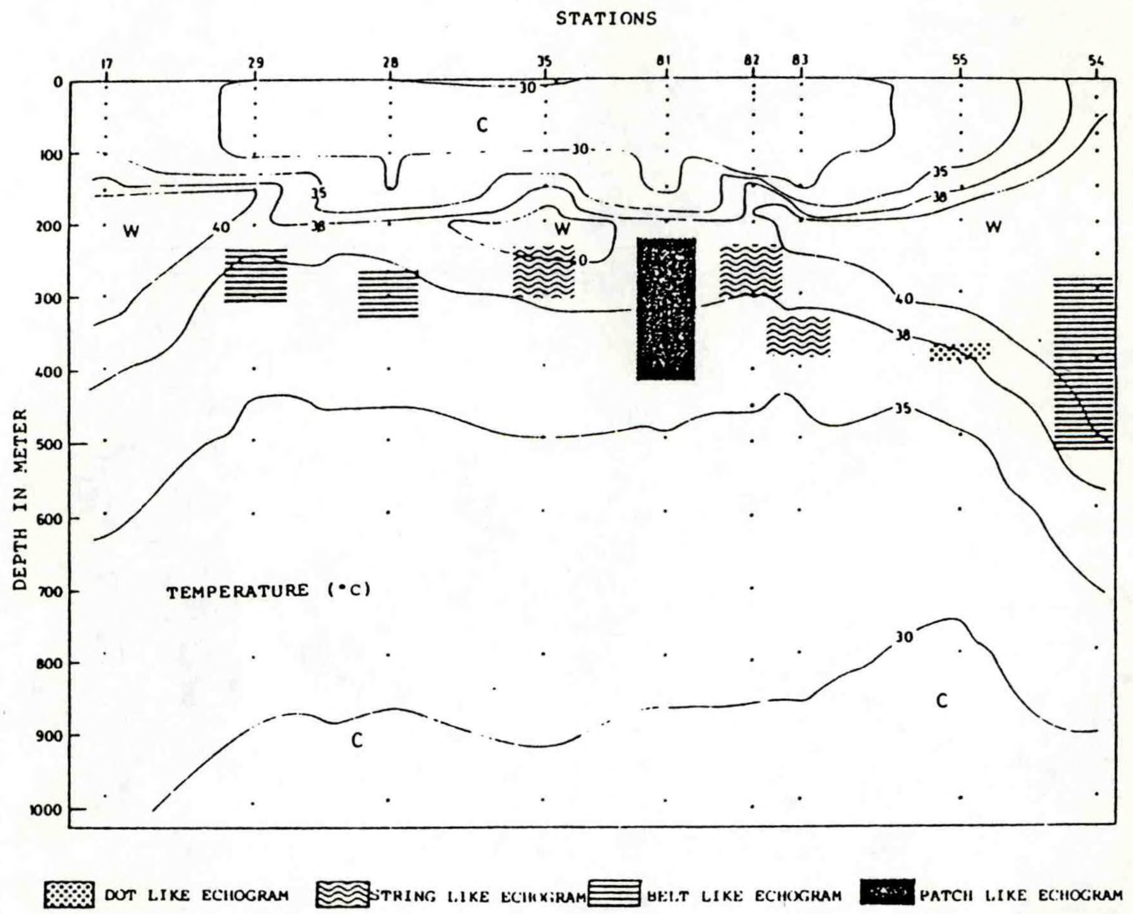


Fig. 47. Relationship between vertical distribution of water temperature and echogram patterns of pelagic pollock along the northeast-southwest section in the Aleutian Basin from Japanese acoustic survey in the winter of 1983 (Okada, 1986).

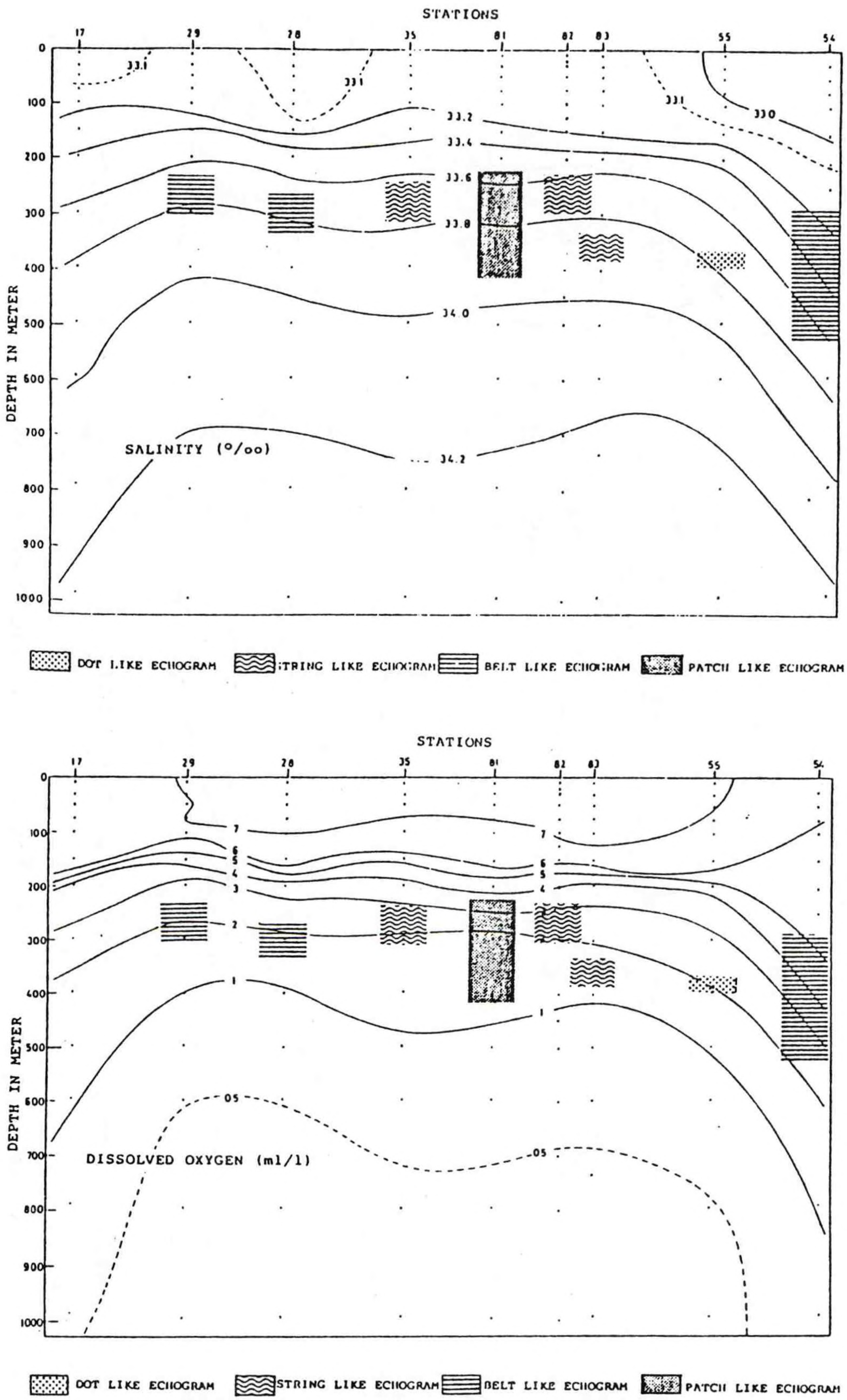


Fig. 48. Relationship between vertical distribution of salinity and dissolved oxygen and echogram patterns of pelagic pollock along the northeast-southwest section in the Aleutian Basin from Japanese acoustic survey in the winter of 1983 (Okada, 1986).

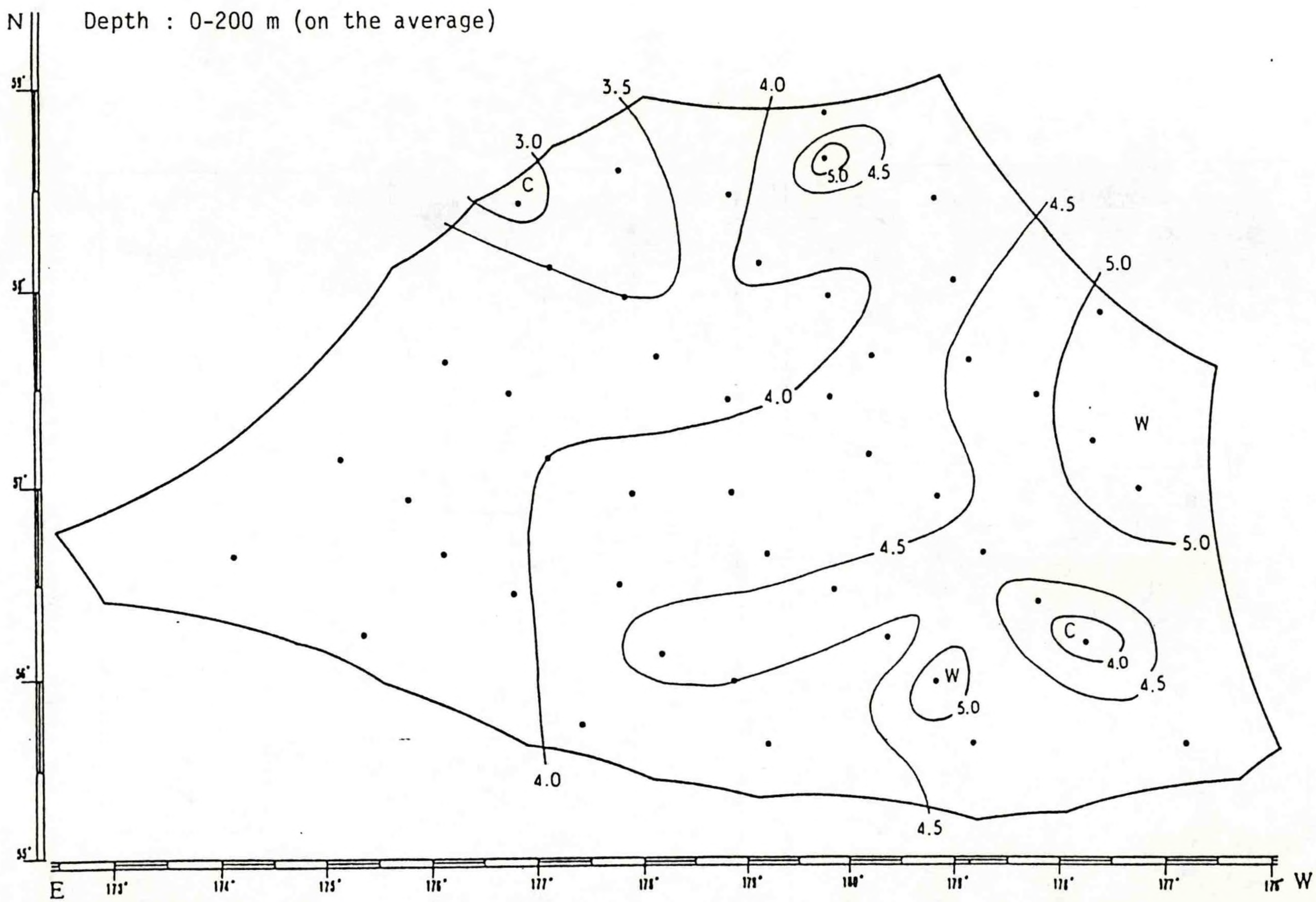
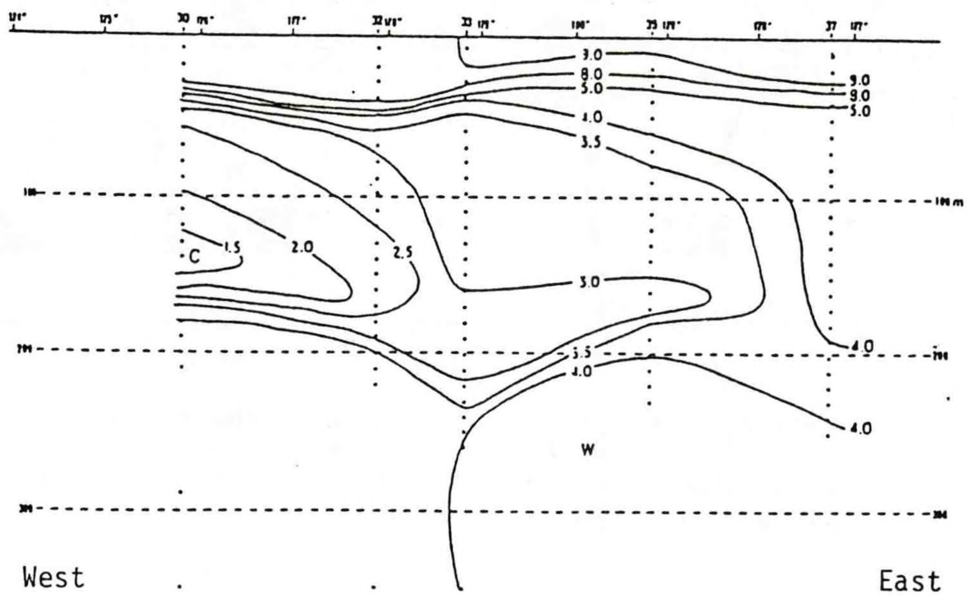


Fig. 49. Horizontal distribution of mean water temperature from Japanese acoustic/midwater trawl survey in the international waters of the Bering Sea in the summer of 1987 (Fisheries Agency of Japan, 1988).

East-West section



South-North section

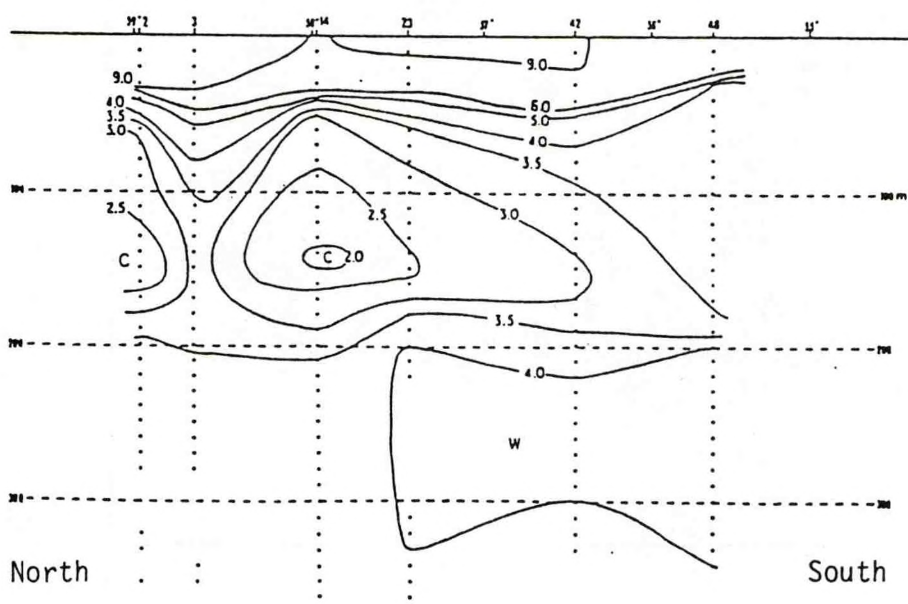


Fig. 50. Vertical distribution of water temperature along the east-west section (57°N) and south-north section (180°) from Japanese acoustic/midwater trawl survey in the international waters of the Bering Sea in the summer of 1987 (Fisheries Agency of Japan, 1988).

ST.NO. / Time / Density (mg/m³)	ST. 93	ST.124	ST.125	ST.127	ST.128	ST.133	ST.134
Time	1427-1523	1016-1043	2013-2039	0931-0956	1455-1516	0302-0337	1333-1402
0m - 150m	28	270	172	7	29	462	236
150m - 300m	421 (150m - 650m)	1174	146	331	807	318	1030

Fig. 51. Comparison of density of zooplankton in the 0-150 m layer and 150-300 m layer from Japanese acoustic/midwater trawl survey in the Aleutian Basin in the winter of 1983 (Fisheries Agency of Japan, 1984).

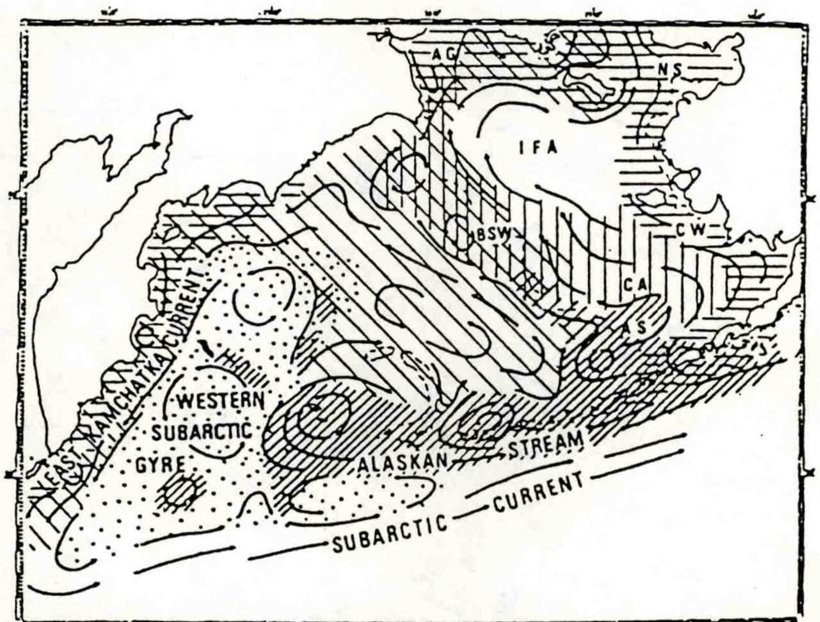


Fig. 52. Schematic illustration of water current in the Bering Sea (Ohtani, 1973).

APPENDIX 2

Papers from Panel B

STOCK IDENTIFICATION OF BERING SEA WALLEYE POLLOCK

by Pierre K. Dawson

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INTRODUCTION

A stock can be defined as a group of fish that is reproductively isolated from other groups. Thus, a stock of fish could spawn in one location in isolation but then mix with other stocks during other periods. It is important to determine not only what walleye pollock (Theragra chalcogramma) stocks exist in the Bering Sea but also what stock mixing might be occurring.

TAGGING STUDIES

Although many pollock have been tagged in the Bering Sea, few have been recovered. In addition, very few, if any, pollock have been tagged in the Aleutian Basin itself, allowing limited insight into pollock movements within the basin. Results from tagging studies show there is some movement of pollock from the western Bering Sea into the doughnut hole and into the eastern Bering Sea. Five of the 20 tag returns in the Bering Sea have crossed international boundaries.

In September 1982, the Northwest and Alaska Fisheries Center (NWAFC) tagged approximately 7,000 trawl-caught pollock in the southeastern shelf of the Bering Sea, with four recoveries all from the same shelf/slope region (A. Shimada, 7600 Sand Point Way NE, BIN C15700, Seattle, WA 98115. Pers. commun., 1987).

From 1966 to 1976, Japanese researchers tagged a minimum of 17,000 pollock in the Bering Sea with 15 of those fish recaptured (Yoshida 1979). The results are shown in Figure 1. Only two pollock tagged in the Bering Sea have been recovered in the basin. One was a fish tagged on the Soviet shelf that was recovered 4 years later in the basin (Fisheries Agency of Japan 1977). The second basin recovery was also tagged in the Soviet portion of the Bering Sea and recovered 8 years later (T. Sasaki, Japan Fisheries Agency, 7-1, 5 Chome Orido, Shimizu 424, Japan. Pers. commun. 1987). A third recovery from the basin was that of a pollock that had been tagged off Hokkaido Island. Apparently the vessel that reported the tag had shortly before been fishing near Hokkaido

Island (T. Sasaki, Japan Fisheries Agency, 7-1, 5 Chome Orido, Shimizu 424, Japan. Pers. commun., 1988).

Unfortunately, most of the tagging in the Bering Sea had been completed long before there was any significant directed pollock fishery in the basin. Thus the absence of many tag returns from the basin may only indicate a lack of effort there. Two pollock tagged on the Soviet slope that were recaptured on the U.S. slope indicate that there is some interchange of fish between Soviet and U.S. waters, although it is unknown if those pollock spent any time in the basin. Within the U.S. Exclusive Economic Zone (EEZ) no pollock tagged on the shelf/slope regions has been recovered in the basin. One of four recaptured pollock which had been tagged on the U.S. northeastern slope was recovered on the U.S. southeastern slope, suggesting some movement between those areas. Northeastern and southeastern slopes refer to that portion of the eastern Bering Sea with depths from 200 to 2,000 m that is northwest and southeast of the Pribilof Islands, respectively.

MORPHOMETRIC AND MERISTIC STUDIES

At least one study has looked for morphometric and meristic differences between pollock from different areas of the Bering Sea. Serobaba (1977) found differences between pollock from the eastern, northern, western, and southern portions of the Bering Sea. Unfortunately, no pollock from the basin were included in that study.

GENETIC STUDIES

Major genetic differences have been found between pollock from the area around Hokkaido Island and those from the eastern Bering Sea (Iwata 1975), but no differences have been found among pollock in the eastern Bering Sea (Grant and Utter 1980). Small but detectable differences were found between pollock from the eastern Bering Sea and from the Gulf of Alaska, but no samples were included from the basin. Research completed in December 1987 at the NWAFC found little difference in allele frequencies for pollock from the Bering Sea, Shelikof Strait, and Puget Sound (G. Winans, unpubl. manuscr.). Unfortunately, sample sizes were too small to look for genetic differences within the Bering Sea. Thus, no studies have looked in detail at the genetic relationship between pollock in the basin and other areas in the Bering Sea and North Pacific Ocean.

GROWTH OBSERVATIONS

Differences in growth rates have been found among pollock in the eastern Bering Sea. From pollock collections made from 1976 to 1983, Lynde et al. (1986) looked at length-at-age by area, season, and year. While pollock from the basin and northeastern shelf/slope regions have similar growth rates, those rates are lower than those of pollock from the southeastern shelf/slope region (Figs. 2,3; Lynde et al. 1986). The other feature Lynde et al. found was seasonal deviations in growth, which the authors attributed to migration. They suggest that smaller basin pollock may be moving onto the southeastern slope in some years and lowering the observed mean length-at-age during the spawning season.

AGE COMPOSITION

Marked differences exist in the age composition of pollock taken in commercial fisheries in the Aleutian Basin and on the eastern Bering Sea shelf, based on samples collected and aged by NWAFC. From 1983 to 1988, 5-year-old pollock were the first age group to occur in fairly large numbers in the basin, whereas on the shelf, 2-year-old pollock were often caught in significant numbers (Figs. 4,5).

Not only are young adult pollock scarce in the basin but so are juveniles. In a cooperative U.S.-U.S.S.R. ichthyoplankton survey of the basin and the eastern shelf in 1987 with participation of NWAFC scientists, very few juveniles were found in the basin, while tremendous quantities were found over the shelf (Fig. 6).

From both commercial fishery and research survey data, the 1978 year class has been dominant in both the basin and the eastern shelf. From 1980 to 1985 they were the dominant year class on the shelf. In 1985, the 3-year-old 1982 year class supplanted them on the shelf. In the basin, the 1978 year class was present as 5-year-olds in 1983 and by 1984 had become dominant, representing 24% of all the fish sampled. That percentage increased until by 1988 approximately 40% of the pollock sampled in the basin were from the 10-year-old 1978 year class. In 1988 in the basin no other single year class represented more than 10% of the population. A comparison of the age distribution of fish older than 5 years on the eastern shelf and in the basin reveals no consistent pattern. However, the small sample size of older fish on the shelf hampers this comparison.

In 1988, age distribution comparisons were possible between an important spawning ground for pollock of the basin, Bogoslof Island, and the doughnut hole region. Samples were collected by NWAFC scientists during the spawning period in February at Bogoslof

Island on the extreme southeast border of the basin and inside the doughnut hole during March-April. Even though the Bogoslof Island area is only 65 miles from the nearest part of the eastern shelf, the age distribution is quite different and is a very close match to the sample from the doughnut hole (Fig. 5). In both the doughnut hole and Bogoslof Island samples the 1978 year class makes up over 35% of the population, with the other year classes each contributing less than 10%. In addition to the similar age distribution, the mean length at age is also similar, especially considering the close match at 10-year-olds where 40% of the samples resides (Figs. 7,8).

The age distribution data suggest a basin population that is much older than the eastern shelf population. The break between the two populations apparently occurs over a short distance. The similarity of pollock in the doughnut hole and in the Bogoslof Island area suggests interchange between the two areas. The lack of young adults and juveniles in the basin suggests that recruitment comes from other areas.

CONDITION FACTOR

From pollock collected in 1984, Hinckley (1987) found inconclusive results in comparing the length-weight relationship of pollock from the various areas of the eastern shelf and the basin (Fig. 9). At best, differences between areas were minor.

SPAWNING OBSERVATIONS

Spawning apparently occurs earlier in the Aleutian Basin than it does on the eastern shelf. In 1984 and 1985 spawning occurred from January to March in the southeastern basin, from March through June over the southeastern shelf/slope region, and from June through August in the northeastern shelf/slope area (Fig. 10)(Hinckley 1987).

Spawning was first observed in the southeastern basin in 1983, when a Japanese winter survey found extensive spawning in the area of the basin east of lat. 177°W with the largest concentrations of eggs found in the area east of lat. 172°W (Okada 1986). In 1984 a broad band of spawning was observed stretching from the southeast corner of the doughnut hole southeast towards the Aleutian Islands (Hinckley 1987). In 1986 a spawning concentration of pollock was reported for the first time near Bogoslof Island. By 1987 that spawning concentration supported a large fishery, and approximately 300,000 metric tons (t) was harvested. Again in 1988 a large fishery occurred on dense spawning concentrations of fish in the Bogoslof Island area.

There is some suggestion that pollock may leave the doughnut hole during the peak spawning period, mid-February to mid-March.

In 1983 the Japanese winter survey, which was scheduled to cover a large section of the basin, concentrated on the southeast basin apparently due to a reduction in the distribution of pollock (Okada 1986). In 1987 a reduction in catch rates was reported in the doughnut hole during the peak spawning period (Sasaki and Yoshimura 1987). In February 1988, a U.S. survey vessel found very few fish inside the southern portion of the doughnut hole. Large concentrations of spawning pollock were instead found in the southeastern basin near the area where the 1983 Japanese winter survey also found spawning concentrations. During that same period in February 1988, fishermen were reporting difficulty in finding any fishable concentrations of pollock in any part of the doughnut hole.

Pollock only mature one group of oocytes per year which are probably spawned over a period of a month. Significant migration is probably unlikely during active spawning. Thus, it is improbable that an individual fish spawning in the basin would then spawn again on the shelf (Hinckley 1987).

FECUNDITY

Fecundity differences have also been found between regions, with the basin pollock having a lower fecundity for the same body size than pollock from the shelf/slope areas (Fig.11). Within the shelf/slope areas, the northeastern slope pollock had greater fecundity per unit body weight than pollock from the southeastern shelf/slope areas (Hinckley 1987).

EGG and LARVAL DRIFT

Given the very small numbers of juveniles and young adults found in the Aleutian Basin an important question centers around the fate of the eggs and larvae spawned in the basin. For the southeastern basin spawning areas some information exists on the currents during the spawning season. From density measurements taken January through February 1983, Kitani (1983) calculated an eastward flow north of the Aleutian Islands that turned and flowed northwestward at the edge of the continental shelf (Fig. 12, Kitani 1983). In February 1986, satellite-tracked drifters were placed in concentrations of spawning pollock in the southeastern Bering Sea (Fig. 13, Reed et al. 1988). Both drifters eventually made their way onto the eastern continental shelf.

It is possible that eggs and larvae spawned in the southeast basin might be carried if not actually onto the shelf then at least along the edge of it so that the shelf would be a short swim away. Thus, the larvae might develop on the shelf.

WORKING HYPOTHESES

The following working hypotheses are thought to contain the range of possible relationships of pollock in the doughnut hole of the Bering Sea to pollock elsewhere in the Bering Sea including the U.S. EEZ portion of the Aleutian Basin area, U.S. EEZ shelf/slope, and the Soviet EEZ, both basin and shelf/slope areas. The hypotheses are in order from the most restrictive (a separate doughnut hole stock) to the most encompassing (a single stock for the entire Bering Sea).

1) The doughnut hole pollock are an independent stock. There is no evidence available that supports this most restrictive hypothesis. There is no oceanographic or biological feature that suggests that this legal boundary coincides with any physical/biological boundary for pollock. The finding that pollock in some years are in reduced abundance in the doughnut hole during the spawning period and the similarity in age composition and mean length-at-age between Bogoslof Island pollock and doughnut hole pollock suggests that doughnut hole pollock are not a separate population from pollock in the other areas of the basin.

It is important to point out that of the hypotheses considered here, this is the only hypothesis under which the harvest of doughnut hole pollock would have no effect on the pollock in the surrounding zones.

2) The pollock in the basin, including the U.S. and Soviet EEZ and the doughnut hole, are an independent stock. This implies that doughnut hole pollock mix with pollock in the U.S. and Soviet EEZ basin areas. Under this hypothesis, harvest of pollock in the doughnut hole would have an effect on pollock in the surrounding basin zones. This hypothesis is not supported by the available data on the distribution of juvenile and young adult pollock. The number of young pollock found in the central and eastern part of the basin, including the doughnut hole, has been small and insufficient to account for the adult population found in the basin. Recruitment to the basin population apparently comes from areas outside of the basin. However, the NWAFC has no knowledge of any surveys in the western part of the basin that have looked for young pollock.

3) The doughnut hole pollock are part of a basin population and this population mixes with the stocks in the adjacent regions during some part of their life history; recruitment to the basin comes from older-age fish on the shelf/slope areas. The eggs spawned by basin fish might end up on the shelf/slope areas with the adults from those eggs making their way back to the basin at age 5. Support for the first part of this hypothesis--doughnut hole pollock as a part of a basin population--comes from the observation of reduced abundance of pollock in the doughnut hole during the spawning period and the similarity of biological characteristics between pollock from Bogoslof Island and the

doughnut hole. Support for the second part of the hypothesis comes from the observation that few young pollock are found in the basin. Currents in the southeastern basin suggest that eggs and larvae spawned there may end up on the eastern shelf.

4) The basin pollock and the northeastern slope pollock are a single stock, which is separate from the pollock in the southeastern shelf/slope region of the eastern Bering Sea. This hypothesis is suggested by the finding of similar lengths-at-age for basin and northeastern slope pollock, which are different from the lengths-at-age of southeastern shelf/slope pollock (Lynde et al. 1986). The data on fecundity differences between the basin and the northeastern slope do not support this hypothesis.

5) The doughnut hole pollock and pollock elsewhere in the Bering Sea are part of a single stock. The interchange between basin and shelf/slope areas might consist of basin adults making seasonal migrations up onto the shelf/slope regions to feed or spawn and/or fish from the shelf/slope regions making seasonal migrations into the basin to feed or spawn. In addition, recruitment to the basin comes from older-age fish from the shelf/slope regions. Support for this hypothesis comes from the lowered mean lengths-at-age among pollock spawning on the southeastern slope during some years, a suggestion of migration to that area by basin pollock during the spawning period. Additional support for this hypothesis comes from two tag returns of pollock tagged on the Soviet shelf/slope that were recovered in the Basin, evidence which also supports hypothesis 3.

ONGOING RESEARCH

In order to help identify the stock structure of Bering Sea pollock the following projects are under way or the plans for the projects are firmly in place:

1) Morphometric and meristic study of adults and juvenile pollock from the Bering Sea including the Aleutian Basin.

2) Mitochondrial DNA study to look at genetic relationships within pollock in the Bering Sea including the basin.

3) Pilot tagging study on the eastern shelf.

4) Otolith composition study to look for a natural tag.

5) Cooperative U.S.-Japan hydroacoustic survey of the central and eastern basin during the spawning period in 1989.

FUTURE RESEARCH NEEDS

In addition to the ongoing work, the following needs to be done:

1) Comprehensive collection of biological samples from the catches in all areas of the Bering Sea during all seasons but especially during the spawning period. Samples need to be taken in a compatible fashion for each country's research effort. Comparisons of size, age, growth, year class strength, morphology, fecundity, maturity, and biological tags (such as genetic markers or otolith composition) can help identify stocks and stock mixing. This same information is also critical in determining rates of yield from a population.

2) Detailed survey of the entire Bering Sea during the spawning season to estimate spawner abundance and distribution. This would allow determination of the relative importance of each spawning area in the Bering Sea and help identify the area from where the spawners might be coming.

3) Mark recapture study of pollock in the entire Bering Sea with emphasis on the basin. The analysis of biological parameters is useful to make broad separations in populations but may not be very useful in determining rates of actual mixing. Mark recapture studies offer a direct way of determining mixing of populations.

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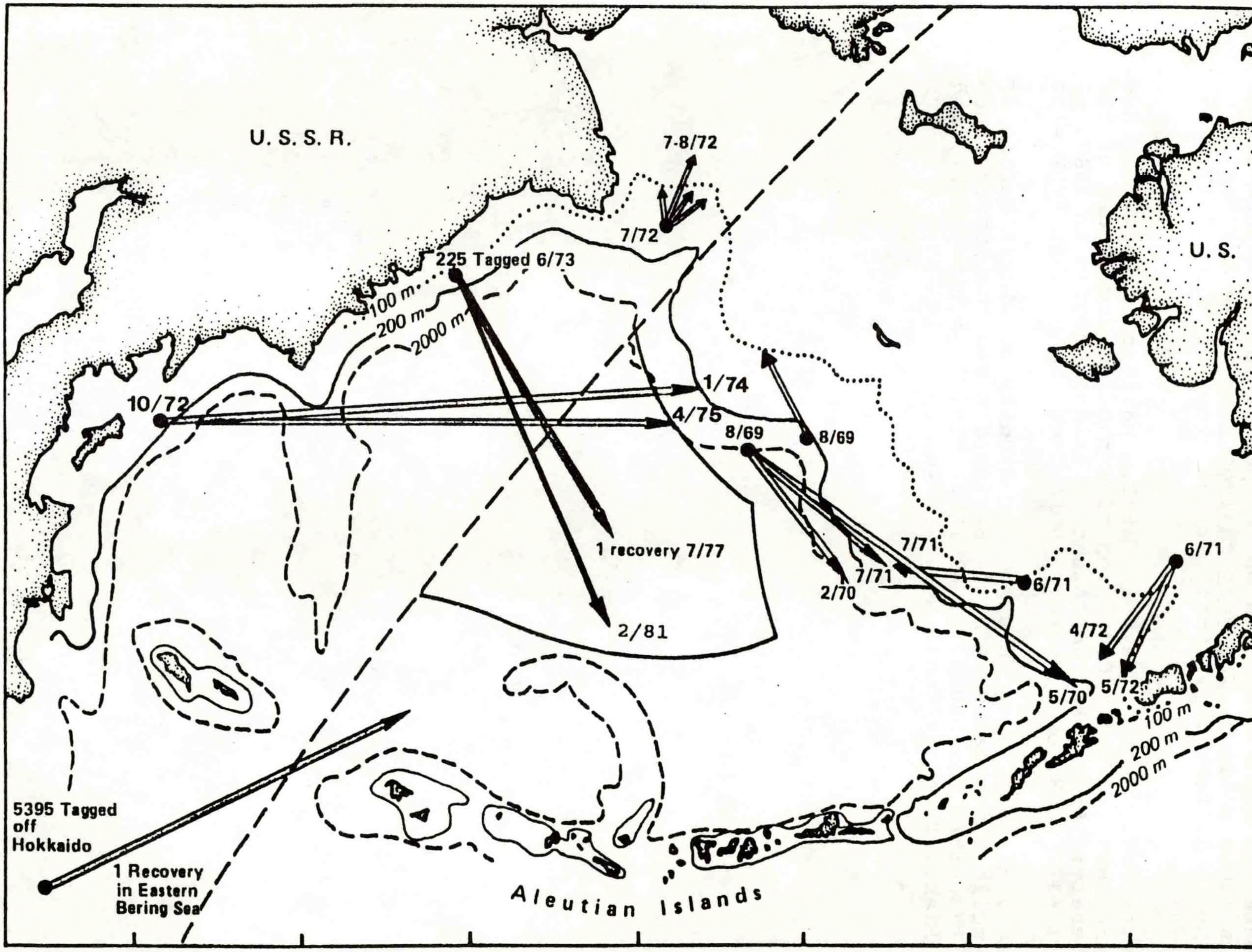

Figure 1.--Movement of Japanese tagged pollock in the Bering Sea (from Yoshida 1979, Sasaki 1987 pers. commun.).

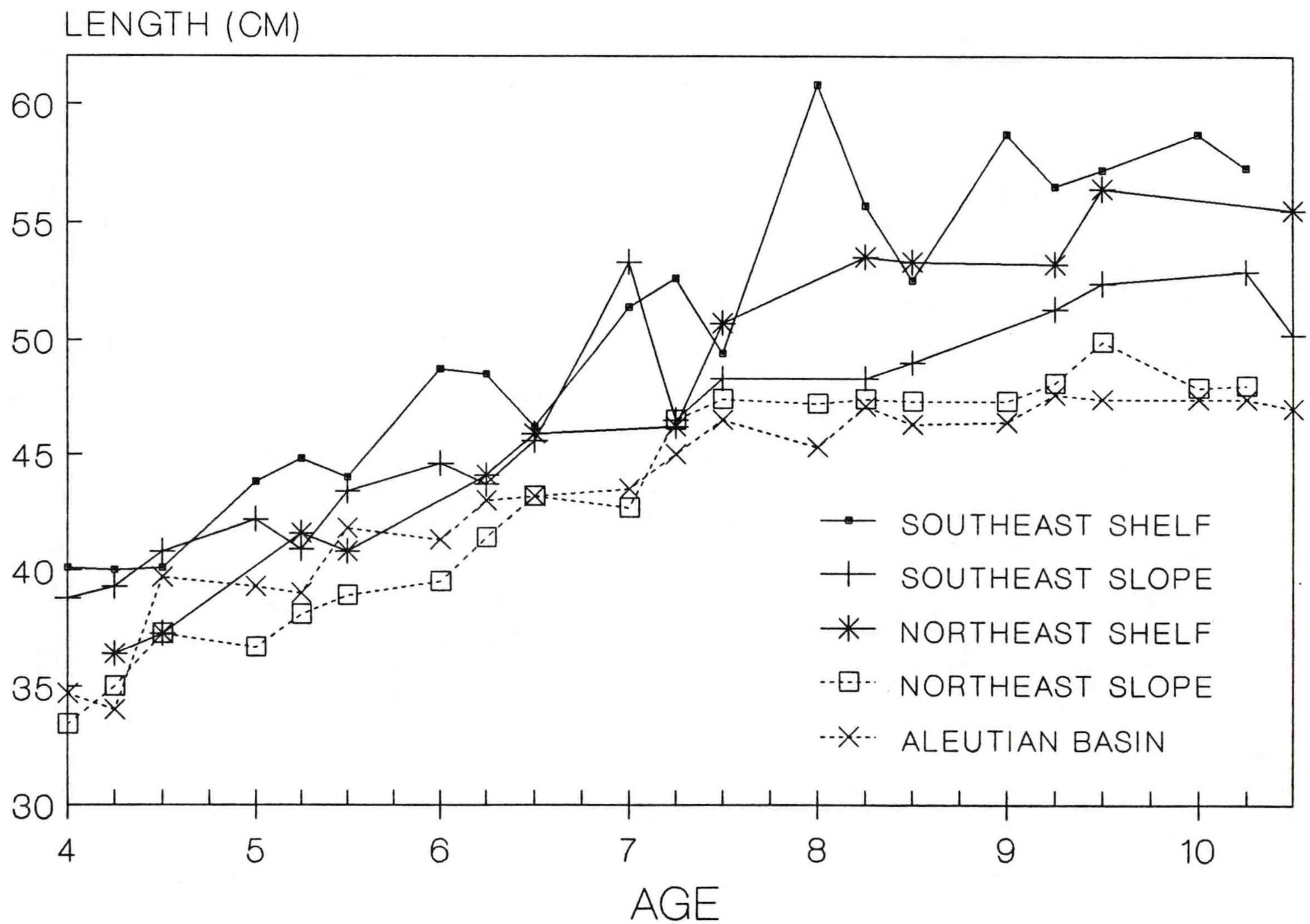

Figure 2.--Mean length-at-age for male pollock in the Bering Sea 1978-83 (from Lynde et al. 1986).

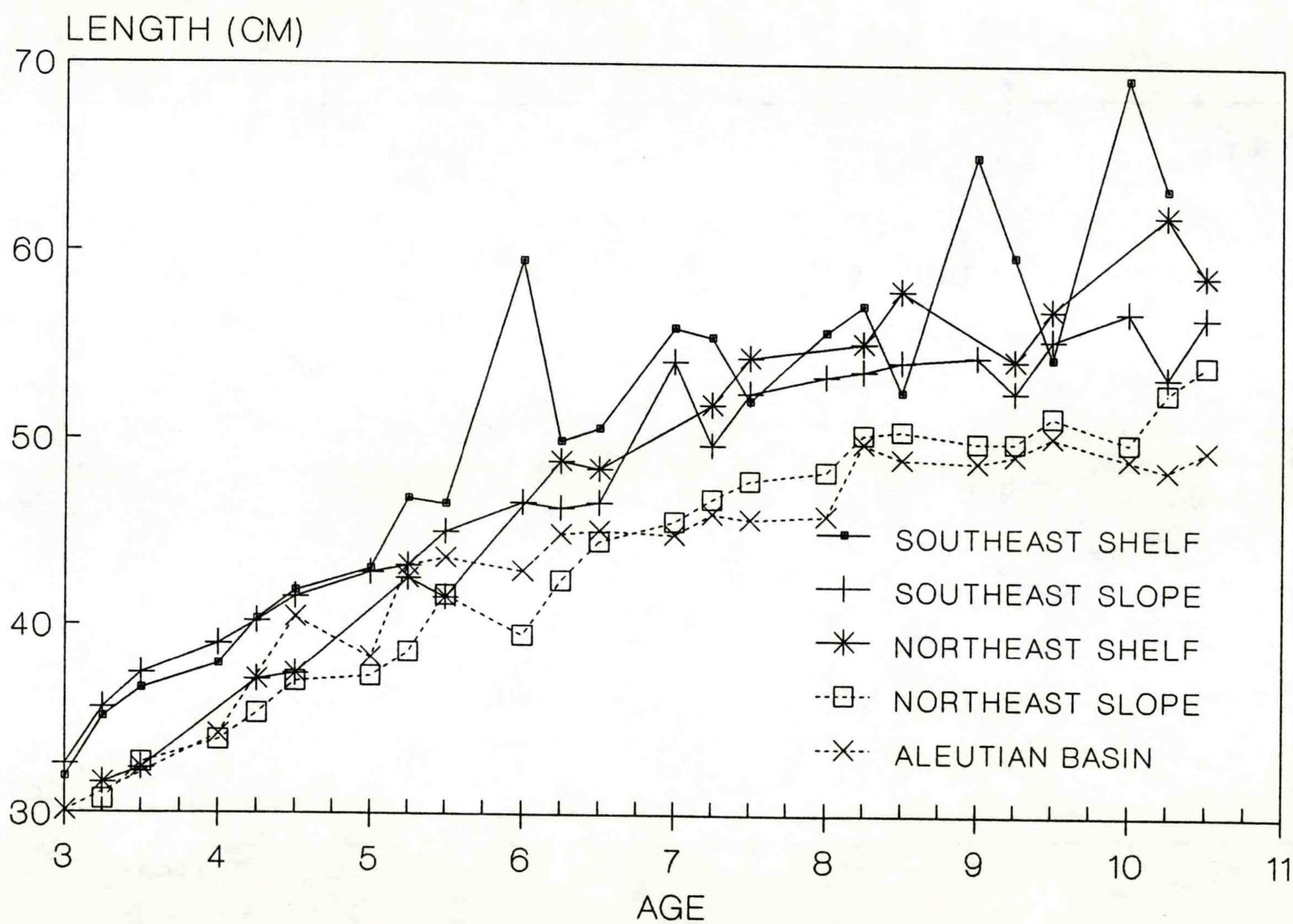

Figure 3.--Mean length-at-age for female pollock in the Bering Sea 1978-83 (from Lynde et al. 1986).

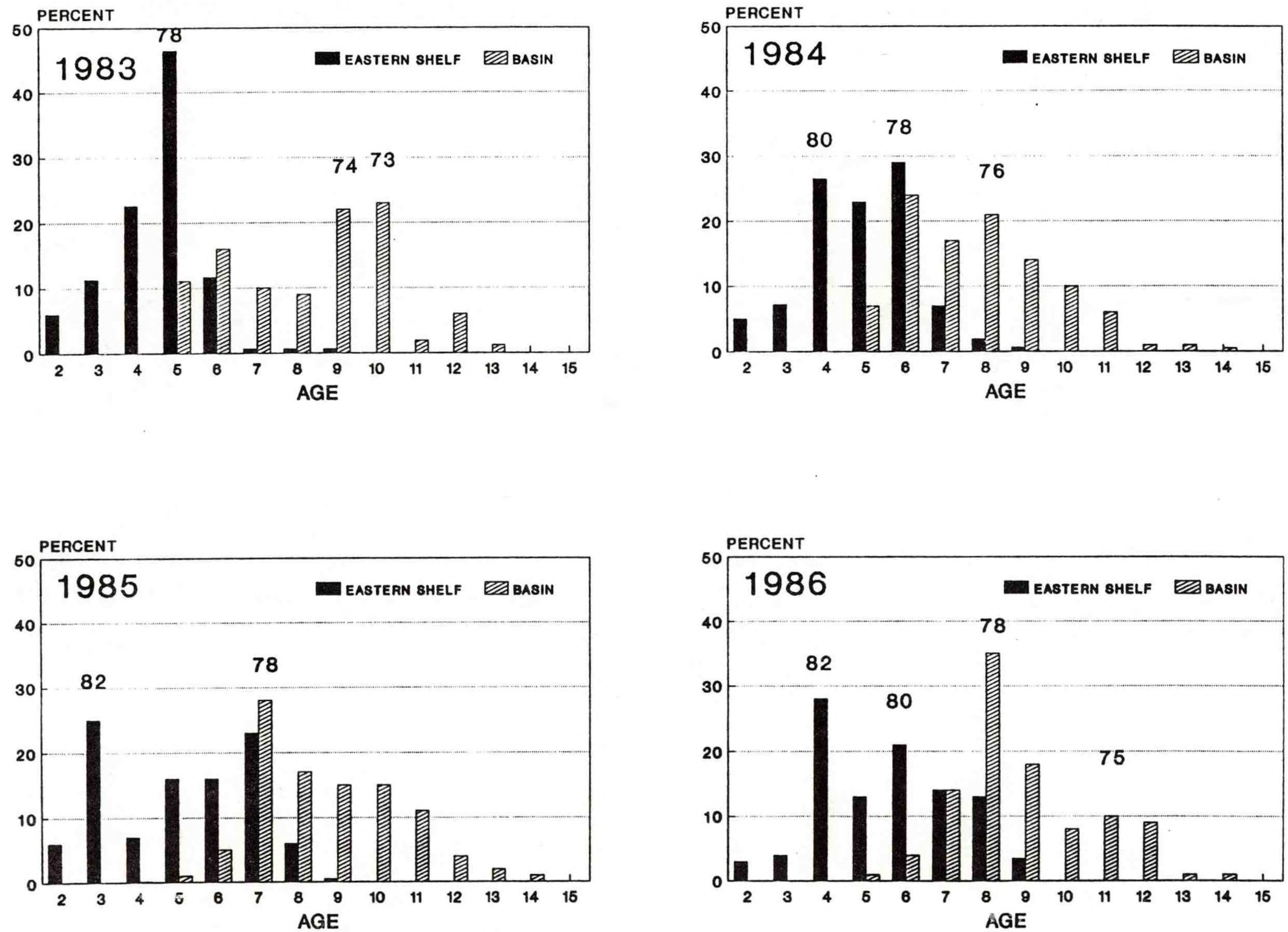

Figure 4.--Age distribution for pollock in 1983-86 on the eastern shelf and in the Aleutian Basin.

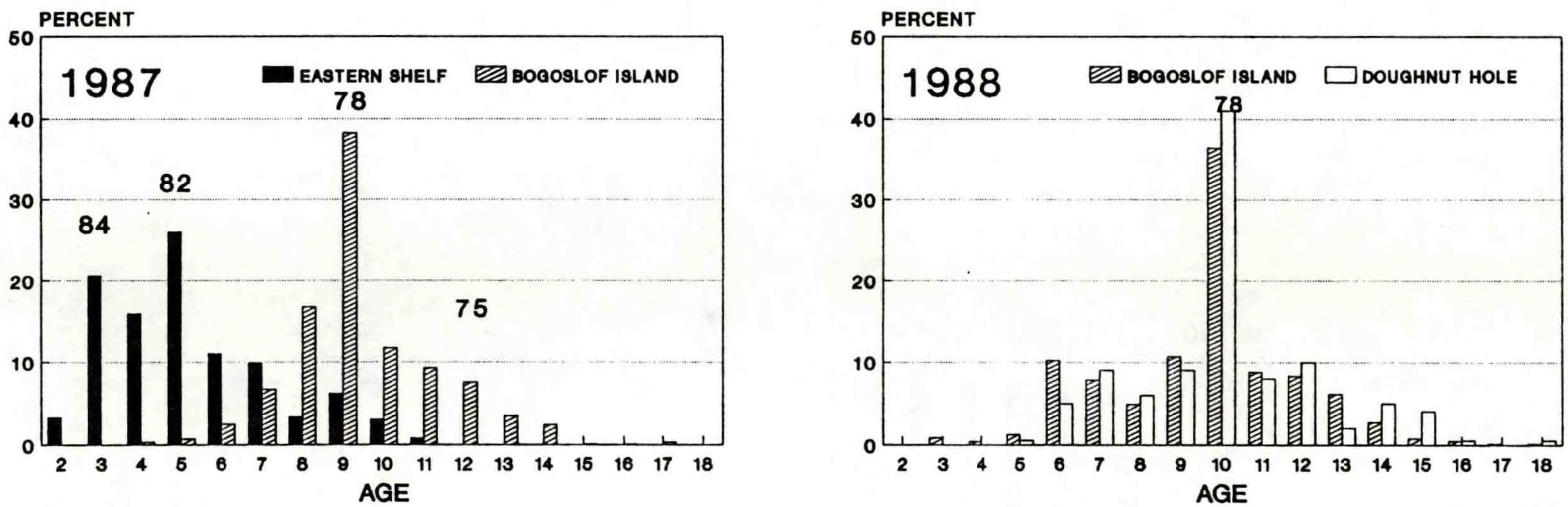

Figure 5.--Age distribution for pollock in 1987-88 on the eastern shelf, in the Bogoslof Island area, and in the doughnut hole.

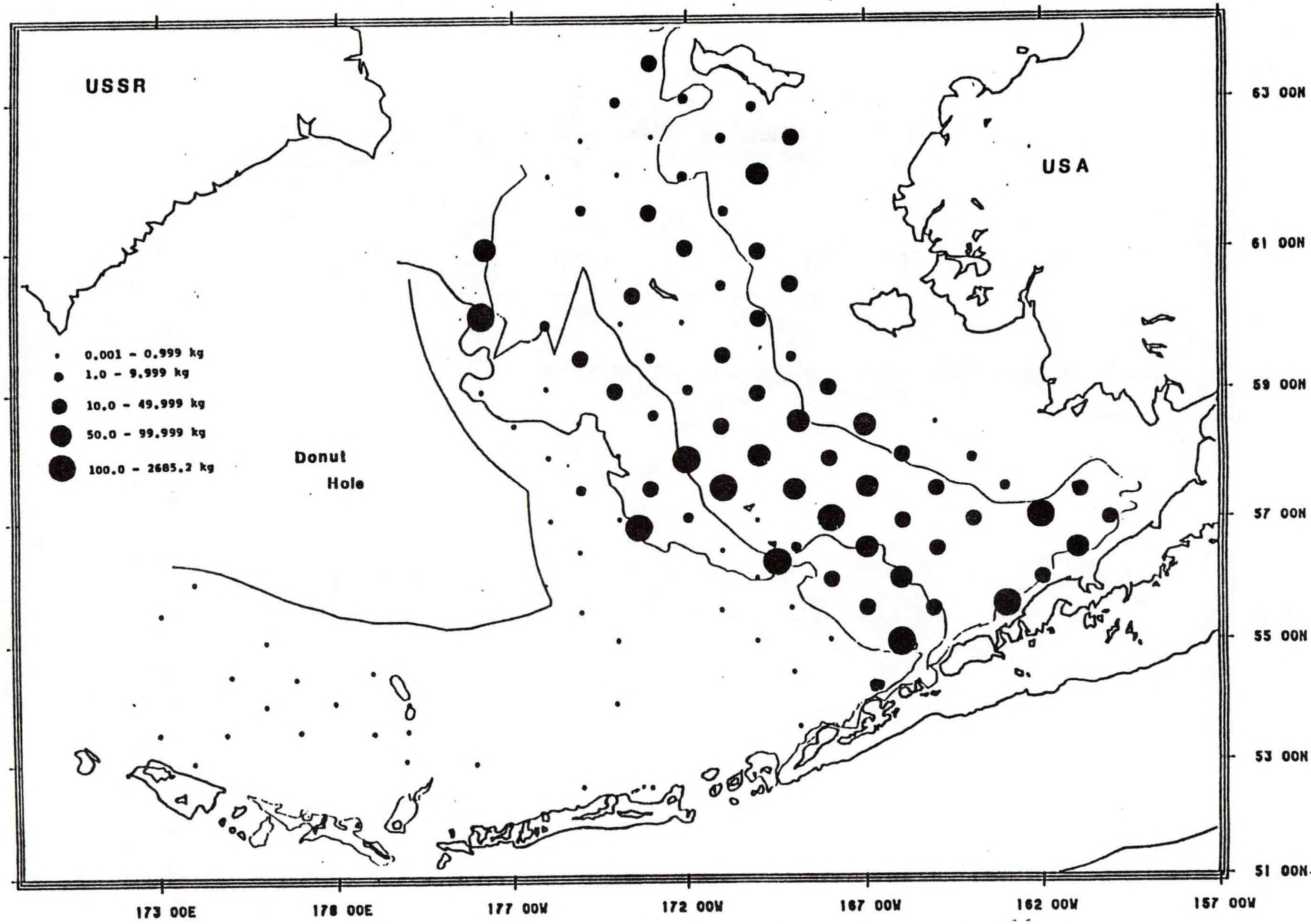

Figure 6.--Relative juvenile pollock abundance from the RV Darwin, 22 August-8 October 1987.

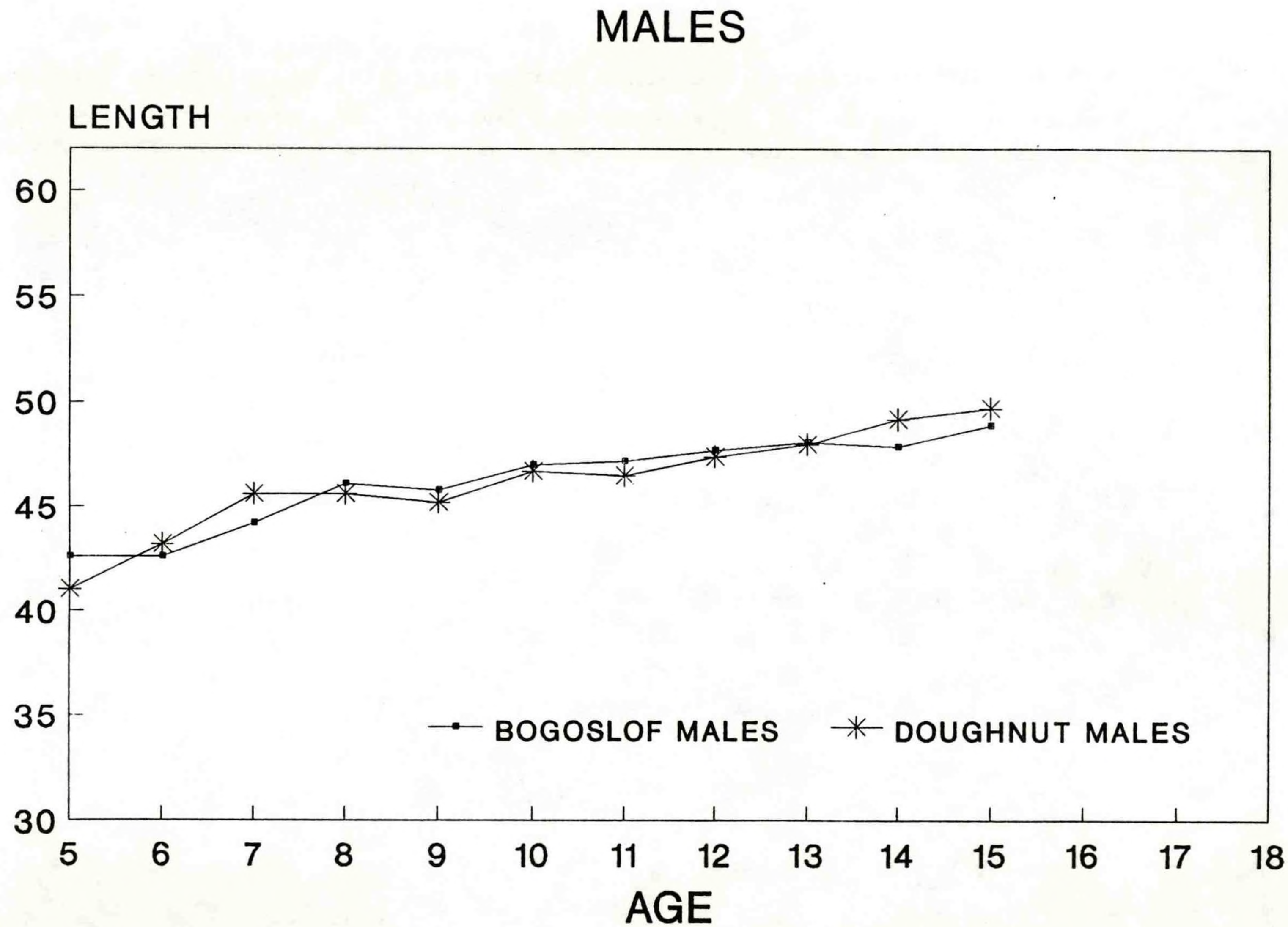

Figure 7.--Mean length-at-age for male pollock in 1988 between Bogoslof Island area and the doughnut hole.

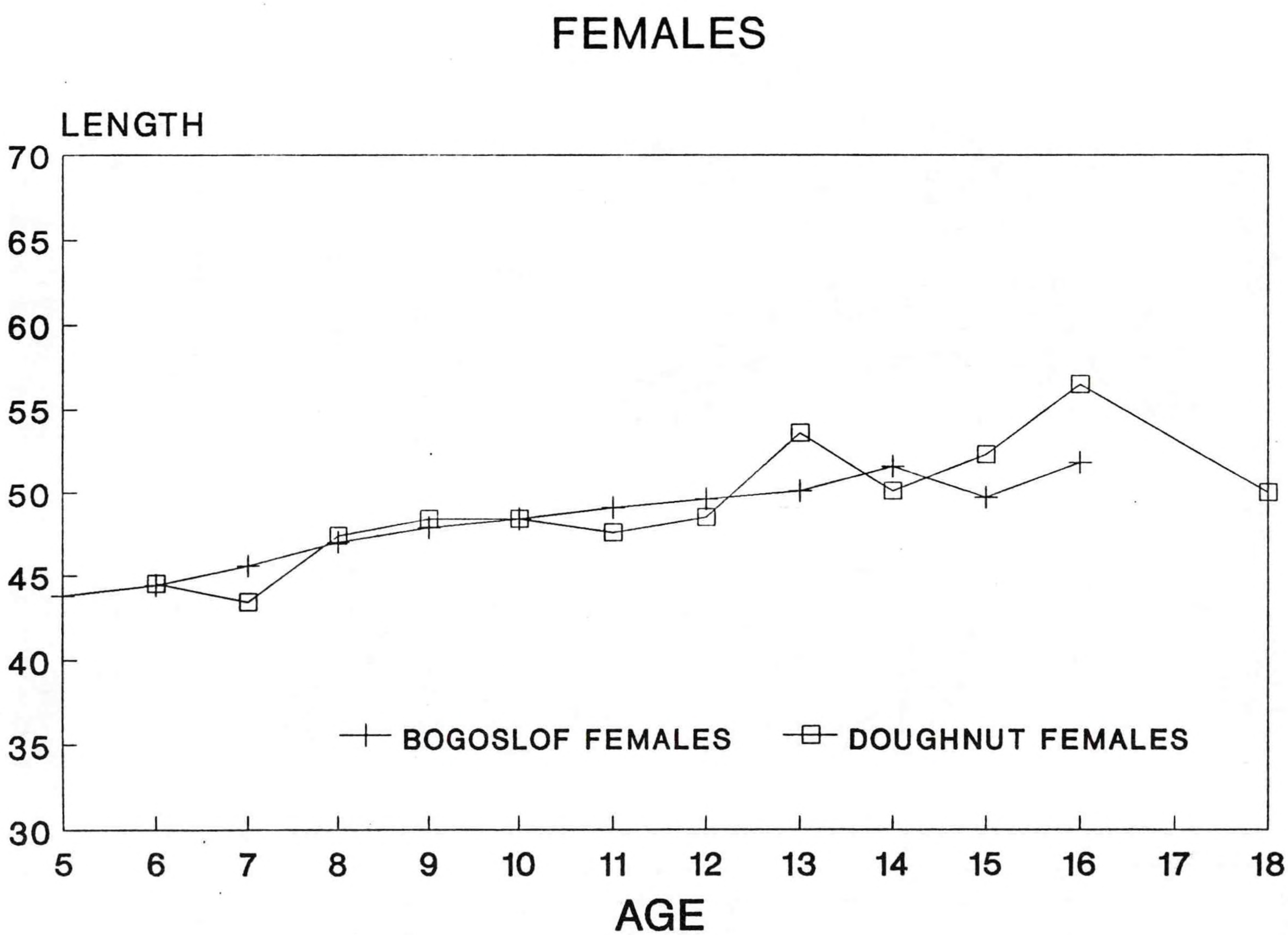

Figure 8.--Mean length-at-age for female pollock in 1988 between Bogoslof Island area and the doughnut hole.

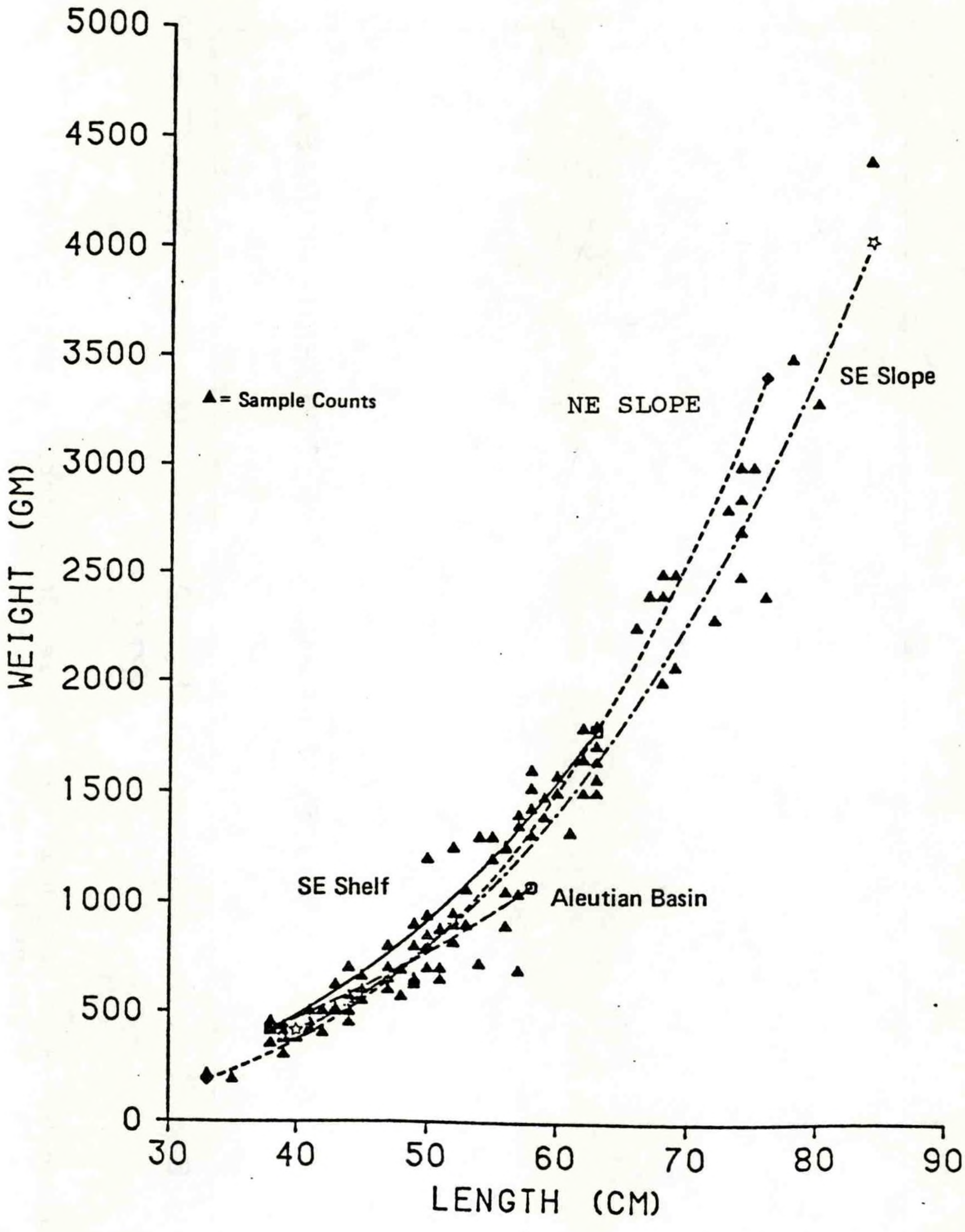

Figure 9.--Length-weight relationship between pollock from four areas of the Bering Sea (from Hinckley 1987).

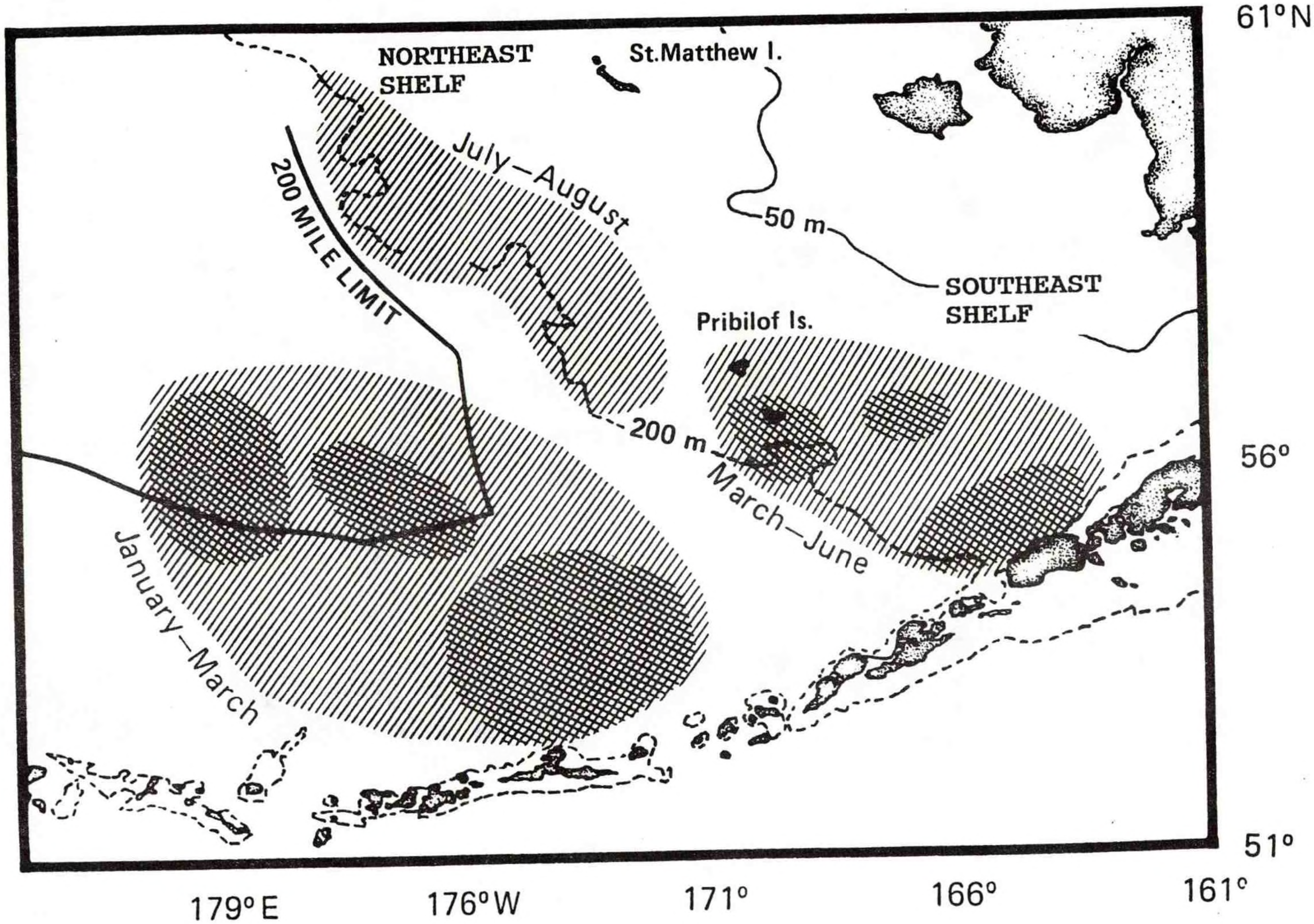

Figure 10.--Spawning locations in the central and eastern Bering Sea, 1984-1985 (adapted from Hinckley 1987).

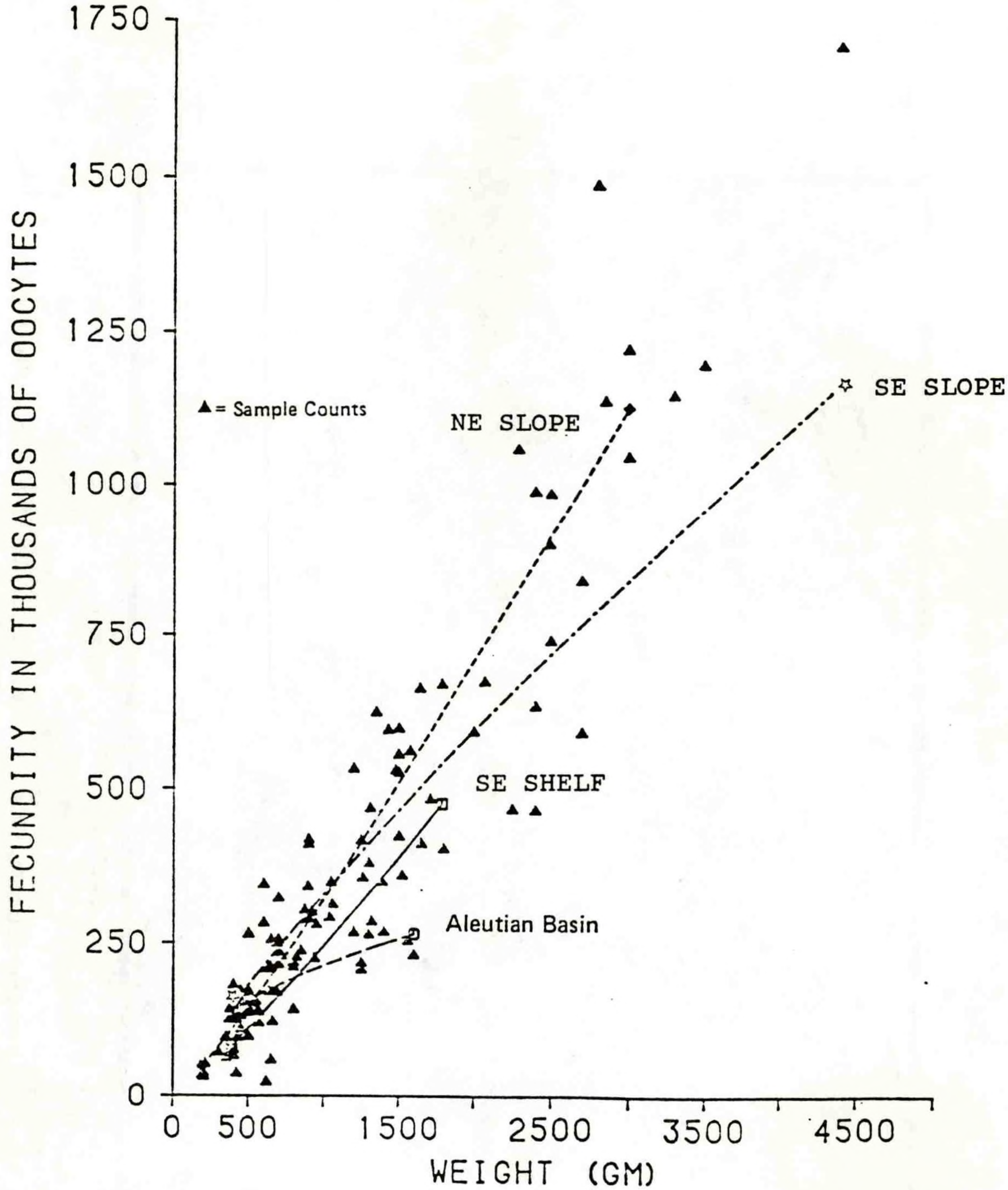

Figure 11.--Relationship between fecundity and weight for pollock from four regions within the Bering Sea (from Hinckley 1987).

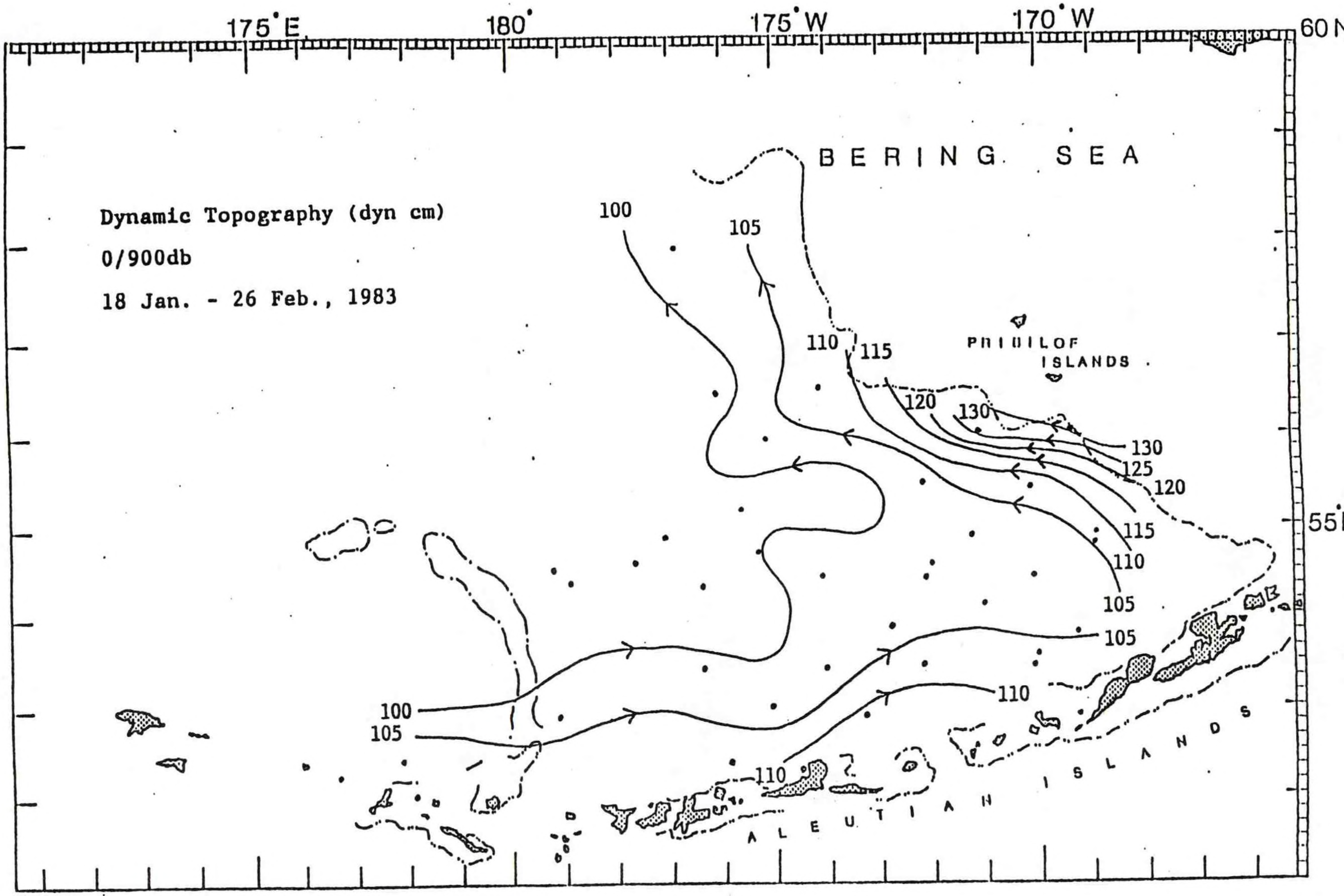

Figure 12.--Geopotential anomaly in the southeastern Aleutian Basin at the sea surface with respect to the 900-decibar surface (from Kitani 1983).

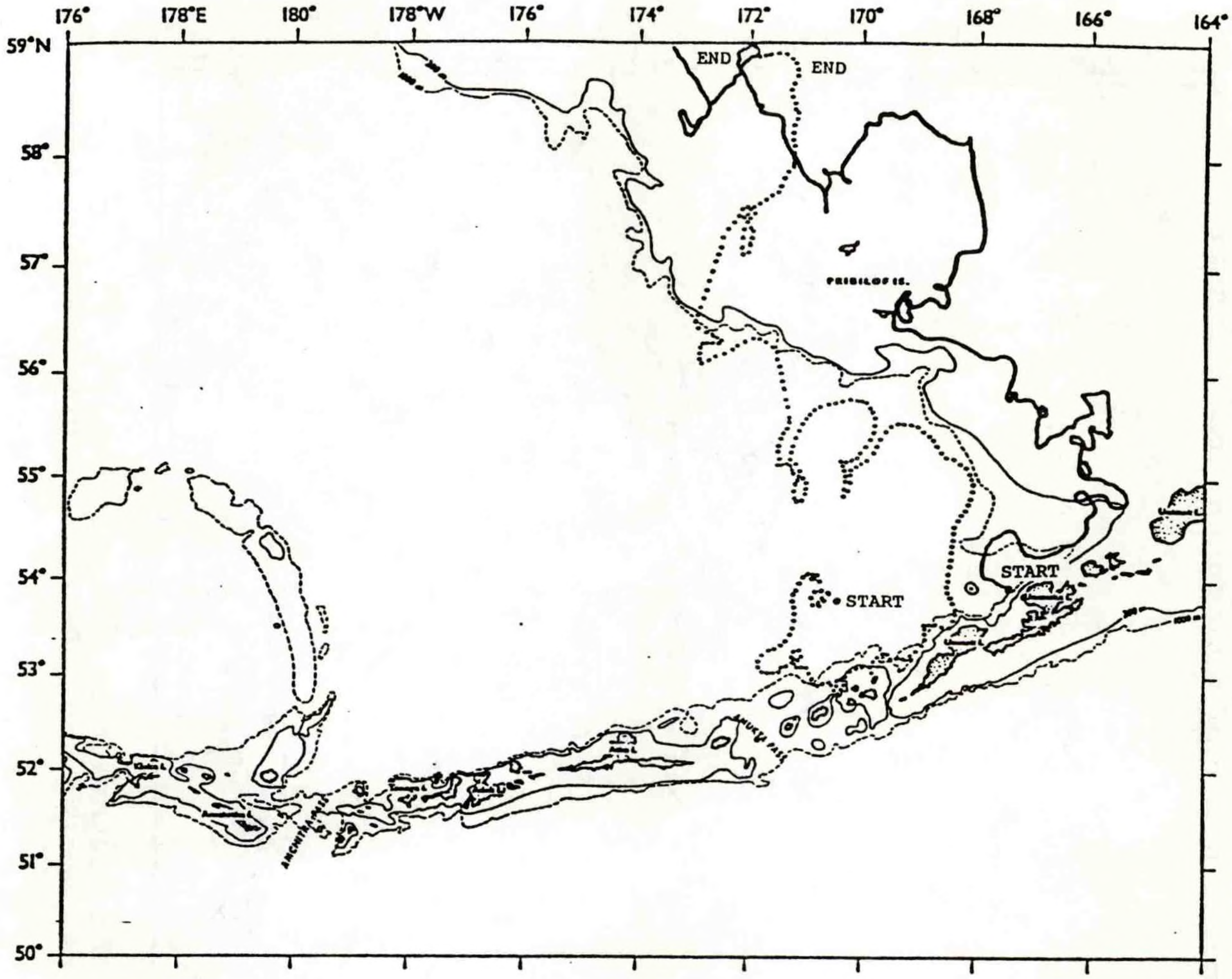

Figure 13.--Trajectories of satellite-tracked buoys deployed in the southeastern Aleutian Basin in February 1986 (from Reed et al. 1988).

THE SPATIAL STRUCTURE OF THE BERING SEA POLLOCK AND THE GENERAL DIRECTIONS OF THE FISH RESOURCES INVESTIGATIONS

Fadeev N.S. TINRO

In the last 20 years the primary commercial fishery species in the North Pacific is the pollock having been consistently leading both in the absolute catch and the relative percentage. The total yield of pollock reached 6 mln. tons and after a slight decrease in the late 70-s stabilized at 5 to 5.5 mln. tons.The pollock are fished practically all over the entire range of their distribution at the different fishing rate close to the natural limit in the majority of fisheries. The primary importance is attached to the pollock in ecosystems for the dominance in biomass and abundance among all the species. The Bering Sea is one of the largest fishing areas. The pollock fishery started to develop here somewhat later than in the other areas of the pollock range and prevailed in the eastern Bering Sea which is now under the US jurisdiction. By the mid 70-s the pollock yield reached 1.8 mln. tons and the total for the sea catch was 2 to 2.5 mln. tons. After the extention of national jurisdiction over 200-mile zones the total Bering Sea catch fell to 1.5 - 1.8 mln. tons and stabilized at this level until it was increased almost by 1 mln. tons because of the high seas fishery over the Aleutian trough in the mid 80-s. Thus the total harvest of pollock in the Bering Sea is at present about 2.8 mln. tons, i.e. much larger than before the 200-mile FCZs establishing.

Speaking of the Bering Sea pollock fishery one can't but mention the fact that in late 50-s when the eastern Bering Sea fisheries were on the rise the pollock abundance was relatively low. By the estimates of some US scientists the pollock biomass did not exceed 500,000 tons in the 50-s. The pollock was comparatively low abundant species like, for instance, cod, herring and rockfish. It was only in 60-s when the pollock abundance greatly increased and with the progress in this fish processing technology contibuted to the growth of the pollock fishery. There are several hypotheses almost equally grounded in relation to the causes of the rapid growth of the Bering Sea pollock abundance. Weakness of the hypotheses is attributed to the lack of factual data on the pollock resources before the 60-s. But there is no doubt that the period of 50-s in the Bering Sea, in its eastern part in particular, should bear the title of the "pollock-less" period.

In view of the great significance of the pollock for fisheries, their important role in the ecosystems and the growth of the harvesting rate the Soviet scientists conduct extensive investigations on this species. Every year the complex of trawl-acoustic and ichthyoplankton surveys alongwith hydrological and hydrobiological observations are executed by 2 - 3 research vessels in the Bering Sea. Our investigations cover the oceanic populations of the pollock too over their habitat in the Gulf of Alaska. The principal aim of these investigations is assessment of the fishery stocks and the absolute abundance (biomass). For this purpose the techniques of assessing the pollock resources by means of eggs and trawl-acoustic surveys have been developed and employed that could be illustrated with the recent cruise of R/V "Darwin" in March - June (Table 1). Estimates made by both the eggs and the trawl-acoustic surveys have appeared to be rather close if to bear in mind that the trawl catchability (efficiency) has been assumed equal 100%. In the recent years the studies of the intraspecific structure of the Bering Sea pollock have acquired the utmost importance. This problem is growing critical in view of the large-scale pollock fishery in the Bering high seas. Despite all the efforts the problem of intraspecific differentiation of the Bering Sea pollock remains understudied. The important step in this direction is the studies of the pollock distribution by the spawning areas. As a result of the ichthyoplankton surveys which have lately been conducted by the Soviet research vessels simultaneously in the USSR and US EEZones it has been revealed that the major spawning grounds of the Bering Sea pollock are located in the western and eastern parts of the Bering Sea with a distinct spatial interval between them. In the US waters the most intensive spawning occurs in Unimak-Pribilof area and in the Soviet waters it takes place in Olyutorskiy area and partially farther to the North up to about 176°E. Like in all other areas of the pollock range the overwhelming majority of the spawning fish and the spawned eggs are found on the shelf over the depths not exceeding 150 m. In the areas to the north-west and the north-east the abundance of eggs, larvae and spawners is much lower. For instance, in 1985-1986 on the above spawning grounds were about 90% of all observed eggs and in Navarin and St.Matthew areas, i.e. in the north of the Bering Sea only 5 - 10%. In April, 1988 we observed only 3.5% of eggs of the total numbers in the area to the north of Pribilof Islands. Approximately the same ratio in distribution of the pollock spawners has been observed for the areas in the spawning period.

Although practically no spawning occurs in the northern part of the sea the large-scale fisheries have been developed in the border waters along the USSR-US delimitation line. In the Navarin area of the USSR EEZ the annual catch for the period of 1977 to 1986 was on the average 500,000 tons with the maximum catch exceeding 900,000 t. A considerable portion of the maximum sustainable yield in the US EEZ has been taken in the area to the north of St.Matthew Island where in 1984 over 70% of pollock were harvested. Thus, the USSR-US bordering waters make the largest pollock fishing area not only in the Bering Sea but in the North Pacific too. From the very start of the fishery and investigations in the Navarin-St.Matthew area our attention has been drawn to the predominance of small size pollock, mainly immature and under 35 cm length in the catches. Besides the distinct clinal variability of the size composition has been revealed from the south to the north both in Asian and North American waters. The prevailing mean and modal sizes are found consistently shifting to the left in the direction of the north-west and the north-east from the spawning grounds. The decrease of sizes and the consequent increase of immature fish percentage have been clearly traced in all the years of observations including 1988 of R/V "Darwin" cruise (Table 1). In fall of 1987 the young pollock, mostly immature, with predominance of 2 - 4 year old fish were observed in St.Matthew area of the US EEZ. Almost the same size and age structure has been observed in the adjacent waters of the USSR EEZ.

On the other hand, the analysis of fishery and biological statistics exposes the consistent changes in the catches and their structure in Navarin area during a year. Catches per effort and the percentage of large size pollock notably increase in the summer-fall period which has been well evidenced by the mean for many years (1982-1986) and annual data. The maximum catches and percentage of mature fish are normally observed in August-November and their minimum in January-May, i.e. in the spawning period. At the time the sequential increase of sizes of fish after spawning has been traced in the direction from the south to the north in the USSR EEZ. These observations can be attributed only to the postspawning pollock migration to the N.

Table 1

Results of the Pollock Surveys in the Eastern Bering Sea in April - May, 1988 (R/V "Darwin)

Abundance of eggs and larvae (10^{11})		- 2597
including that of the areas:		
Unimak		- 1185
Pribilof		- 1320
St. Matthew		- 92
Pollock biomass based on trawl-acoustic survey (10^3 tons)		- 4335
including that of the areas:		
Unimak		- 723
Pribilof		- 1547
St. Matthew		- 2065
Percentage of fish 25 - 35 cm and 40 - 50 cm in length by the areas:		
Unimak		2.1 - 46.1
Pribilof		12.5 - 42.3
St. Matthew	1	41.1 - 23.0
"	2	52.9 - 9.6
"	3	63.9 - 1.2

The virtually complete lack of the pollock spawning in the northern Bering Sea and the consistent patterns of the spatial variability of size and age structures in the Asian and North American waters are the established facts. When combined they give the ground to believe that the Bering Sea area in question is inhabited by the recruitment, immature part of pollock stocks produced on the Asian and North American spawning grounds, in other words, this is the area mixing for the pollock from different spawning grounds. In the

Aleutian and Kommander Basins. Here the pollock are mostly found in scattered rather mobil schools but sometimes, particularly in the fall - winter period the fish form the dense and stable aggregations heavily fished in the international waters. For establishing the origin of that pollock the evidence of spawning or lack of spawning is of principal importance in this area. Analysis of the size and age structure has shown that this area is always inhabited by large pollock over 36 cm in length at the 5+. No immature fish under 35 cm in length have been obderved during the entire study period. It is also known that over the virtually entire range of distribution the pollock spawn on the shelf. There is no data on the pollock spawning beyond 300 m isobath while occurrence of feeding pollock aggregations is usual in the areas over great depths. The spawning grounds are recognized normally by revealing the eggs in ichthyoplankton and the spawners in catches. Insofar no evidence of such facts has been found in the Bering high seas. Aggregations of large pollock are observed here from May to February. In the period of March to April, i.e. the peak of spawning, the pollock are either absent or very few in numbers in this area and scattered which is not characteristic for their spawning behavior. In late February and early March, 1988 R/V "Darwin" fulfilled about 30 ichthyoplankton stations by sampling the 0 - 500 m layer with IKS-80 net. No single egg has been found in the samples. The pollock, according to our observations and the information of the fishing boats, were found in small quantities and very scattered which is characteristic for migrating fish. The eggs started to occur in ichthyoplankton only with the approach to the southeastern shelf, approximately from 110 m isobath. The dense aggregations of pollock were discovered over the slope in Pribilof-Unimak area. In the first week of March the spawning had just started and the eggs catches were small in comparison of those in April with the absolute predominance of eggs at early stages of development. The April survey gave the evidence that the peak spawning started in late March and lasted to the mid April. By the end of April about 70% of females were spawned but the spawning continued through May and even June. The similar situation was observed in the western part of the sea where R/V "Gissar" conducted surveys. All the eggs were caught at depths not beyond 200 m with the obvious trend of decreasing frequency in the direction of the continental slope.

In May, 1988 R/V "Darwin" filfilled several ichthyoplankton sampling stations with IKS-80 and Bongo nets in the eastern part of the high seas area. The eggs were caught only at one station of horizontal sampling, while the samples taken nearby contained no eggs. Females of the pollockfished here (2 - 3 tons per 4 hours trawling) were all spawned whereas in the catches over the shelf about 30% of females contained still ripening eggs. Approximately similar results acquired R/V "Gissar" conducted investigations in the west at the same time. Judging by the fishery evidence the pollock were very mobil, formed no stable aggregations, were scattered and intensively feeding. The fishing conditions were extremely unstable.

In 1988 the pollock stock over the shelf of the eastern Bering Sea has been estimated around 6.4 mln. tons including 3.7 mln. tons of adult fish. On the Asian spawning grounds the spawning rate retained the level of the previous years. On the other hand, based on the trawl-acoustic surveys the estimate of the mature pollock stock in the Aleutian and Kommander Basins has been approximately 7 - 8 mln. tons. The results of R/V "Darwin" surveys in 1987 showed that in the eastern part of the sea the older aged mature pollock were very scarce in September-October and thiscoincided in time with formation of their dense aggregations and the intensive fishery in the high seas area. In case the spawning occurs in the high seas area one would expect the greater frequency of eggs in ichthyoplankton samples in view of large quantities of adult fish. The eggs numbers here should be more commensurable to those annually observed on the North American and Asian coastal spawning grounds. Nothing of the kind is observed in reality. Hence the conclusion is that no noteworthy spawning of pollock occurs in the Bering Sea high seas. The feeding aggregations in the Aleutian and Kommander Basins are formed by the pollock spawning on the North American and Asian grounds. In July right after the spawning the pollock steadily migrate to the west and the east and widely disperse over the entire sea, intensively feed and only in fall they gather in dense aggregations mainly in the deepwater areas of the Bering Sea. In January-February the back migration starts for the spawning grounds.

It is too early so far to speak of the rate of mixing of the Asian and American pollock populations and its interannual variability. As the matters connected with intraspecific structure of the Bering Sea pollock are of great practical significance in view of the stock management there appears the necessity to expand the researches and to apply the new impact and content. The efficiency of researches will considerably increase provided the international cooperation, first of all between the scientists of the USSR and the USA is developed as these are the countries directly concerned over the stock conservation.

The cooperation of the USSR and US scientists in investigations of the fish resources of the North Eastern Pacific has been lasting since long ago. A certain success has been gained, the programs of the cooperative and coordinated researches have been worked out and implemented. The dozens of cooperative surveys have been fulfilled on the Soviet research vessels. The most fruitful were the cruises in which participated the US specialists. This is related, first of all, to the Westcoast waters off Washington, Oregon, California and the Gulf of Alaska. As regarding the Bering sea the cooperative research here has been lagging behind not rising upto the significance of the sea's resources for the both countries. The scientists of the USSR and the USA conducted investigations under their national programs and with almost no coordination. In the cruises on the Soviet vessels took part mostly the US observers in majority nonspecialists. The Soviet scientists have never participated in the US vessels' cruises. The exchange of materials has been executed on the regular basis but because of incompatibility of programs and techniques the data have been rarely used. Hence the great discrepancy occurred in the stock estimates. We believe that cooperation of the USSR and US scientists in research of the Bering Sea resources and the resources on the whole could be considerably expanded and put on the far stronger methodical basis. The successful and exemplary in this regard is the latest cruise of R/V "Darwin" in the course of which alongwith the American were conducted the ichthyoplankton surveys in the Gulf of Alaska and the bottom trawl surveys on the eastern Bering Sea shelf. Right after their completion has been executed the exchange of the primary materials and this will further prevent duplicating the cruises.

The necessity of close cooperation in the Bering Sea resources studies is dictated by, first of all, the unity of the ecosystem on the whole, the common stocks of some species and the growing rate of fishery in the high seas area. With this in view it seems reasonable to work out and discuss the program of cooperative research on the whole and for selected areas. Having in mind the state of knowledge and the biology of the principal species, I suggest to plan implementation of several standard surveys and selected research programs in the framework of the General Plan for the nearest 5 years.

Taking into account the high fishing pressure on some species the primary task remains the same: monitoring the state of resources and environment. In this connection it is necessary:

1. Every year to conduct the ichthyoplankton surveys on all the pollock spawning grounds for the purpose to estimate the spawning rate , abundance and biomass of adult fish and recruitment. The most optimal term for the entire Bering Sea survey is April to May,if the surveys be conducted by the standard grid of stations maximum simultaneously in the same period all over the sea and every year their value would essentially increase. The surveys could be fulfilled both on the Soviet vessels or on the boats of the USSR and the USA simultaneously. In the first case it would require to solve the problem of, at least partial compensation of the expenditures by the parties cocerned. During such surveys it is necessary to provide for collecting samples for morphological and genetics-biochemical studies of all the Bering Sea pollock and samples for drawing the charts of the size-age structure keys, fecundity and the maturing rates.

2. Every year to conduct the bottom trawl survey over the shelf of the eastern and northern parts of the Bering Sea for studies of distribution and the state of stocks of groundfish and crabs. If trawls are properly rigged this survey could be used for assessment of abundance of 1 year old and 2 year old pollock with a view to develop the techniques of forecasting abundance of year-classes. The best time for this survey is June to July with the duration (for one vessel) 1.5 months. The survey should be accompanied with ichthyoplankton sampling for collecting eggs and larvae of flatfish and the pollock of late spawning.

The following surveys could be organized every 2 or 3 years:

1. In January - March, 1989 to conduct the trawl-acoustic and ichthyoplankton surveys in the high seas of the Bering Sea including the Aleutian and Kommander Basins. The surveys should be carried out on two vessels with the agreed upon the grid of stations and the fishing gear calibrated in advance. The exchange of specialists on the partners' vessels should be compulsory.

2. Every three years to conduct the bottom trawl surveys over the continental slope of the Bering Sea on the whole or in selected areas by turns. The state of fish resources of the Bering Sea bathial has not been studied for tens of years now.
3. To make an emphasis on investigations of fish resources in the Pacific waters adjacent to the eastern islands of Aleutian Range. In this area the independent populations of pollock and cod are not unlikely to occur. For this purpose to perform a special research cruise including the trawl-acoustic and ichthyoplankton surveys.

It is suggested to conduct the large-scale pollock tagging on the major spawning grounds in 1989-1991 for studying the migrations and the rate of mixing of separate pollock stocks.

RESULTS OF THE POPULATION STUDIES OF WALLEYE POLLOCK *Theragra chalcogramma* IN THE BERING SEA

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and Magdalena Kowalewska-Pahlke*

Abstract

Materials for the study were collected in two regions of the Bering Sea in the spring of 1987. A total of 219 specimens (11 samples) collected in the international waters of the Bering Sea (Donut Hole) and 98 specimens (4 samples) from south-eastern shelf were analysed. Pollock from international waters was characterised by distinctly lower mean lengths in age groups as well as lower weight than fish from shelf waters. The results of investigations of meristic and morphometric characters, analysed by means of methods used in numerical taxonomy (discriminant analysis, cluster analysis, principal component analysis) have made it possible to reveal significant difference between samples from international waters and those from south-eastern shelf of the Bering Sea.

INTRODUCTION

In 1985-1987 pollock catches in the international waters of the Bering Sea increased rapidly, reaching one million tons per year. The knowledge of the pollock stock structure with special emphasis on stocks definition problem in Bering Sea is necessary for proper fishery management.

A number of fishery scientist point to several differences in the population structure of pollock from different regions of the Bering Sea. Iwata (1975) differentiated eight local forms of pollock in the Sea of Japan and the Sea of Okhotsk. Serobaba (1977) discussed considerable differences in meristic and

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morphometric features as well as growth of pollock from various areas of the Bering Sea. According to him there are four pollock stocks in the Bering Sea: northern, western, eastern and another one in the Aleutian Basin. Lynde *et al.*(1985) revealed statistically significant differences in the growth of pollock from the Aleutian Basin and the south-eastern shelf. Hinckley (1987) differentiated three separate spawning stocks in the Bering Sea area: the first in the Aleutian Basin, the second over the north west continental slope, and the third on the south east shelf and slope and on the north west shelf.

In this paper, the results of morphometric and meristic and growth studies of pollock from the Donut Hole and the south-eastern shelf of the Bering Sea, carried out by the Sea Fisheries Institute in 1987, are presented.

MATERIAL AND METHODS

Materials for the study were collected between January and March 1987 on a Polish factory trawler "Sirius" fishing in international waters and taking part in joint venture on the south-eastern shelf in March. A total of 317 specimens of pollock collected in 15 samples was studied. The samples came from two regions: Donut Hole - 219 specimens (11 samples) and the south-eastern shelf - 98 specimens (4 samples), (Table 1, Fig. 1). Immediately after capture, fish total length as well as standard length and head length were measured to 1 mm, weight was recorded with an accuracy of 5 g, and the rays in dorsal, anal and pectoral fins, gill rakers on the first gill arch, and vertebrae (including urostyle) were counted. Otoliths were also collected for later age determination and their length and highs (left otolith) was measured.

Mean lengths at age for both sexes were determined. Due to the absence of young fish in the samples, growth parameters from the von Bertalanffy's model were not calculated.

The relationship between length and weight of fish was determined from the following formula:

$$W = k * L^n$$

where: W = weight of pollock in grams,

L = total length in centimetres,

k, n = coefficients.

For comparison of morphometric and meristic features in pollock from the two study areas, three statistical methods used in numerical taxonomy were applied: discriminant analysis, cluster analysis, and principal component analysis.

RESULTS

Length-age relationship

Mean lengths of pollock by age groups (Table 2) reveal distinct differences in fish growth in Donut Hole and on the south-eastern shelf. Mean lengths were much larger for fish of the same age from the shelf area than those from Donut Hole. This was true both for males and females. Figures 2 and 3 illustrate a situation in which 95% confidence limits of mean lengths from samples in age groups 7 to 9 do not overlap. These means are thus significantly different at the assumed confidence limit.

Length-weight relationship

The analysis of the pollock length-weight relation revealed that this relationship is the same up to length of 45 cm in both areas. In higher length classes, the weights of fish from Donut Hole are smaller than in south-eastern shelf. Because of the small number of analysed fish, the length-weight relationship was calculated jointly for males and females in the two areas (Fig. 4). The presented results might be biased by differences resulting from gonads maturity stages. In the Donut Hole area the gonads of the majority of females (95%) were at a premature stage, while the majority of females (54%) in the shelf area had gonads at spawning and postspawning stages. This attests to to the earlier spawning of fish in the area of the south-eastern shelf of the Bering Sea. It may be generally said that the differences in weight of pollock between the two areas are most visible in fish over 45 cm in length.

Analysis of morphometric and meristic features

In the study of morphometric and meristic features of pollock, three methods used in numerical taxonomy were applied. A general presentation of the mean values of the characters studied in pollock from Donut Hole and the south-eastern shelf of the Bering Sea are presented in Table 3, while means of samples used for taxonomic analyses - in Table 4.

D i s c r i m i n a n t   a n a l y s i s

Numerical variables concerning mean values of the samples were grouped according to sampling areas: international waters (10 samples) and southeast shelf (4 samples). Moreover, a third group concerning only a single sample (sample no. 10) was arbitrarily created as it comprised only females, differing considerably in age and length from the remaining samples. Thus it was possible to derive the third discriminant function and obtain a scatterplot of the results. The values calculated for discriminant functions for mean values of meristic and morphometric features of the samples, parameters of the centres of the groups selected, and the results of classification obtained on their basis are presented in Table 5, while discriminant functions are graphically depicted in Fig. 5.

The material analysed is well discriminanted by the variables. All groups are clearly defined by both functions and do not overlap.

C l u s t e r a n a l y s i s

The mean values of 12 variables (characters) were used to characterise 15 samples of pollock. A rectangular matrix was formed. A linear transformation of the variables was performed to standardise the matrix: the difference between the observed value and the mean of each variable was divided by standard deviation. The standardised data were used to compute a dissimilarity coefficient for interval measure data. A formula of average taxonomic distance has been applied:

$$d_{ij} = \sqrt{\frac{\sum_{k}^{n} (x_{ki} - x_{kj})^2}{n}}$$

where: d_{ij} - interval between samples "i" and "j",

x_{ki} - value of feature "i" for object "k",

x_{kj} - value of feature "j" for object "k",

n - number of objects.

On the basis of symmetric matrix obtained, an average linkage clustering was performed (unweighed pair-group method using arithmetic averages), as described by Sneath and Socal (1973). The correlation of the tree matrix obtained was 0.747. The results are presented in the for a dendrogram in Fig. 6. Three samples collected in international waters (12, 14, 15) are well groped. The fourth sample (13) differed distinctly from all analysed data. It could be a result of the lowest mean number of rays in fins characterising this sample.

P r i n c i p a l   c o m p o n e n t   a n a l y s i s

The rectangular matrix of the data standardised in the above described manner was transformed into a symmetric correlation matrix. Eigenvalue and eigenvector matrices were computed using the scaling option where length of the vectors equals the square root of their eigenvalues. The distribution of samples is presented in Fig. 7. Samples from international waters could be well separated from south east Bering Sea shelf samples on the presented graph.

CONCLUSIONS

The results obtained in the study may indicate that there are different stocks of pollock in international waters and south-east shelf of the Bering Sea.

The following differences were revealed:

- differences in growth rate of pollock between the two areas; the growth of fish from the Donut Hole area is much slower, pollock of the same age group attain smaller individual length;

- differences in length-weight relationship of the fish above 45 mm; weight of pollock from the Donut Hole was distinctly smaller at a given length;
- taxonomic differences; the morphometric and meristic studies reveal significant differences between fish inhabiting the two areas.

The study was limited to the analysis of samples from two areas of the Bering Sea situated at a considerable distance from each other. They thus constitute but a small contribution to a study of the problem requiring more extensive studies. However, the revealed differences between specimens collected in international waters and on south-east shelf of the Bering Sea suggest that the fish studied in the two areas belong to different stocks.

The observed differences in biological features, such as age, growth, and weight as well as in meristic and morphometric characters are difficult to account for solely by the differences in spatial or temporal distribution of specimens belonging to a single population.

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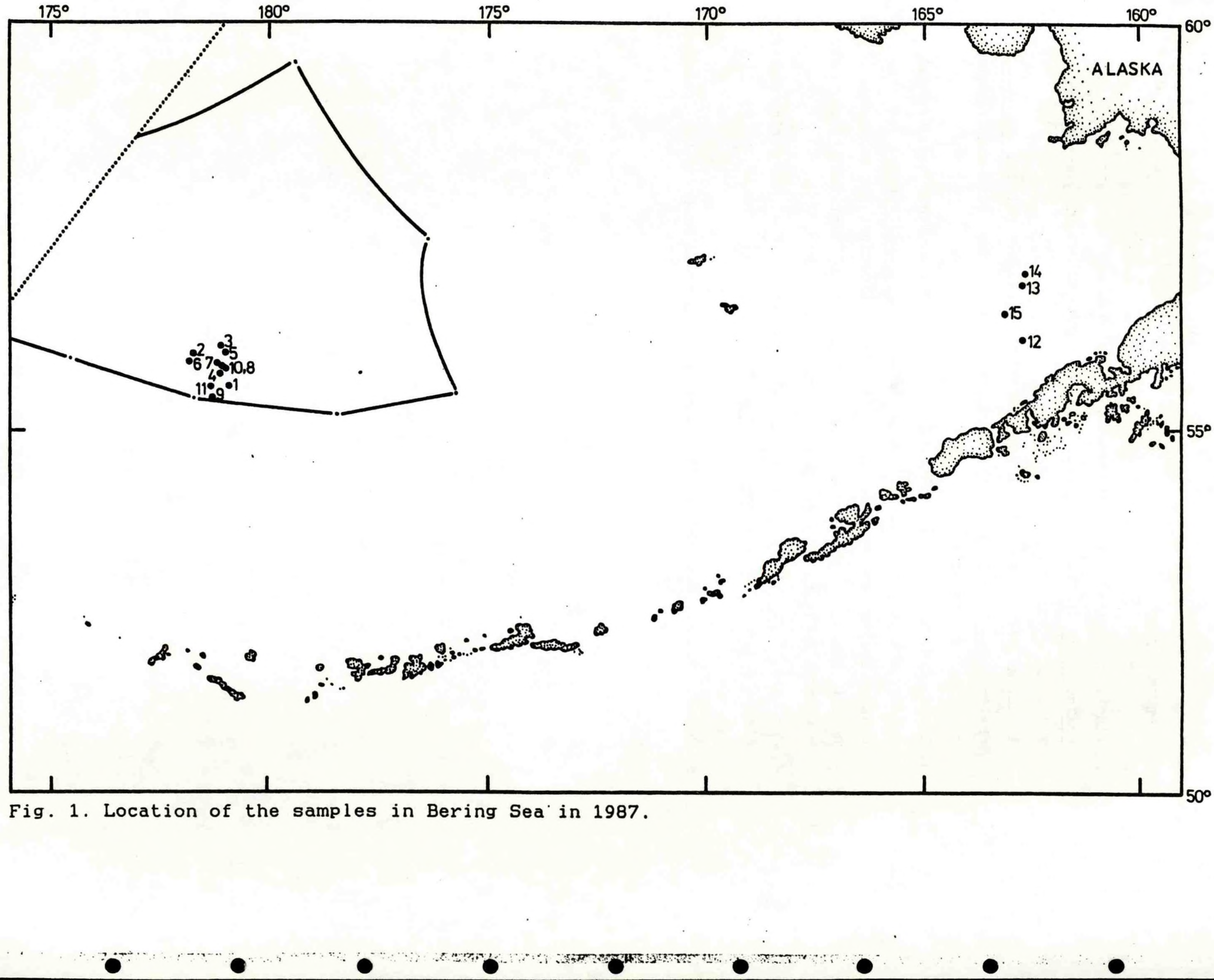

Fig. 1. Location of the samples in Bering Sea in 1987.

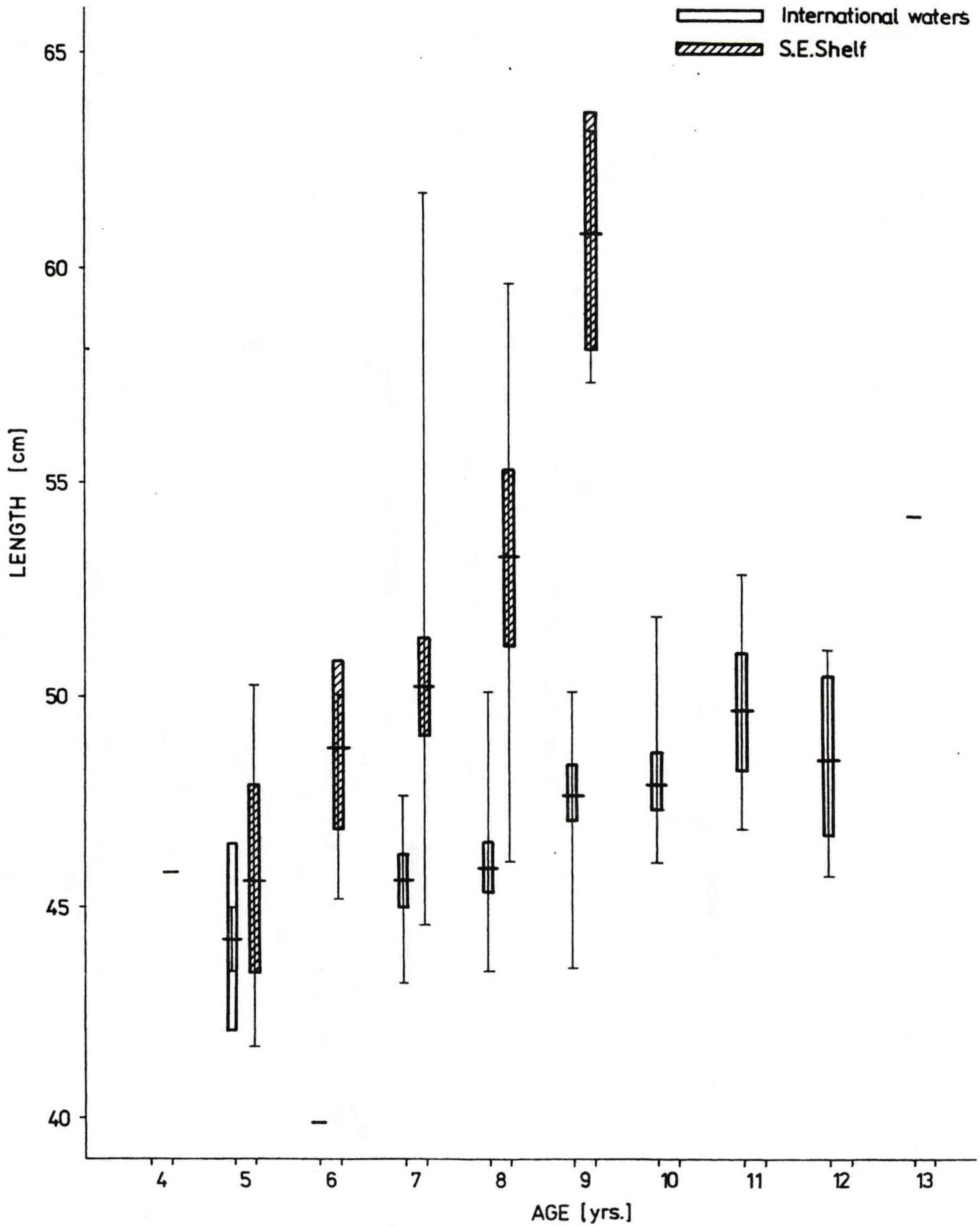

Fig. 2. Mean length at age of pollock males by investigated areas. Vertical lines indicate length ranges, horizontal lines - sample means, vertical bars - 95% confidence limits for the means.

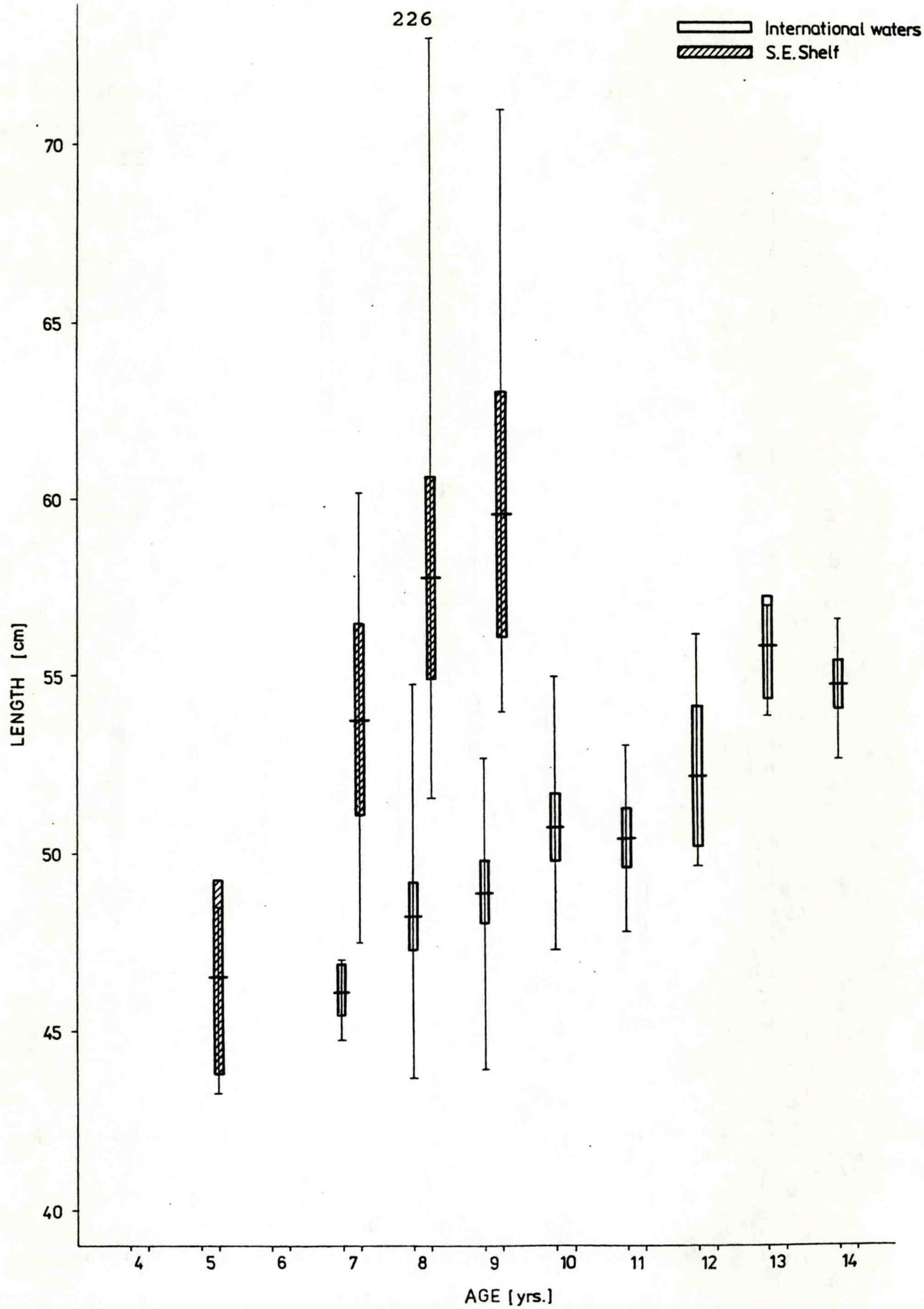

Fig. 3. Mean length at age of pollock females by investigated areas. For explanation see Fig. 2.

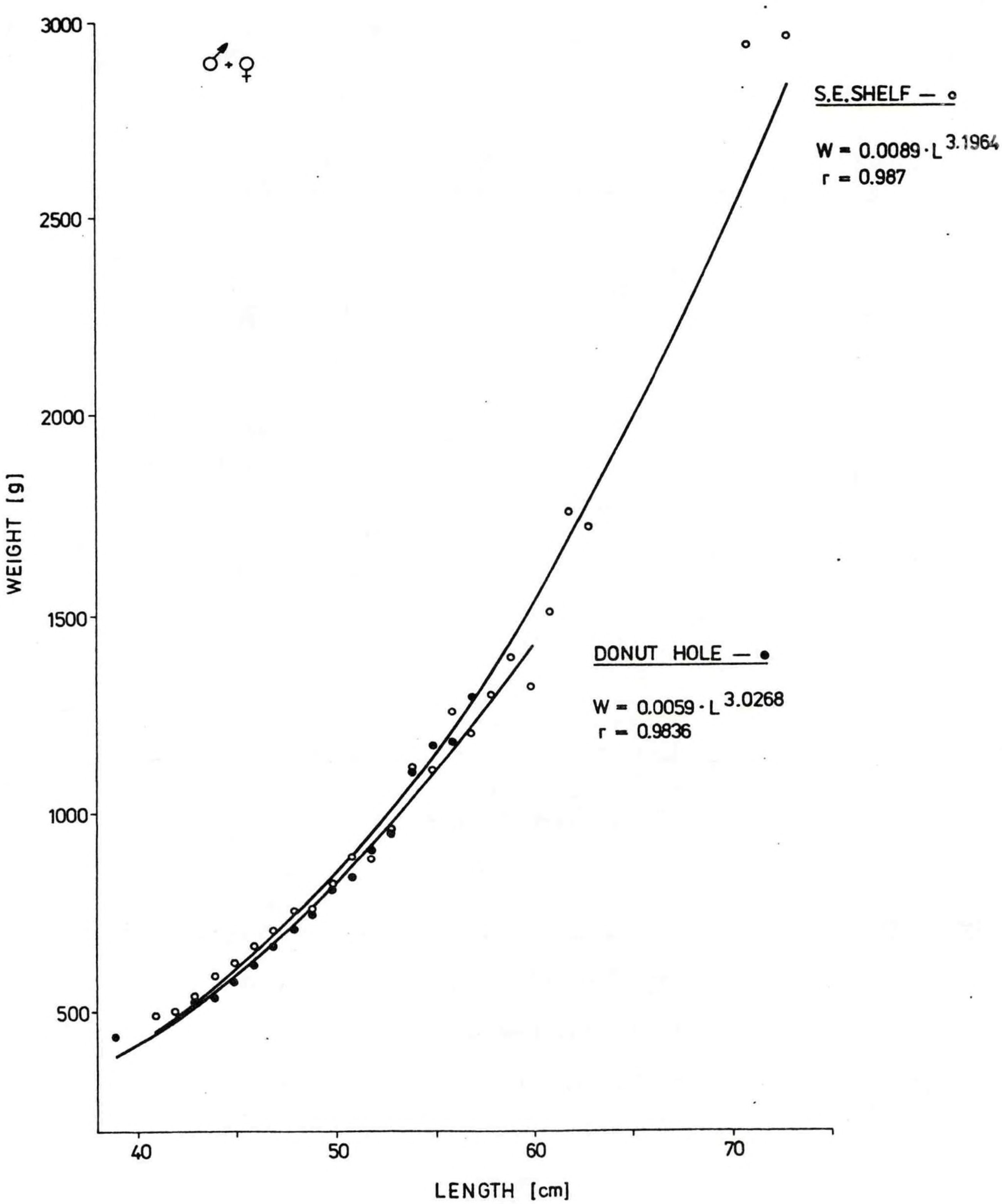

Fig. 4. Length-weight relationship of pollock by survey areas.

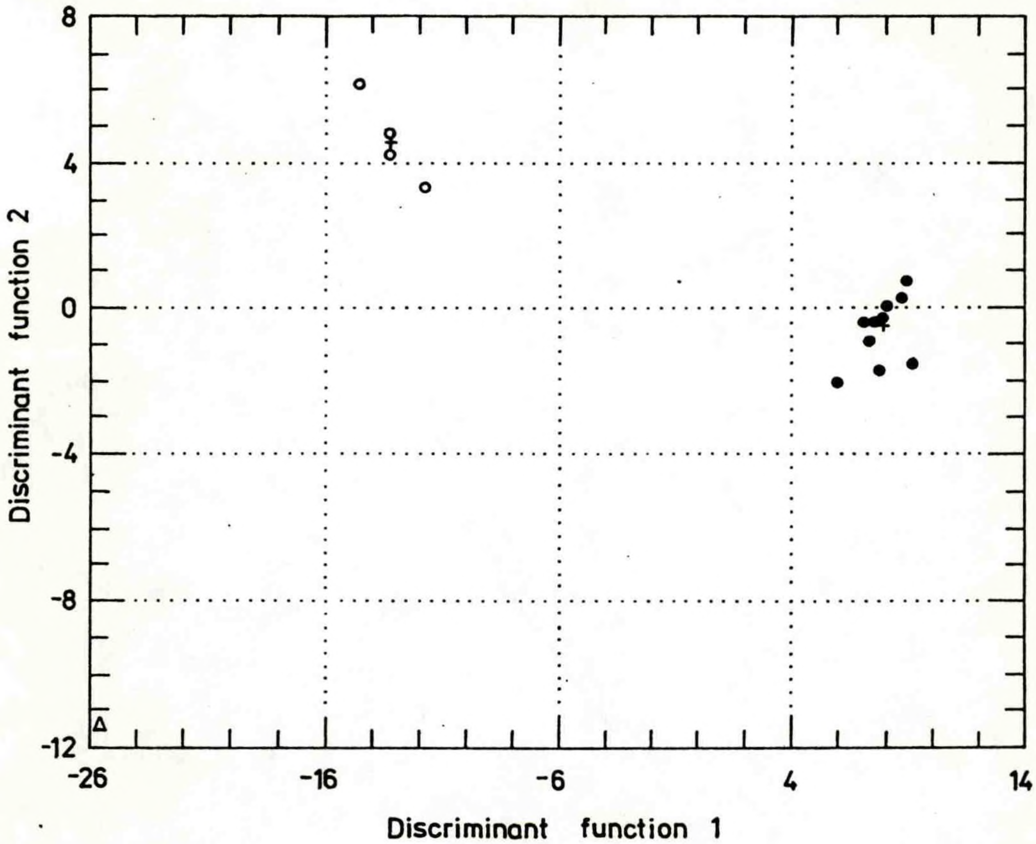

Fig. 5. Discriminant function plot for pollock samples. Solid dots - samples 1-9, 11 (Donut Hole); open circles - - samples 12-15 (south-eastern shelf); a triangle - sample 10 (Donut Hole); crosses - group centroids.

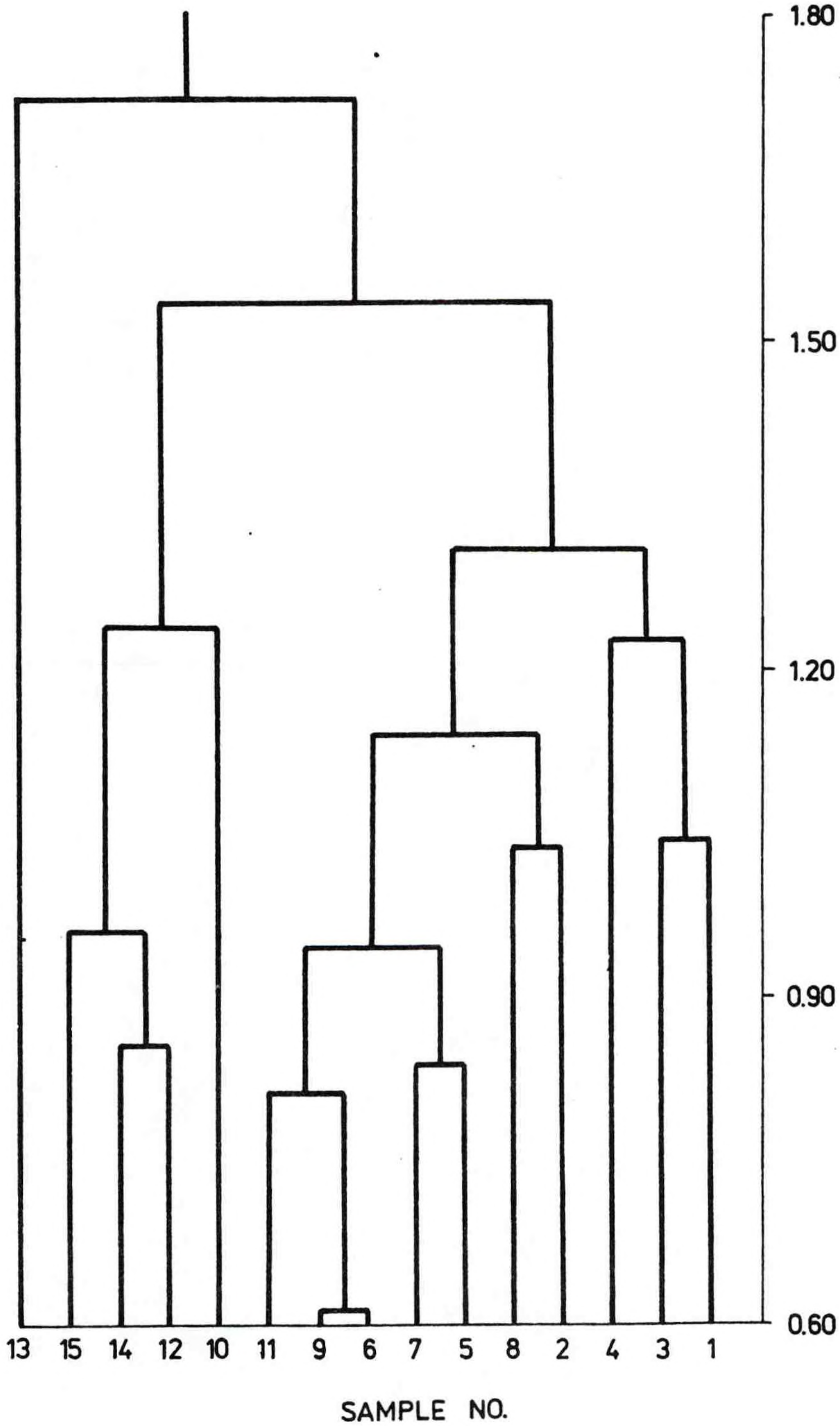

Fig. 6. Dendrogram for pollock samples dissimilarities.

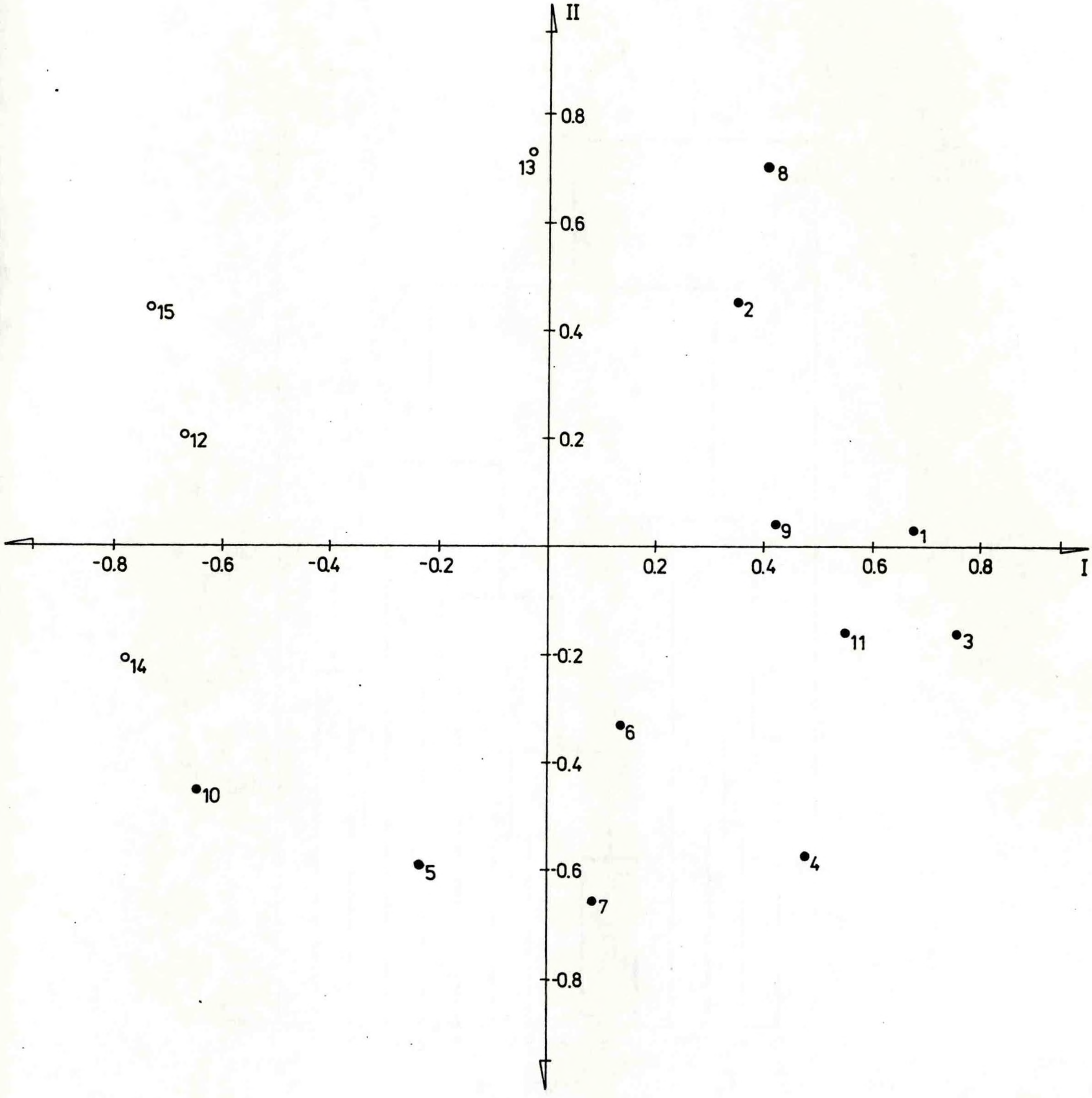

Fig. 7. Ordination plot from principal component analysis for pollock samples. Solid dots - Donut Hole; open circles - south-eastern shelf.

THE COMPOSITION AND THE PRESENT STATE OF PELAGIC FISH COMMUNITIES IN THE WESTERN BERING SEA

Sobolebskiy E.I., Shuntov V.P., Volkov A.F. TINRO

The comprehensive assessment of the biological resources and the state of the Bering sea environment is of great importance for the Far Eastern Fishing Association "Dalryba" harvesting about one million tons of fish. The significance of the Bering sea for the commercial fisheries, as our studies show, will even increase in future. The results of our complex surveys enable to verify the quantitative data on the main commercial species - pollock, herring, salmon, their juveniles and take a new objective attitude in assessing the biological resources, bioproductivity of the region and the structure of the pelagic communities. The particular attention is drawn to the discovery in September-December of the large aggregation of pollock to the North-East of Kommander Isls.

Taking into consideration the great interannual variability in bioproductivity, abundance of fish year-classes it is necessary to conduct the complex surveys over the entire Bering sea to verify the species distribution, their migrations, the patterns of commercial fish aggregations forming and the significance of pelagic fish in the biological balance of the Far-Eastern seas.

In this paper are mainly presented the results of the macro-surveys of epipelagic waters conducted in the Western Bering sea on R/V "Babaevsk" in 1986 and R/V "Gnevniy" in 1987.

Material and Methods

The surveys have covered the entire Western Bering sea within the USSR economic zone in September-October. The sampling has been conducted with the midwater rope trawls of 118/620 and 108/528 sizes with the vertical opening 50-60 m. The codend had the small meshed insertion over its entire length for sampling the fry and fingerling. The speed of trawling was kept constant, no less than 5 knots. With the hourly trawlings at stations the covered area was approximately 650,000 sq.m and the sampled water volume about 26 mln. cu.m. In the day time the horizon of trawling was determined depending on the records of fish school density on the Fish Finder but not deeper than 200 m and at night the surface layer of 50-70 m was sampled, as a rule.

the data collection and primary processing.

The hydrobiological works included the sampling of meso- and macroplankton and fish stomach contents. The plankton samplings at stations were conducted with BSD net having the opening area of 0.1 sq.m and the cone bag with 0.168 mm mesh in 0-200 m layer.

Macroplankton was sampled with the twin Bongo net having the total opening area of 0.56 sq.m and 0.5 mm mesh cone bags. The samples were mainly taken at night for comparison with the samples taken with BSD net and for their mutual correction. In processing the zooplankton was divided into three different fractions - small (under 1.5 mm), average (1.5-3.5 mm) and large (3.5-30 mm). The methods of the biomass calculation, the used coefficients of efficiency of trawls and plankton nets have been described earlier. The obtained information was processed to be average for 12 biostatistical areas (Fig.1) in the Bering sea (Shuntov et al., 1988).

Results of Investigations

The quantitative distribution of fishes in the Western Bering sea is rather non-homogeneous (Fig.2). Among the pelagic fishes absolutely predominant is the pollock (Fig.3) accounting for upto 85% of the total fishes biomass (Table 1). In many areas over the shelf and the continental slope the pollock share reaches 95-99%. The pollock predominate also over the deep-water part of the sea, in particular to the North-East of Commander Isls where CPUE are sufficiently high and the pollock form the dense commercially exploitable aggregations. In the fall period exclusively large pollock migrate (40 cm) in this area (Fig.4 and 5). The fisheries biologists have been since long discussing the problem of mutual replacement of certain species by the other ones in communities under the impact of environment and fisheries. Recently the "problem of pollock" became critical in particular in the Far-Eastern seas, and of especially great interest are the causes of the rapid growth of the pollock abundance and the character of this fish relations with the other fishes. The investigations showed that the "flash" increase of pollock numbers should, probably, be considered as the consequence of the complex influence of a number of natural and anthropogenic factors and have nothing to do with the overfishing of herring, rockfish and other species (Sokolovskiy, Glebova, 1985, Shuntov, 1985, 1986).

In the Western Bering sea the large-scale pollock fishery started in early 70s and in the Eastern Bering sea even earlier in mid 60s. At present the pollock prevail in commercial landings (Fig.6). It has been noticed that the large-scale pollock fishery does not, in principle, destroy the present structure of fish communities. And the structure of catches reflects, to a certain extent, the structure of a fish community. In the deepwater areas of the Bering sea we have found rather large biomass of lanternfishes (the dominant are anchovy (Stenobrachius leucopsarus) and smelts (Leuroglossus stilbius)). It should be mentioned that biology and the state of resources of mesopelagic fishes have been studied insufficiently and, at the same time due to their great biomass the volume of consumed by them the medium and large fractions of zooplankton is essential. In this case one should speak of not the feeding competition with the large pollock in the open sea areas but of the expansive occupation by zooplankton of the different horizons (the amplitude of the daily vertical migrations of mesopelagic fishes is much greater than that of pollock). Besides the share of mesopelagic fishes, the lanternfishes in particular, in the pollock diet is significant and rather consistent.

For the purpose of considering the problem of the pollock competitive influence upon the other fishes besides the comparison of feeding habits it is necessary to avail the data on the food resources and the rate of their consumption. Such results have been obtained with the help of TINRO express-analysis techniques enabling to process samples at sea. On the basis of this data the total biomass of zooplankton in epipelagial of the Western Bering sea is around 95.3 mln. tons. This figure is rather significant since the survey was conducted in the fall when the plankton biomass is 2 - 3 times less than in summer. The daily plankton consumption by all fishes was estimated upon the data of R/V "Babaevsk" to be 101,000 tons including around 77% of pollock. The ratio of the total plankton biomass to the summed fish diet close to 90 : 1 reflects the relative sufficiency of food, if to bear in mind that the calculations have not included the plankton production and the fishes have mainly completed their feeding. However the ecological situation looks quite different if to make similar comparison of separate areas. It could be noticed that most frequent are such unusual

Table 1

The composition and ratio of finfish and shellfish in epipelagial of the Soviet economic zone in the Bering sea

Species	1986 Biomass 000 tons	1986 %	1987 Biomass 000 tons	1987 %
Pollock	5532.2	85.0	6974.6	50.4
Lanternfishes	437.0	6.7	4541.2[x]	32.9
Herring	131.5	2.0	221.5	1.6
Chum salmon	82.6	1.3	81.5	0.6
Capelin	88.0	1.4	85.0	0.6
Smelts	35.7	0.6	1820.0[x]	13.2
Pink salmon	26.1	0.4	+	+
Red salmon	19.8	0.3	16.3	0.11
Atka mackerel	18.9	0.3	3.4	0.02
Sand lance	4.7	0.1	1.2	0.01
Salmon shark	9.7	0.1	1.9	0.01
Polar cod	-	-	30.3	0.2
King salmon	-	-	7.3	0.05
Coho salmon	-	-	0.4	+
Other finfish	119.4	1.8	41.5	0.3
Total fishes	6505.6	100.0	13826.1	100.0
Shrimps	68.2		-	-
Squids	137.7		42.9	
Jellyfish	567.8		193.6	

Note : For calculations of biomasses of lanternfishes and smelts in 1987 we assumed the trawl catchability coefficient equal to 0.04 (0.1 in 1986).

ratios as "much plankton-little fish" and "much fish-little plankton"(Fig.7). This circumstance exposes the necessity of the careful analysis of every specific situation in every area. In September and October the fingerlings of pollock, herring and salmon fed on zooplankton of large and medium sizes, therefore in Table 2 the calculated data are given only for large and medium fractions. Of the total 95.3 mln. tons of zooplankton in the Western Bering sea the large-size fraction accounted for 75.4, the medium-size one - 9.4 and the small-size one - 10.5 mln. tons. The composition of the large-size fraction was as follows: euphausids - 15.2, amphipods - 4.2, copepods - 20.5 and sagittas - 35.6 mln.tons. Areas 1, 2 and 4 (Anadyr Bay) have significant resources of plankton but the fishes biomass is low there. In the deepwater areas 8 and 12 the fishes biomass is high, in particular in area 12 where the biomass of large pollock, according to the double survey conducted on R/V "Gnevniy" in September-October 1987, was estimated to be 4.3 mln. tons and that of lanternfishes - 3.2 mln.tons. Thus the most abundant in fish area located to the North of Commander Isls has at the expense of the greater coverage the large resources of plankton. It is worth noting that the feeding conditions of the deepwater areas 8 and 12 are favourable for fish. As most unfavourable in the food carrying capacity should be considered areas 3, 6, 9 and 10 located over shallow waters and close to the shore. These areas are the major habitats for aggregations of fish juveniles including fingerlings. The shallow water area 10 in Karaginskiy Bay deserves special attention, there the plankton consumption is the greatest and the area is mostly occupied by the fingerlings of Korfa-Karaginskiy herring and pollock. The main spawning areas of the Western Bering sea pollock are situated over the Korfa-Karaginskiy shelf. In 1984 O.Bulatov assessed the biomass of mature pollock of the Karaginskiy-Olutorskiy population based on the eggs survey to be 2 mln.tons. The same area is the basic area for Korfa-Karaginskiy herring reproduction. And the rate of competition between these two species depends, to a great extent, upon the area's food carrying capacity. The estimate of the total numbers of the pollock fingerlings made for this area in 1987 was 18 mln. fish that is 3.5 times less than the R/V"Babaevsk"'s estimate calculated for 1986. In the areas farther to the North the catches of fingerlings in 1987 were also extremely low. All this makes it possible to presume that the pollock abundance of

Table 2

The Quantitative ratios in pelagic ecosystems and plankton consumption by pelagic fishes in some areas of the Bering sea in September - October 1986

Areas	Biomass of fish,'ooo t	Biomass of large and medium zooplankton, '000 t	Zooplankton-fish ratio	Daily diet of fish, '000 t	Zooplankton-2 month diet of fish ratio
1	45.5	2881	63	1.40	34
2	46.8	9853	210	1.65	49
3	708.5	5142	7	33.10	2.6
4	9.6	3333	347	0.39	142
5	966.0	8043	8	9.02	14.8
6	165.5	746	5	4.45	2.8
7	429.0	2767	6	2.99	15.4
8	714.5	29266	40	9.18	53
9	222.0	443	2	3.11	2.3
10	249.0	621	2.5	15.16	0.7
11	489.4	2280	4.7	7.16	5.3
12	2460.0	23456	9.5	13.80	28

1987 year-class is low because of abnormally low temperature regime unfavourable reproduction conditions. Based on R/V"Gnevniy" survey the biomass of pollock fingerlings is 52,000 tons, that of herring fingerlings 4,300 tons while the total biomass of all pelagic fishes is estimated around 70,500 tons in the area. Thus the pollock fingerlings are predominant over the rest fishes in the area. In 1986 according to R/V"Babaevsk" data the abundance of herring fingerlings found in the southern part of Litke Strait was 50 times lower.

Insufficient availability of plankton for fingerlings of pollock and herring in the Karaginskiy area is proved by the data on the pollock fingerlings growth rates. In October 1986 the mean length of the pollock fingerlings in Litke Strait was 7.6 cm, that of Olyutorskiy Bay 10.7 cm and that of Korfa Bay 9.2 cm. In October of nonabundant 1987 the mean length of the pollock fingerlings in Karaginskiy area was by 1.2 - 2.0 cm less than in 1986. The differences in mean lengths were evident also for separate areas. Thus at the present level of fish abundance in the area of the major reproduction of the large Karaginskiy-Olyutorskiy pollock stock and the Korfa-Karaginskiy herring stock the"density factor" undoubtedly cannot but adversly affect the abundance of both the herring and pollock.

Based on R/V "Gnevniy" survey the estimate of the total herring biomass is 221,500 tons (Table 1). In future the stock size is likely to decrease as the general ecological conditions remain unfavourable in the main herring spawning area. The greatest problem faced by the fingerlings in feeding arises when they start to feed on plankton of medium and large fractions. Until that moment their feeding was better as the small size plankton was abundant. The large herring solve the problem of macroplankton shortage by means of migrations to rich in food areas 7, 8, 12. At the time of the feeding migrations the herring might reach the Navarinskiy area. In the similar way the problem of the food deficit is solved by the large pollock at the age 5+, 6+ and 7+ in large numbers, according to data of R/V "Babaevsk" and "Gnevniy", feeding in the rich with plankton deepwater areas of the Bering sea (areas 12 and 8). It is obviously one of the causes of the large pollock concentrations in the area to the North East of Kommander Isls.

The results of our investigations reveal the deficit of macroplankton being the food of fingerlings, large fry and mature fish.

This deficit is most frequently observed in some shelf areas. Therefore it is not occasional that the young salmon leaving the estuaries do not remain over the shelf and head for the deep-sea areas.

Thus the results of our investigations enable us to suggest that the density factor is of great importance in a number of areas of the Bering sea and in Karaginskiy Bay in particular. Such situation occurs in connection with the dominance of pollock in numbers over the rest fishes in the epipelagic fish communities. This factor is of great significance and must be taken into account in estimating the size of the yield.

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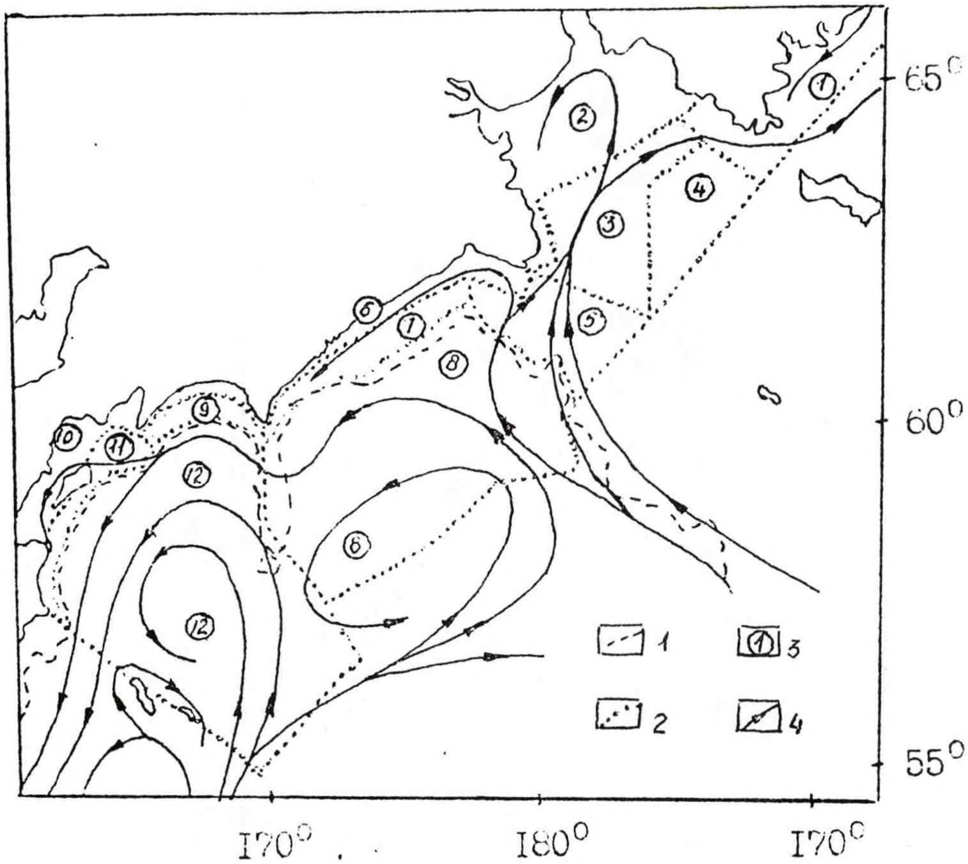

Рис. I. Районы (I-I2) осреднения биостатической информации в западной части Берингова моря (сентябрь-октябрь I986 г., БАТМ "Бабаевск")

I - изобата I000 м, 2 - граница районов; 3 - номера районов; 4 - генерализированная схема течений

Fig. 1 Areas (1 to 12) of the average biostatistical information obtained by R/V "Babaevsk" in the Western Bering sea in September-October, 1986

1 - 1000 m isobath
2 - area limit
3 - area number
4 - a generalized scheme of currents

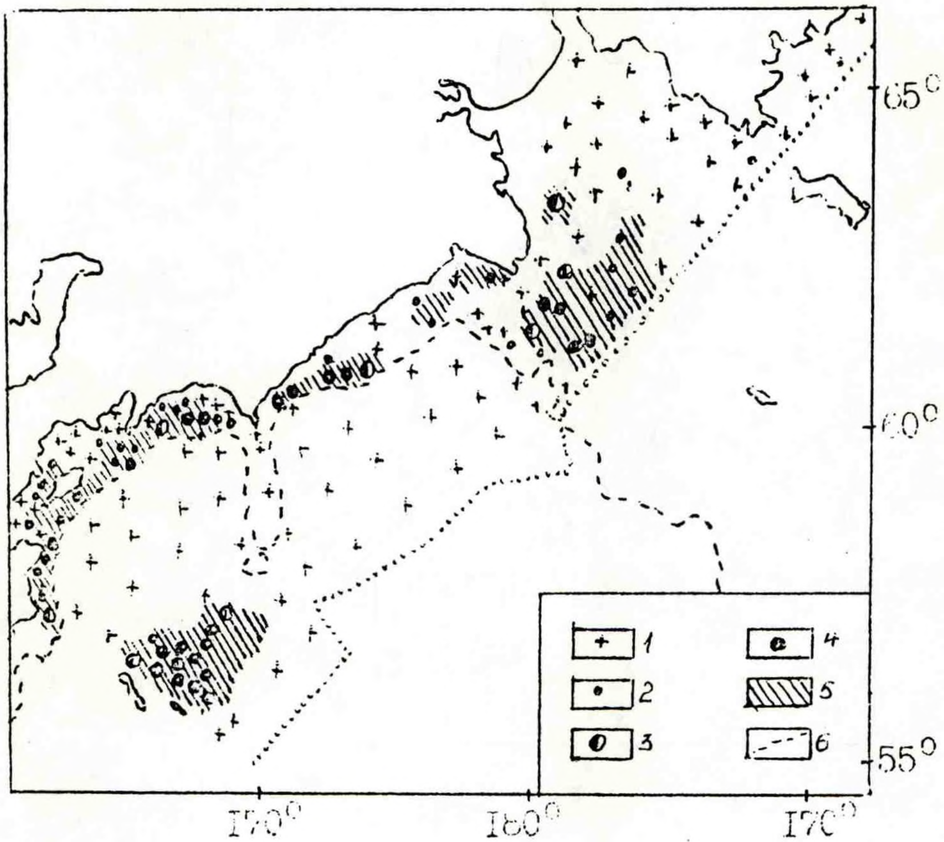

Рис. 2. Распределение уловов рыб в западной части Берингова моря в сентябре-октябре I986 г.

I - менее I; 2 - I.I-5; 3 - 5,I-I0; 4 - более I0 т/ч траления; 5 - районы значительных эхозаписей; 6 - изобата I000 м

Fig. 2 Distribution of fish catches in the Western Bering sea in September-October, 1986 (tons/hour)

1 - under 1 ton
2 - 1.1 to 5 tons
3 - 5.1 to 10 tons
4 - over 10 tons
5 - areas of fish concentrations
6 - 1000 m isobath

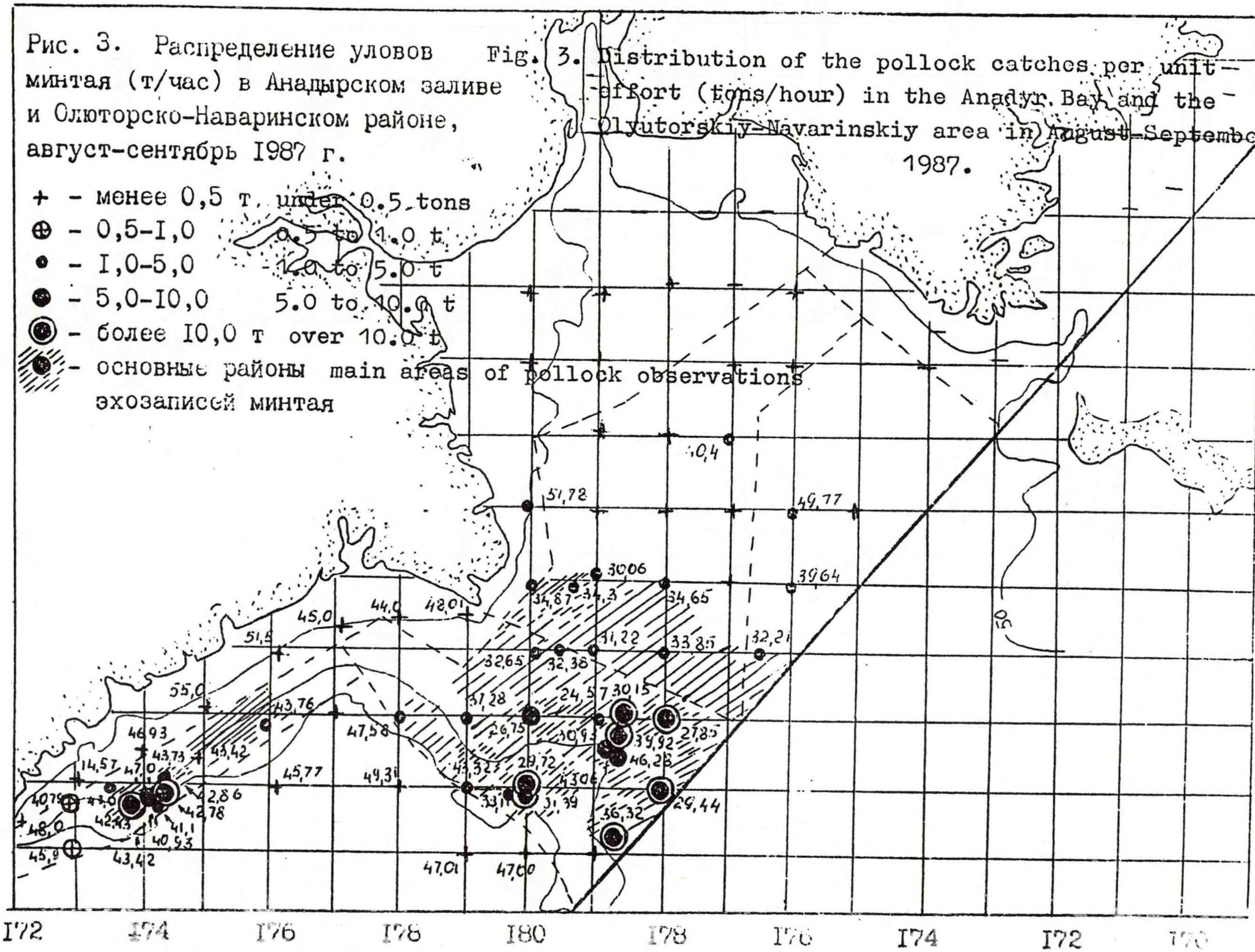

Рис. 3. Распределение уловов минтая (т/час) в Анадырском заливе и Олюторско-Наваринском районе, август-сентябрь I987 г.

Fig. 3. Distribution of the pollock catches per unit effort (tons/hour) in the Anadyr Bay and the Olyutorskiy-Navarinskiy area in August-September, 1987.

+ – менее 0,5 т under 0.5 tons
⊕ – 0,5–I,0 0.5 to 1.0 t
• – I,0–5,0 1.0 to 5.0 t
● – 5,0–I0,0 5.0 to 10.0 t
◉ – более I0,0 т over 10.0 t
▨ – основные районы эхозаписей минтая main areas of pollock observations

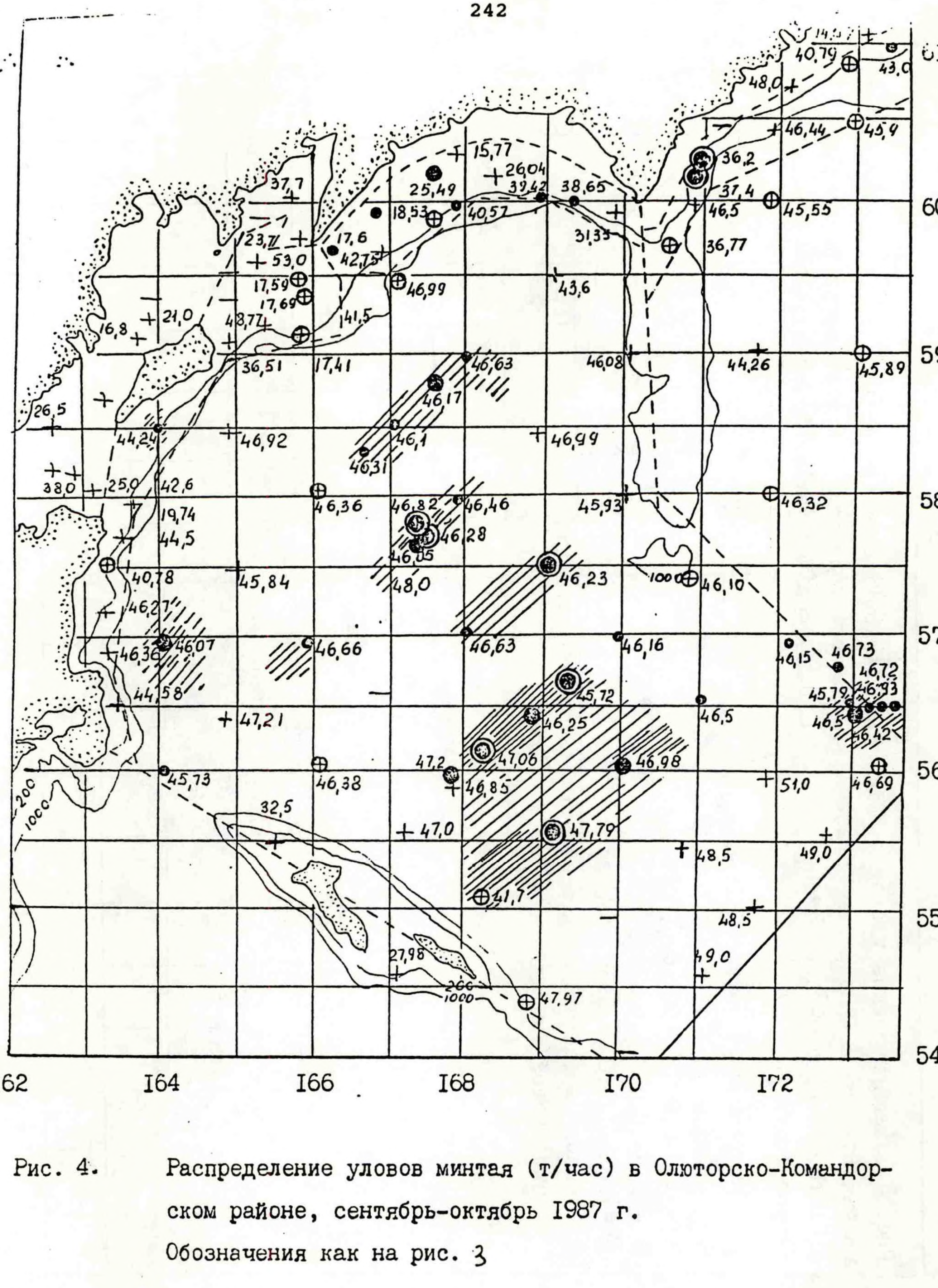

Рис. 4. Распределение уловов минтая (т/час) в Олюторско-Командорском районе, сентябрь-октябрь 1987 г.
Обозначения как на рис. 3

Fig. 4 Distribution of pollock catches per effort unit (tons/hour) in the Olyutorskiy-Kommander area in September-October, 1987

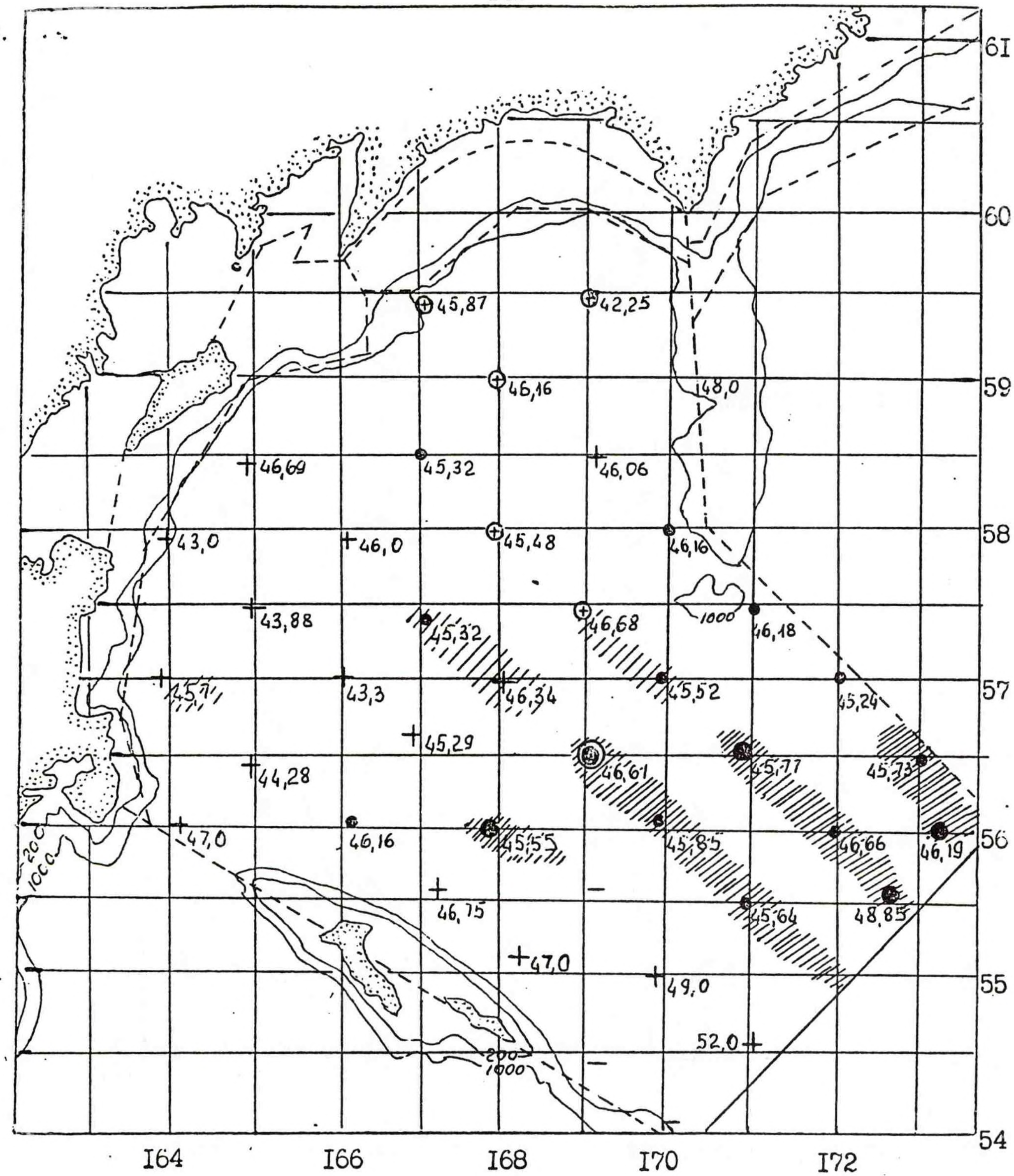

Рис. 5. Распределение уловов минтая (т/час) в Олюторско-Командорском районе в октябре 1987 г. Повторная съемка. Обозначения как на рис. 3

Fig. 5 Distribution of pollock catches per unit effort (tons/hour) in the Olyutorskiy-Kommader area in October, 1987. the repeated survey. Legend as on Fig. 3

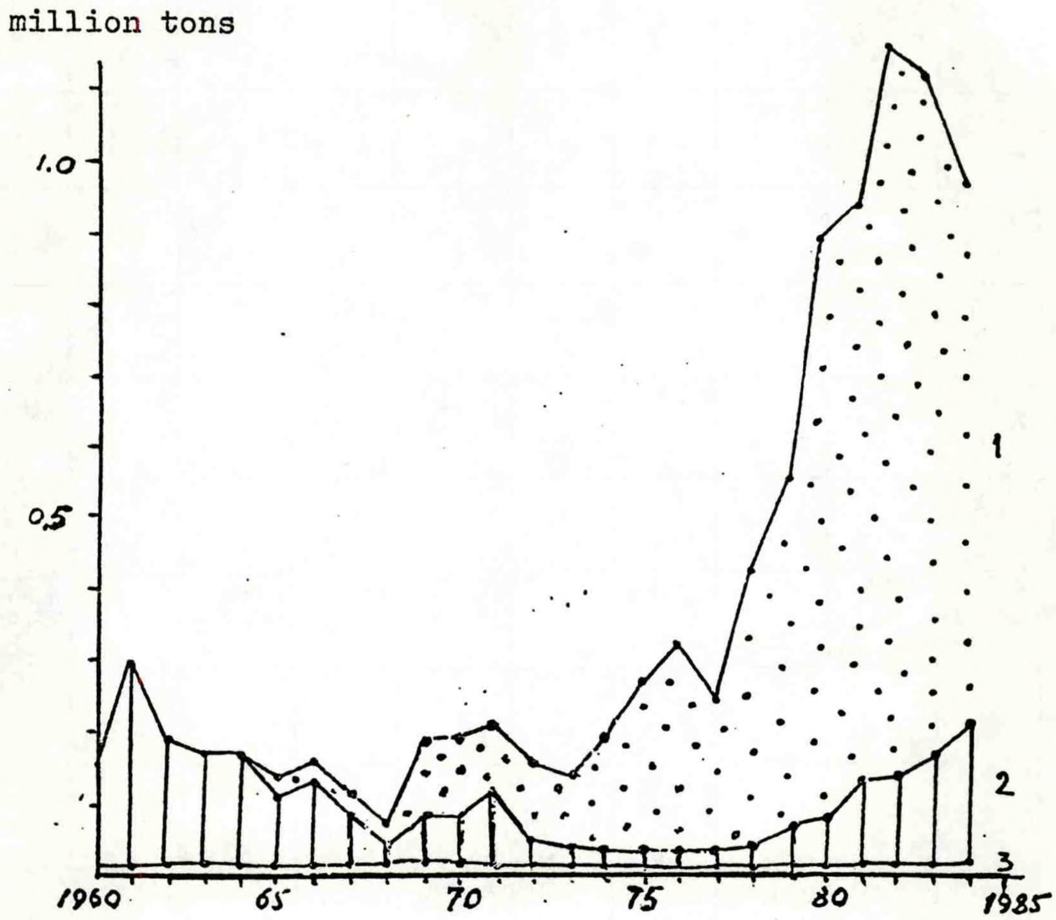

Рис.6. Динамика вылова всеми странами рыбы и нерыбных объектов в Беринговом море после 1960 г
I - минтай; 2 - прочие рыбы, 3 - нерыбные объекты.
По оси абсцисс - годы; по оси ординат - объем вылова, млн. т

Fig. 6 The total fish catch (by all the countries) dynamics in e Bering sea after 1960
1--pollock 2--other fishes 3--shellfish

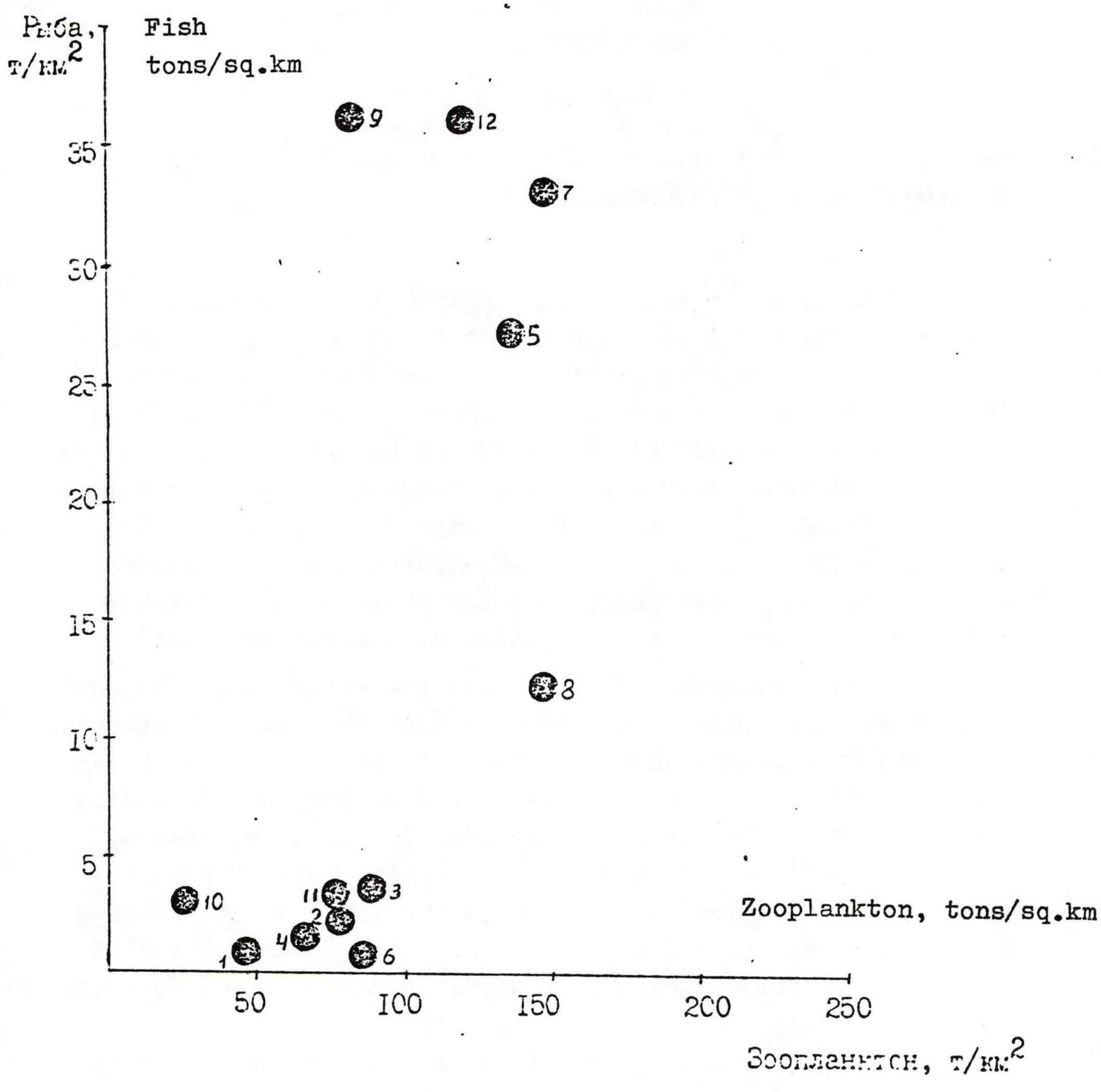

Рис. 7 Соотношение концентраций (т/км^2) крупной и средней фракций зоопланктона и пелагических рыб в различных районах Берингова моря (сентябрь-октябрь 1987 г.) 1-12 - районы (см. рис. 1).

Fig. 7 The Ratio of concentrations (tons/sq.km) of large and medium size zooplankton fractions and pelagic fishes in selected areas of the Bering sea(September-October.1987)

THE STATE OF STOCKS AND DISTRIBUTION OF POLLOCK IN THE BERING SEA

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Pollock is an object of the largest scale fishery in the Bering Sea for the last decades. After introducing 200-mile zones pollock have been exploited in the eastern Bering sea (the US zone) and the western Bering sea (the USSR zone) on the basis of estimates on abundance and biomass using ichthyoplankton and trawl-acoustic surveys conducted regularly for the last decade according to the national programs and also by joint efforts of the USA,the USSR,Japan (in the eastern part of the sea). Furthermore,in the 80-s the USSR started the ecosystem surveys for estimation of the present state of pelagic fishes communities in the western Bering sea. The equilibrium yield of pollock has been estimated to be 1200 thousand tons (the US estimate) made on the basis of surveys in the eastern part of the sea in the second half of the 80-s,including the joint USSR-US surveys (Report US-USSR bilateral meeting, 1987), and 500-600 tsnd tons in the western part. The annual catch during this period has reached the level of equilibrium yield and is determined on the basis of the annual estimation of biomass of the spawning part of the population and the recruitment.

At the same time the unregulated fishery started to develop in the international waters of the central Bering sea in the 80-s. In the second half of the 80-s the annual catch in this area (Japan,South Korea,Taiwan,Poland) exceeded 1 mln.ton by expert estimates. Intensive fishery of pollock in the international waters is conducted during the feeding period,mainly during the prespawning migrations and also for a short period when postspawning aggregations are formed (October-May). The fishery in these waters takes into account neither several spawning groups to which supposedly belong the pollock harvested by the above-mentioned countries,nor their abundance and enormous differences in abundance of year-classes.

The analysis of the results of regular standard surveys definitely revealed the stable spawning groups both in the western and eastern parts of the sea.

The most significant center of reproduction and the strongest spawning aggregations are found annually in the western Bering sea (the USSR zone) in April-May in the Korfa-Karaginskiy area and less significant ones in the Olyutorskiy-Navarin area (171^{o}-176^{o}W) (see the fig.). Biomass of the spawning pollock in the Korfa-Karaginskiy area was estimated to be 2 mln.tons based on eggs' and larvae survey in 1984, and in 1986 - 2,9 mln. tons (Bulatov,1987a,1987b). In the Olyutorskiy-Navarin area 320 thousand tons of spawning pollock were registered at the same period. These biomasses are underestimated as the fishing efficiency of ichthyoplankton net (IKS-80) has been taken to be 1 at the time of calculations.

In the eastern part of the sea (the US zone) the stable spawning areas and the spawning groups were found on the south-eastern shelf and the slope to the north-east from the Unimak Isl. (the Unimak area),off the Pribilof Isls.(the Pribilof area), the north-western shelf and the slope to the south-west from St.Matthew Isl.(St.Matthew area),using the analysis of the results of observations for many years,including those conducted under the long-term program of the joint USSR-US surveys.

Furthermore, similar data on distribution of pollock eggs and larvae and also data on the surveys conducted by the US and Japanese specialists in the deep-water part of the sea beyond the limits of the slope and also data on distribution of prespawning pollock,collected by the US observers on the fishing boats (Hinckley,1987) make it possible to suggest the existence of the stable spawning area in the Aleutian trough. Observations on interannual variability in distribution of the spawning pollock, their eggs and larvae revealed that the above-mentioned areas with the highest pollock spawning rate were stable interannually and the spawning groups could be regarded as relatively independant stocks of reproduction (Bulatov,1987, Hinckley,1987).

Notwithstanding the fact that stable differences in growth and fecundity of pollock are revealed in various spawning areas annually, these data can suggest that pollock return to the same discrete areas every year, (Hinckley, 1987) long observations on distribution of major spawning areas and also the study of relation between interannual variability of oceanological conditions and abundance of separate year-classes and also the population as the whole (Sokolovsky,Glebova,1986; Khen et.al., 1986; Khen,1987) show that abundance of populations can be relatively stable or vary independently from abundance of year-classes of any spawning group at considerable interannual fluctuations of spawning rate and abundance of year-classes in some revealed areas of reproduction. These data suggest the possibility of redistribution of spawning pollock and spawning depending on oceanological conditions,primarily on distribution of water masses.(Khen,1987). The same pattern appears to be characteristic for other species of the North Pacific, their ecology of spawning is similar to that of pollock,in particular Oregon hake (Stepanenko, 1987).

Nevertheless,it is possible to distinguish in space and time the spawning groups in the eastern Bering sea.High rate of spawning in the Unimak area occurs in March-April as is suggested by average for many years data,in the Pribilof area - in April-May, St.Matthew area - May-June, in the Aleutian trough - in January--March. Biomass of spawning pollock was estimated to be 1-2 mln. tons in the Unimak area using the results of conducted surveys, in the Pribilof area - 3-4mln.tons and in the St.Matthew area - - 0,5 mln.tons. Comparative data on distribution of prespawning and spawning pollock and their eggs allow us to suggest that the Aleutian trough biomass can be estimated to be 2-3mln.tons.

Thus,total biomass of pollock spawning in the eastern Bering sea is estimated to be 7-10mln.tons. The biomass of pollock was estimated by the American specialists in 1987 to be 8,8mln.tons in the eastern Bering sea and about 1 mln.tons in the Aleutian area.

In postspawning period density of aggregations significantly decreases and in the summer time its biomass falls down several times in these areas as the trawl-acoustic surveys showed. The young pollock and pollock of the oldest age groups prevail over the shelf.Trawl surveys conducted in the deep-water part of the Bering sea by the Japanese,American and Soviet research vessels proved the wide distribution of feeding pollock in the open waters of the western and central parts of the sea including the international waters,the Kommander and Aleutian troughs. The range of feeding pollock migrations of various spawning groups is different and identification of pollock of certain groups in various areas as well as interannual variability of such migrations have not yet been established.

It is natural to suggest that extensive pollock migrations in the postspawning period are related to the low carrying capacity in the spawning part of the area, feeding in the areas where carrying capacity is high,specifically,in the deep-water part of the sea. Over half of macroplankton resources (in 1986- 57%) concentrate in the deep-water trough of the western Bering sea (the USSR zone) and specifically large resources of zooplankton in September-October were observed in the oceanic areas of the Kommander trough and Koriak coast (Shuntov et.al., 1988a). According to the data of these authors high concentration of plankton in the area is explained not only by increased dynamics of waters but by their drift to the area from the adjacent oceanic areas as well. About half of the plankton is consumed by fishes inhabiting this area. Proceeding from the calculations of daily ration of fishes in the western part of the sea which is 101 thousand tons (for pollock - 77,2%) it is determined by the authors that there is the deficit of macroplankton in the Karaginskiy area.Besides macroplankton there are significant resources of myctophidae and squid is in abundance,consumed by pollock in large quantities in the deep-water part of the sea.

Similar situation related to the food deficit is likely to have place in the spawning areas of the eastern Bering sea as well.

The scale of this phenomenon could be higher in this area due to the fact that biomass of fishes,and primarily,pollock are higher,and the biomass of food plankton is lower as a whole than in the western part of the sea.

Biomass of pollock was estimated to be 5530,61 thousand tons in the western Bering sea based on pelagic trawl survey conducted in September-October 1986. (Shuntov et al.,1999a). The major aggregations of feeding pollock were observed over the continental slope and outer shelf in the Navarin area,off the Koriak coast and Olyutorskiy Bay. According to the data of this survey 1968 thousand tons of pollock were estimated to be in the Kommander trough in October. The rate of feeding was not high,concentration of plankton was much lower than in the oceanic areas off Koriak coast due to high feeding rate in the previous period. In fall 1986 in the deep-water area of the western part of the sea concentrated 46% and in 1987-76% of all pollock estimated for this part of the Bering sea. (Shuntov et al.,1986b).

Thus,a few facts are evident: in the postspawning period the pollock migrate from the spawning grounds both in the eastern and western part into the deep-water part of the sea where they feed on great food resources of open waters; there is constant deficit of food in the spawning area of pollock; in the summer-fall period the pollock biomass in the western part of the sea and in the Kommander trough in particular exceeds significantly the biomass of mature pollock estimated in the spawning period; in fall the pollock migrate from the area of the Kommander trough into the areas farther off shore in the eastern directions due to the deficit of food; such extensive migrations are characteristic only of large pollock (40-52cm), the six -year pollock dominate among them.

It is worth noting that from the areas off East Kamchatka the large pollock migrate in the feeding period into the deep--water part of the Bering sea,specifically into the Kommander trough,the increase of catches in the direction of Kamchatka strait suggests it (Shuntov et al.,1988b). The deficit of plankton is also observed in fall in the coastal areas off East Kamchatka and migration of pollock to the high seas was not observed in this area.

Therefore,several stocks of pollock are exploited in the Bering sea during the year both in the Soviet and American zones and in international waters,and the ratio of their exploitation varies related to their seasonal distribution.

Large pollock spawning in January-March in the area of the

Aleutian trough, migrate in the high seas in the western direction in the postspawning period. Some pollock spawning in the Pribilof area also migrate into this area in April-May. The start of such migration and distribution of postspawning pollock into the eastern part of neutral waters of the central Bering sea were observed in late April and early May 1988 on board the research vessel "Darwin". Insignificant,so called residual spawning was observed here too. Pollock eggs occurred only in the surface layer,they were nonfertilized or dead. As a rule females (up to 85%) dominate in such postspawning aggregations and could be observed for 2-3 weeks.

In the summer period pollock have relatively uniform distribution in the deep-water part of the sea. In August some old pollock migrating into the deep-water part of the sea in the western direction most likely from the Aleutian trough and the Pribilof area,is distributed westward beyond delimitation line of the USSR and US zones and later distribute in the area of the Kommander trough and Shirshov ridge,where could mix with pollock of Asian origin. The R/V "Darwin" trawl survey conducted in August-September 1987 in the deep water part of the US zone and neutral waters showed that pollock had uniform distribution and did not form aggregations. The aggregation of young pollock was found only in the north-eastern area of the US zone adjacent to Navarin cape. The trawl surveys conducted during the last years have showed that pollock migrating to the Kommander trough from the eastern areas as well as their distribution over here could considerably vary interannually related both to the oceanological conditions and the abundance of the most actively migrating age group. In the summer period the pollock have relatively uniform distribution over the vast area of the Kommander trough and start forming dense aggregations in fall prior to the return prespawning migrations.

Active migration of pollock both of American and Asian origin from the Kommander trough (the USSR zone) into the eastern direction,to the international waters and the US zone,just caused by the deficit of food,could last from the second half of September to early November, these data are based on the results of surveys conducted in 1986-1987 (r/v "Babayevsk",1986, r/v "Gnevny",1987, r/v "Darwin",1987). Such migration started in late September in relatively cold 1987 (in the western part of the sea),whereas in warmer 1986 - in late October-early November.

Distribution of pollock of asian origin during the feeding period to the eastern direction from the areas of the Kommander trough and Koriak coast,that of pollock of american origin to the western direction,the vast area of mixed habitation of these groups and duration of joint feeding period are likely to vary considerably in the interannual plan.

In fall the pollock start forming dense aggregations which could be harvested both in the south-eastern part of the Kommander trough and in the international waters. Later on in the winter time these aggregations were constantly shift in the eastern direction both within the limits of the US zone and in the international waters of the central Bering sea. The major aggregations of migrating pollock were observed in the international waters in 1987 just off the southern boundary of 200-mile US zone in December-early February and probably in adjacent waters of the US zone. From the 20 January to 5 February 1988 one of the aggregations shifted from 175°E to 178°W where over 70 large-fishing boats of some countries have been engaged in commercial fishery. In the second half of February -early March the major aggregations of prespawning pollock shifted farther eastward to the US zone,into the spawning areas.

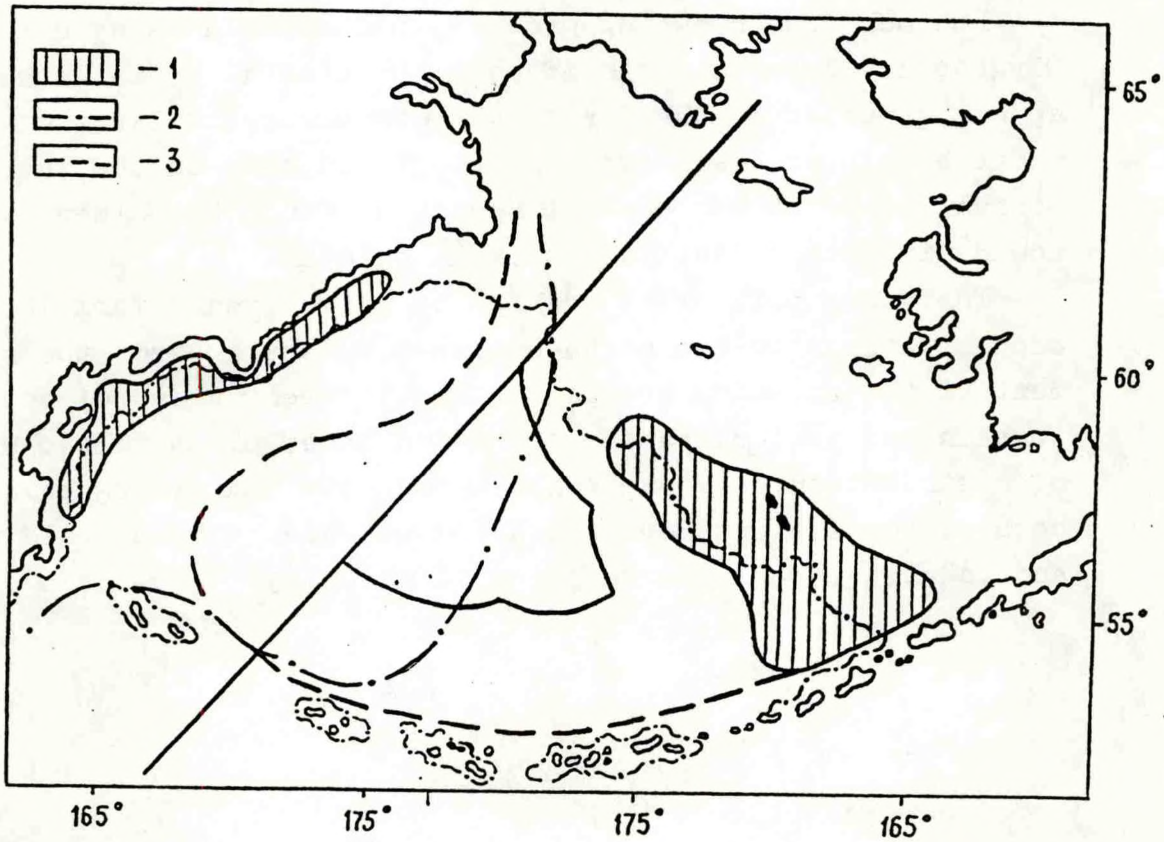
Pollock from the Unimak spawning ground also migrate to south-western direction in the postspawning period along the Aleutian ridge and likely to inhabit the prealeutian area within the limits of the US zone during the feeding period.

Large pollock,spawning in the area of the north-western slope in late spring and early summer,so called St.Matthew spawning group,distribute in the postspawning period along the slope in the northern direction and in the summer period the part of aggregations distribute in the Navarin area. Some pollock of St.Matthew group spawning beyond the limits of the slope are likely to distribute over the deep-water part of the sea in the north-western direction.

In the fall-winter period large mature pollock migrate from the Navarin area to the spawning grounds in the St.Matthew and Pribilof areas that is why in winter the young pollock dominate there to an increasing degree.

Pollock from spawning grounds in the Korfa-Karaginskiy and Olyutorskiy-Navarin areas inhabit the coastal area in the post-spawning period in the first half of summer and later on they distribute over the Kommander trough and also in the international waters of the central Bering sea and the US zone where could mix with pollock of american origin.

The young pollock at the age of 2 to 4 years form large concentrations in the north-west Bering sea whereof the recruitment of the spawning groups in the different areas of both the western and eastern parts of the sea takes place. The character of distribution of young pollock suggests that young pollock both of the eastern Bering sea and of asian origin could mix and inhabit the same area prior to maturity.



Drawing. The scheme of distribution of the main areas of spawning (1) of pollock in the Bering sea and boundaries of distribution of pollock of asian (2) and american origin(3).

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APPENDIX 3

Papers from Panel C

THE SHRIMPS OF THE BERING SEA: DISTRIBUTION, BIOLOGY, ABUNDANCE

Ivanov B.G., Zgurovskiy K.A. VNIRO, TINRO

Introduction

The Soviet shrimp fishery investigations in the Bering Sea and the Gulf of Alaska started in 60-thies in the framework of the Bering Sea fishery research trawling expedition by TINRO and VNIRO (Ivanov, 1962, 1964). The very first expeditions carried out before the 200-mile economic contigious zones were established resulted in discovery of the offshore shrimp (<u>Pandalus borealis</u>) concentrations off Shumagin Islands, and later on off Kodiak Island. The discoveries provided opportunity to develop the Soviet shrimp fishery in the areas in 1965-1970.

In 1960 abundant stock of this species was studied off Pribilof Islands. The shrimp fishery was carried out mainly by Japanese and, in lesser degree, by Soviets there and the year catch exceeded 80,000 tons. Later on, by 1964, the Pribilof stock practically disappeared not only because of overfishing but also due to changes of oceanological conditions (Ivanov, 1974).

~~By that time~~ in 1967, the abundant concentrations of another shrimp species, <u>Pandalus goniurus</u>, were discovered in the Gulf of Anadyr. In the early 70-s the shrimp biomass in the area decreased and the Soviet shrimping shifted to the southern Koryak coast area (Dezhnev Bay, Anastasiya Bay). Naturally, when 200-mile economic zones were established the Soviet shrimp fishery and biological researches were also transferred to the western Bering Sea (Ivanov, 1974, 1979).

In the present paper the main results of the Soviet research of the commercial(and potencially commercial) Bering Sea shrimps for the 25 years period are summarized.

Shrimp distribution

The most abundant Bering Sea shrimp species in the trawl catches are: <u>Pandalus borealis</u>, <u>P. goniurus</u>, <u>Eualus macilentus</u>, <u>Sclerocrangon boreas</u>, <u>S. salebrosa</u>, <u>Crangon dalli</u>, <u>Argis dentata</u>. The distinct zones of the shrimp distribution were defined on the eastern Bering Sea shelf. <u>C. dalli</u> are widely distributed in the shallow waters, not deeper than 50 m normally, where temperature in winter is below 0°C and in summer the water is fairly warm. <u>P. goniurus</u> and <u>E. macilentus</u> are common at the depths from 50 to 80 m on mud bottom mainly where the layer of residual winter cooling contacts the bottom. P. borealis are distributed in waters deeper than 80-100 m which are warmed up by relatively warm deep water. The species frequently concentrates in two belts: (1) slightly deeper than the layer of residual winter cooling (the most abundant yet unstable concentrations are off Pribilof Islands), and (2) on the continental slope. Unfortunately, the latter shrimp concentration belt was investigated most insufficiently because the rough bottom made it almost impossible to trawl on the slope.

In the western Bering Sea where the shelf is much narrower and the slope is much steeper than in the central and eastern parts, the shrimp distribution zones layout is somewhat different: S. boreas, S. salebrosa, A. dentata and sometimes juveniles of P. goniurus are common in waters not deeper than 50 m on gravel and mud bottom. The crangonids are rather abundant in the northern Karaginskiy Zaliv and in some areas off Koryak coast where catches were up to 100 kg (Ivanov, 1975). In the bottom adjoining layer of residual winter cooling on the mud bottom (like in the eastern Bering Sea) mature P. goniurus and E. macilentus are widely distributed but, unlike the central and eastern shelf, these species on the western shelf form the commercial concentrations. They are discovered in the Gulf of Anadyr, to the south and south-west of Navarin Cape and in the troughs off Dezhnev and Anastasiya Bays (Fig. 1). Distribution of these species are frequently overlapped, but in the years of their abundance it is clearly seen that P. goniurus confine to the layer of the residual winter cooling periphery and the zone of different water masses interaction, while E. macilentus tend to be concentrated almost to the very nucleus of residual winter cooling layer (Fig. 2).

Along the continental slope the density of P. borealis concentrations increases but, unlike central and eastern shelf, this species are practically rare on the western shelf in waters shallower than 180-120 m.

Migrations

The season migrations of P. borealis were observed when the Pribilof stock existed. In winter the shrimp concentrations were found in deeper waters than in summer, and the stock center shifted 30-40 n.m. to the south-west (Ivanov, 1970).

In the western Bering Sea P. goniurus migrate more significantly, but many details of the migrations have not been investigated yet. In the abundant years the biggest catches were observed in spring and early summer (May to June), but in mid-summer and fall (July to October) the shrimp concentrations usually disperse and the catches go down. The general plan of P. goniurus migrations is shown on fig. 1. The repetitions of the trawl surveys in May through November allowed to assume that the shrimps from Navarin Cape area migrate to the Anadyr Bay (Zgurovskiy, Ivanov, 1982). We can judge about reverse migrations in winter only on the basis of indirect evidence. Stocks migration in summer and fall is connected with the different water masses interaction and the depth of penetration of the Bering Sea trough water mass flow into Anadyr Bay (Zgurovskiy, Khen, 1988). There is some evidence of P. goniurus migrations along the Koryak coast from the troughs nearby Dezhnev Bay and Anastasiya Bay towards Nataliya Bay. Further shrimp migrations in the area have not been studied. Shrimp concentrations off Koryak coast were not observed after the stocks'depletion in 1979. Taking into consideration the currents'direction and speed it is possible to make a conclusion that those concentracions are the population or subpopulation dependent upon the Anadyr Bay and Navarin Cape stocks.

The shrimp migration mechanism is not known for certain. It is quite possible that the migrating pandalid shrimps are carried by currents during their ascend into water column at night. Both P. goniurus and E. macilentus extensively migrate upward at night (Barsukov, Ivanov, 1979). P. borealis vertical migrations in the Atlantic are commonly known. But we did not observe the distinct bottom trawl catch drop of P. borealis at night in the Pribilof area. Supposition about the nightly rising shrimps carried by currents can not be sufficiently explain the pattern of the seasonal migrations off Pribilof Islands. Small male shrimps are known to be more apt to swim than females and transitional specimens (Berenbojm, Popkov, 1980, Berenbojm, 1986). In this case the immature and male shrimps must be in the avant-garde of the migrating population avoiding winter cooling while the females must be behind small-sized shrimps. But in reality we observed a quite different pattern in winter: the egg-bearing females were nearer to the slope and the males were lagging behind. The pattern can be better explained by active migration by shrimps than by passive shrimp drift by current during their night ascend. In such active migration large specimens have an advantage over smaller males. Possibly, females with eggs are more sensitive to low temperature and began to move towards the slope earlier than males which seem to be more tolerant towards winter cooling (Ivanov, 1970).

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Behavior.

Some P. goniurus behavior features were described using underwater photography (Ivanov, 1981). In the western Bering Sea P. goniurus was found to be strongly oriented presumingly along the off-bottom current. Like in some other researches (Pearcy, 1979; Blaker, 1971), it was assumed that the shrimps' headings were directed against the current. Further underwater observations from the manned submersible showed that the shrimps on the bottom are passive and in case of current speed over 0.1 knots they turn their abdominal parts to it.

Several aggregation levels of P. goniurus can be distinguished: local groups or aggregations around the shelters; meso-concentrations with approximately equal density and size of about several hundreds sq. meters; and macro-concentrations about several hundreds sq. miles in size (Zgurovskiy, Myasnikov, 1986). When the manned submersible stopped with the lamps turned on the shrimps showed weak positive phototaxis and moved at 5-10 cm/min speed with help of their pereiopods.

While observing the set of shrimp traps, it turned out that the juvenile tanner crabs prevented the shrimps from entering the traps almost entirely blocking them up, which made it practically impossible to fish P. goniurus with the trap in this area.

In the midwater submersible observations made in the Anadyr Bay at 3.30 p.m. through to 5.30 p.m. it was noticed that the majority of shrimps mostly swim in the water column rising from the bottom up to 12 m. In the morning some of shrimps were in the water column about 2 m from the bottom. Shrimps' activity varies: they can soar motionlessly in the water column, or they can make energetic movements with their pleopods and uropods and move in the different directions, sometimes in circles. When soaring, their body positions are different. Their limbs (pereiopods, pleopods, uropods), scaphocerites, antennae are straightened out seemingly to increase their buoyancy. We observed the motionlessly soaring shrimps going down to the bottom from 1 m height in 15-20 seconds. Some shrimps go down to the bottom, some of them rise towards the surface. In the night-time their vetical migration range increases. At 10.00 p.m. of local time the shrimps were found from 18-20 m above the bottom and to the bottom. The maximum concentration was observed at 10 m above the bottom. At 10.50 p.m. the shrimps were absent in the 4 m layer off the bottom though some of the individuals were observed on bottom all the time. When the manned submersible was ascending to the surface at 11.30 p.m. individual shrimps were observed at 23-25 m above the bottom and 35-37 m from the surface.

Another important feature of P. goniurus behavior is the fact that their night vertical migrations are not obligatory. In 1982 when conducting night-time underwater observations we did not observe any vertical mass migrations which were sighted in 1975, for example (Barsukov, Ivanov, 1979). Only about 10% of shrimps staying on the bottom were rising by several meters above the bottom meanwhile individual shrimps were soaring motionlessly in the water column. When conducting underwater observations in the Graig Bay (the southern part of the Anadyr Bay) from 11.30 p.m. to 01.10 a.m. all shrimps observed were on the gravel and shringle bottom, the current speed was 0.6 knots in the spot of the observation.

in the Anadyr Bay

off Koryak Coast

When trawling in the near-surface layers at night in 1981 and 1983, rather big shrimp catches were taken (up to several tons). It shows that shrimps' activity changes seasonally and depends on the local situation. P. goniurus vertical migrations range and the off-bottom current speed seem to influence the duration and extent of the stocks horizontal migrations. In unfavourable conditions the shrimps' activity is supposed to increase which results in long-distance transportation of shrimp concentrations by currents, particularly from Navarin Cape area to the Anadyr Bay and probably back, for example.

august

in the Anadyr Bay above depths of 70-80m.

The formation of local shrimps' groups seems to be linked with the defence reactions and, besides, makes it easier to search for the partner in the spawning period.

Crangonids migrate to the deeper areas in winter but these migrations are felt to be not extensive.

Abundance

The Bering Sea is capable to strike one's imagination with its shrimp resources. For example, the Pribilof concentration of P. borealis in 60s was the most abundant of all known concentrations of this species in the world. Nowhere the "shrimp fields" were hundreds miles long. And the shrimp catches (up to 10 tons per hour) were also impressive. At that time only catches off the Shumagin Islands (in the Gulf of Alaska) could be compared with the ones off Pribilof Islands.

The P. goniurus concentrations in the Anadyr Bay have been equally big in the most abundant years. They stretched for hundreds miles and the catches reached dozens tons per 30 minutes of trawling. The fishable biomass was estimated 600,000 tons in 1975 (Ivanov,1981). Unfortunately the abundant stocks have greatly decreased due to the

the cyclic fluctuations.

The stock assessment of the western Bering Sea shrimp populations was made by the conventional method of swept areas (Ivanov, 1981) and, later, by more advanced method of the pattern recognition (~~Polikov~~ Efimov et al., ~~in press~~ 1988). To compare results of the methods see Table 1 with the stock assessment of P. goniurus in the Anadyr Bay in abundant (1978) and poor (1982) years. The results showed that the lower limit of the confidence range of the P. goniurus stocks estimates by pattern recognition is somewhat similar to the estimates obtained by method of swept areas : for 1978 that is 768,000 t and 630,000 t respectively, and for 1982 - 76,200 t and 52,300 t. The stock estimates showed that the range of biomass changes is very wide and in one or two years it can change by more than one order.

Recently even more advanced method was developed for stock assessment which deals with not only analysis of trawl results but include survey design - the method of spline approximation of the stock density (Stolyarenko, 1986; 1987; Stolyarenko, Ivanov, 1987). ~~1988)~~ The method is based on the ship computer usage (e.g. IBM PC XT or more advanced models) and Spline Survey Designer Software System (SSDSS) was developed for stock assessment by means of trawl surveys (Stolyarenko, 1987). The new approach is suppose to be applied for shrimp stocks in the Bering Sea. The use of the method spline approximation has been already very successful in the North-East Atlantic in the Spitsbergen area (Ivanov et al., 1988).

Adequacy and representativeness of the trawl survey data can also decrease due to the shrimps' ability to form highly dense concentrations in a rather limited area which may lead to "overlooking" some concentrations. This may be clearly seen from the July of 1986 experience: one extremely abundant catch substantially (almost 50%) influenced the stock estimate, as the rest of the catches were considerably lower. When the research vessel works in area of high concentrations the density of trawl station location should be increased. The station density should be increased also in areas with changeable catches. Special attention should also be paid to the gradient zone of different water masses interaction where the most abundant shrimp stocks are usually discovered. In this case the spline approximation methodology must be acknowledge as the most useful. The microcomputer usage provides opportunity to exploit experience of the preceding trawl surveys, and ~~provide~~ to perform the adaptive design.

On the basis of the catches data a rather large P. goniurus biomass was observed in 1966-68. Later on, in early 70s, the stock diminished (Ivanov, 1974). The greatest biomass of the shrimp in the Anadyr Bay ~~in the observed period~~ were found in 1975-78. In 1978-1985 the shrimp abundance fell down. But it must be taken into consideration that in 1979 the stock seems to be underestimated because of the later research period (November - October), and in 1980 the research was not carried out at all. Thus the stock decrease in reality could have taken place not in 1979 but in 1980 or even in 1981. After that a gradual rising in P. goniurus western Bering Sea stocks started.

Other shrimp species abundance also sharply fluctuates in years. When in the most abundant years the Bering Sea could be considered as one of the richest areas of shrimping, in the lean years it almost completely loses its commercial importance. The 1960-62 Pribilof area catches of hundreds of kilograms and tons per 30 minutes of trawling can be compared to the 1972 individual samples of P. borealis in the same area (Ivanov, 1974). Unfortunately, we have not had any data concerning the Pribilof area population after 1972.

In the most abundant years density of the P. goniurus western Bering Sea population exceeded 100 individuals/sq.m according to underwater photography (Ivanov, 1981). The species stock density in August 1982 estimated by means of the underwater observations from the manned submersible "TINRO-2" (R/v "Gidrobiolog") was not more than 10 individual/sq.m, average density on the submersible routes ranged from 0.8 to 3.1 individuals /sq. m, and the catches did not exceed 200 kg/30 min-trawling (Zgurovskiy, 1987). In June 1986 the highest density of P. goniurus on the submersible routes was 15-20 individuals/sq.m, and on the average ranged from 1.6 up to 17.5 individuals/sq. m. But at least for 2 underwater observations those values are underestimated as a great number of shrimps could be observed in the water column even in daytime. The calculations of the projective density of the total number of shrimps in the water column showed that in the first case this density is as high as 18 individuals/sq. m, and in the second case - 80 individuals/sq. m, as not more than 15-20% of shrimps were on the ground at the moment of underwater observations.

Large areas observed from the submersible provide opportunity to diminish the systematic error in stock density estimations. The main source of the systematic error in the shrimp trawl surveys is a coefficient of catchability which usually is unknown. It depends on shrimps' escape through the meshes, their avoidance of the trawl mouth, changes in the trawl operating efficiency in its different adjustments and bottom conditions, peculiarities in the shrimp behavior. In 1982 the catchability coefficient ranged widely, from

0.039 to 0.27, the mean was 0.20. If the value of 0.039 is ignored as an artefact, the catchability coefficient of 24.6 m trawl was ca. 0.25 (Zgurovskiy, 1987). The value is rather similar to 0.22 which was received by the underwater photography (Ivanov, 1981).

Sometimes, when the shrimp migrate actively upwards, the efficiency of trawl as a sampler can greatly decrease (coefficient of catchability 0.02-0.06). It results in underestimation of the stock. The situation was observed in 1986. The comparison of the density observations on 4 submersible routes and 7 trawl tows made in the same area not far from each other provided opportunity to calculate the catchability coefficient. It proved to be very small if shrimps in the water column is disregarded. But when the shrimps were taken into account the coefficient increased up to approximately 0.23.

In 1975 very high, up to several tons per 30 min. tow, catches of *Eualus macilentus* were recorded off Dezhnev' Bay and Anastasiya Bay. It seems the only case when the species was found to form really commercial concentrations. But in the consecutive years the abundance of the species decreased very much. Probably, the fluctuations of the species abundance coincides with those of *P. goniurus* because in 1974-75 both species were highly abundant.

The factors determining fluctuations of mass shrimps abundance are poorly studied. In the Pribilof area the strength of year classes of *P. borealis* seems to be related to winter temperature which affect on hibernation of shrimps on the first year of their life (Ivanov, 1969B). For *P. goniurus* strong year classes are supposed to appear in cool periods.

It is noteworthly that fluctuations of shrimp populations can be not only due to repetition of years unfavourable in their temperature conditions (or, otherwise, not only due to several consequent year classes). The negative factors are likely to exist which affect the shrimp population as a whole, not only at some critical stages of life cycle (larvae, juveniles etc.). Changes in the currents system, appearance of mass predators can be such factors. Predatory fishes can withdraw essential part of shrimp biomass - 70-120 thousands tons as estimated in summer 1982 for the Anadyr Bay population of *P. goniurus* (Zgurovskiy, Bulatov, 1983). But the impact of fishes on stock fluctuation of the shrimps of the western Bering Sea has not become so obvious yet as it was for the North East Atlantic (Ponomarenko et al., 1986).

and Pandalus goniurus, is about 6 years. It leads to multiaged structure of their populations. Several size (= age) groups can be identified by length frequency distributions. The strong year classes are well pronounced and their predomonance greatly affects the catch quality: if older groups dominate the shrimp count (specimens/kg) decreases and the quality of shrimp catch is considered to be higher and vice versa.

Yearly shifts of modes on the lenght frequency histogramms can be recognised by the deviation method described by Skuladottir (1981) and by the new more advenced method of succession of generations by Ivanov and Stolyarenko (1986, in press).

Fecundity of P. goniurus in the western Bering Sea is rather high. Egg numbers in one brood increases with the female size from 1660 to 3050 eggs (mean fecundity is 2050 eggs) (fig. 3a). Mean wet egg mass is 0.351 mg and its size is 1.025 x 0.77 mm, while dry egg mass is 0.137 mg. The egg mass is on average 15.5% of wet mass and 28% of dry mass of female body (Romanova, Zgurovskiy, 1979). Length of egg-bearing females ranged from 69 to 88 mm, while the body mass was from 3,000 to 6,400 mg. Relationship between carapace length (CL, mm) and body length (BL, mm) can be well approximated by linear regressions ($r = 0.99$):

$$CL = 0.30\ BL - 0.43$$
$$BL = 3.30\ CL + 2.50$$

(CL is measured from orbital edge to middorsal hind edge of carapace; BL - from the orbital edge to telson tip)

The relationship between the body mass and length of P. goniurus is shown on fig. 3b.

Feeding and production

According to Belogrudov (1971) the spectrum of food in the Anadyr Bay shrimp (presumably P. goniurus) is more limited than that of shrimps in the Gulf of Alaska. The bulk of stomach content are amphipods and isopods. Bivalve molluscs and foraminifers form the essential part of food too. In July 1966 only crustaceans were recorded in P. goniurus stomach. The occurence frequencies for isopods and amphipods were 55.5 and 22.2% respectively. Among the pelagic amphipods only Parathemisto libellula was found. Beaks of cephalopods occurred in the shrimp stomach and it makes poossible to suppose necrophagy in the shrimps. Sand particles and homogenous mass digested were observed in almost all stomachs.

Results of the investigations in 1981 and 1984 (184 stomachs of P. goniurus were examined, occurrence frequency of each food item and stomach fullness were determined) contributed to our knowledge on food spectrum of the humpy shrimp. The fish scales of about 0.1 mm size were the most frequent component of the shrimp stomach content. The scales belonged to fishes of length 5 to 6 cm, i.e. the fish size is comparable to that of shrimp. It provides an evidence to support Belogrudov's suggestion on necrophagy. Otherwise, capability of the shrimp to catch large preys can be supposed. Polychaete setae, sponge spicules, hydroids were common in the shrimp stomachs. For the first time plancton barnacle cypris larvae, mysids and also benthic brittle stars and sipunculids were recorded as food items of P. goniurus. Besides, digested mass and detrit were in the majority of stomachs.

The stomach fullness in young shrimp specimens (of under 5 g mass) in average was significantly higher (120‰o) than that of relatively large specimens weighting from 5 to 10 g (78‰o). It leads to conclusion about a decrease of feeding intensity with growth of size and age of the shrimp. Food availability for adult shrimps does not seem to be a limiting factor for shrimp abundance. Owing to the wide food spectrum, their capacity to use both benthic and pelagic food during the horizontal and vertical migrations, high productivity of bottom and plancton communities of the western Bering Sea the humpy shrimp are enough provided with the food.

Yearly total production (somatic + generative) of P. goniurus in 1978 and 1982 (years of high and low abundance respectively) was estimated to be about 540,000 and 110,000 t respectively, i.e. 60-70% of standing + eliminated biomass (Zgurovskiy, in press).

Problems of shrimp study

Taking into account that shrimp stocks in the Bering Sea can be of great importance and that these stocks can greatly fluctuate the urgent necessity is obvious in monitoring the main shrimp populations (off Pribilof Islands and in the Anadyr Bay). The study of factors affecting the strength of year classes and fluctuations of the shrimp stocks (including predatory fish impact) is of primary importance. The knowledge of the factors can provide the opportunity for long-term forecasting of shrimp stock fluctuations. Shrimp population studies (including growth, mortality, migrations and patterns of distribution, larval drift) are also very significant.

The shrimp trawl surveys are rather costly. So improvement of their efficiency is urgent. Usage of advanced methodology in survey design and in analysis of survey data is extremely promising and can result in significant increase of accuracy of stock assessment and economy of costly ship time. We consider that the method of spline approximation of stock density provides such an opportunity. Hence the introduction of this method and developed software system (SSDSS) in practise of the North Pacific surveys is urgently needed.

The decrease of systematic error in trawl survey which occur due to unknown coefficient of trawk catchability is also important. The underwater photography, TV and manned submersibles are very useful to study absolute stock density and to determine the trawl catchability.

Summary:

1. The most abundant shrimp species in the Bering Sea are Pandalus borealis and P. goniurus. The commercial concentrations of these species are recorded off Pribilof Islands (P. borealis), in the Anadyr Bay, off Anastasiya and Dezhnev's Bays (P. goniurus).

2. The shrimp stocks greatly fluctuate. In years of shrimp abundance the annual catch of P. borealis in the Pribilof area exceeded 87,000 tons. The fishable biomass in the Anadyr Bay was more 600,000 tons. So in such years the catch of shrimp in the western Bering Sea can exceed 100,000 tons. But only in 1-2 years the sudden decrease of stock can happen. Thus, the monitoring of the main shrimp stocks is of great importance.

3. Size composition of the shrimp populations is also very changeable and strongly dependant upon the strength of year classes. So the count of shrimp catches (no. of specimens/kg) and , hence, the value of shrimp also fluctuates. The monitoring of the populations provides the opportunity more or less accurately to predict the shrimp count for the next year.

4. Taking into account that shrimps in the Anadyr Bay and off Navarin Cape are of the same stock while the stock off the southern Koryak Coast belongs to the other stock (although partly dependent upon the Anadyr-Navarin stock) the management of shrimping in these areas should be developed and performed separately.

5. The monitoring of main shrimp stocks, a study of factors causing fluctuations of shrimp abundance, a study of population dynamics (including growth, mortality, migrations, larval drift), improvement of methods of survey design and analysis of survey results (particularly, using the method of spline approximation and

microcomputer software SSDSS developed for this method), using underwater photography, TV and manned submersibles to study stock density, trawl catchability, behavior are considered as urgently needed in the further shrimp reasearches.

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Table 1. The fishable biomass of the humpy shrimp, *Pandalus goniurus* in the western Bering Sea determined by methods of linear interpolation (swept area method) and pattern recognition in August 1978 and August 1982.

Nos. of areas	catch ranges (kg)	concentration areas (sq.km)	Average cathes (kg)	biomass (t)
		Linear interpolation, August 1978		
1	0-0.9	11056	0.8	210
2	1-9	925	6.5	143
3	10-49	9531	20	12300
4	50-99	3918	75	20000
5	100-999	12735	470	420000
6	1000	1551	1600	160000
Total		39716	520	612600
		August 1982		
1	0-0.9	1400	0.9	1409
2	1-9	2880	3.0	9661
3	10-49	4800	20.0	10735
4	50-99	4000	58.0	25443
5	100-499	320	142.0	5081
Total		51920	16.0	52300
		Pattern recognition, August 1978		
1	0-9	1808	1	380
2	10-199	20507	78	340000
3	200-999	7725	715	117500
4	1000-1999	2215	1580	774600
5	2000-3999	568	3370	41000
6	4000	262	4500	25100
Total		49366	517	1169000±400890
		August 1982		
1	0-0.9	47106	0.8	3500
2	1-9	9069	5.0	4300
3	10-49	3666	40.0	13400
4	50-99	3263	80.0	24400
5	100-499	3475	183.0	60500
Total		66579	15.5	106100±29800

Table 2. Food content of the humpy shrimp, Pandalus goniurus, in the Anadyr Bay (data of 1981 and 1984)

Food items	Occurrence frequency, %			
	August 1981			August 1984
	Sample 1	Sample 2	Sample 3	
Fish scales	4.2	84.9	31.6	86.4
polychaetes	37.5	45.5	55.3	25.4
sponges	41.7	50.0	18.4	23.7
hydroids	45.8	21.2	5.3	23.7
foraminifers	-	-	26.3	22.0
bivalve molluscs	-	-	2.6	3.4
barnacle larvae	4.2	-	18.4	-
mysids	-	-	5.3	-
amphipods	-	-	2.6	-
other crustaceans	8.3	15.2	5.3	5.1
brittle stars	-	3.0	-	-
sipunculids	-	1.5	-	-
Nos. stomachs	24	66	38	59

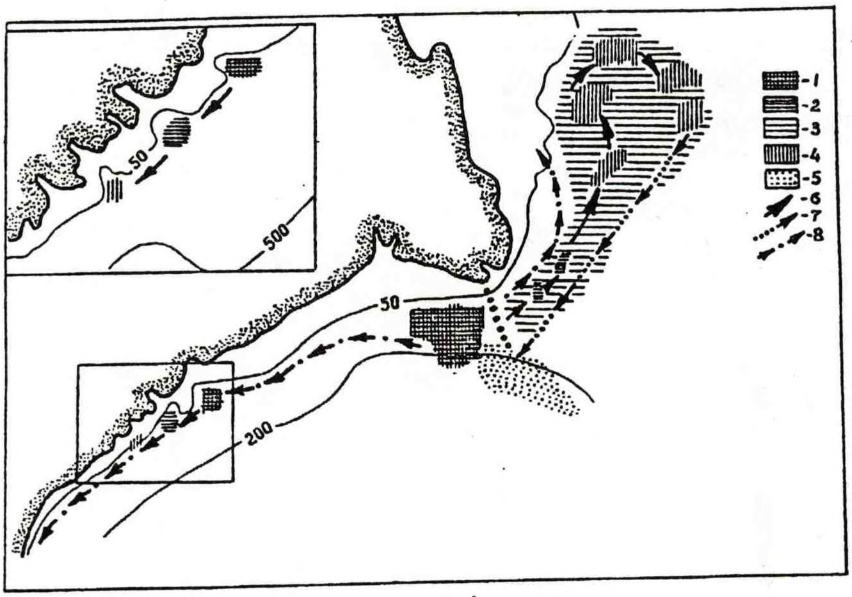

Fig. 1. The commercial concentrations and migrations of the humpy shrimp, Pandalus goniurus, in the western Bering Sea.

1, the locations of the shrimp concentrations in spring; 2, the concentrations in the early and mid-summer; 3, the shrimp dispersal in summer and fall; 4, the concentrations in late summer and early fall; 5, the supposed area of the shrimp hibernation; 6, directions of the shrimp migration in spring to fall; 7, the direction of supposed shrimp migration in late fall and winter; 8, the direction of the larval drift supposed.

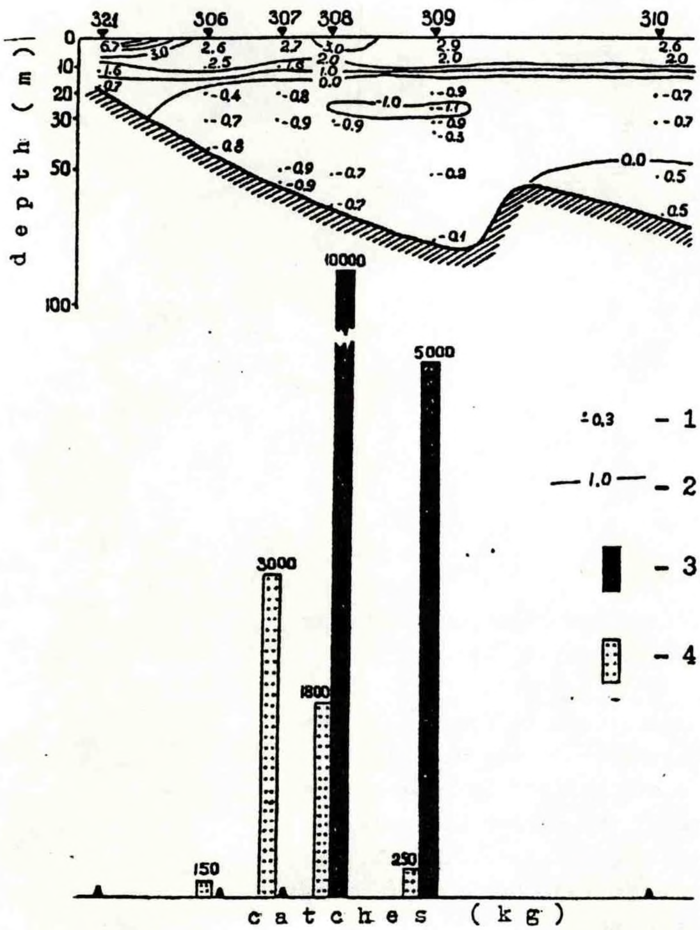

Fig. 2. Distribution of the water temperatures and shrimp catches on the transect through the trough near Anastasiya Bay, June 22-23, 1975.

1, values of temperature (°C) on the transect; 2, isotherms; 3, catches of Pandalus goniurus; 4, catches of Eualus macilentus. Values of catches are shown above the bars, catches of P. goniurus under 1 kg are shown as triangles.

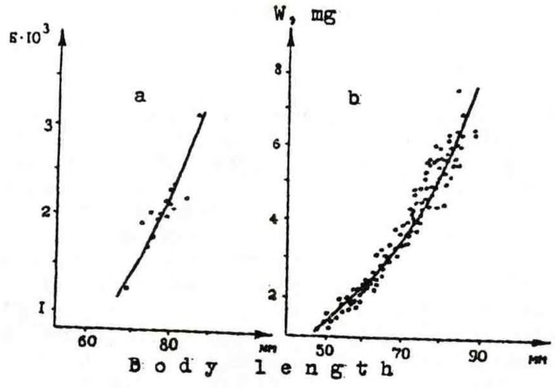

Fig. 3. The relationships between (a) body length (mm) and fecundity (eggs) and (b) mass (g) of Pandalus goniurus from the western Bering Sea.

FEATURES OF FISHERY AND BIOLOGY OF ALASKA POLLOCK TAKEN IN OPEN WATERS OF THE BERING SEA ON THE BASIS OF POLISH CATCHES IN 1985-1988

Edward Jackowski and Bogdan Trociński*

ABSTRACT.From 1985 to 1987 Polish fishing vessels operating in the open waters of the Bering Sea caught between 115.8 and 230.3 thous. tons of pollock per year.The fishing season began in autumn, in October, November, or December and lasted until July-August. The fishery was conducted with a mid--water trawl and was based on commercial concentrations usually occurring in the southern and central part of international waters. The maturity stages of pollock caught were as follows: premature (November, December, January), spawning (February, March), and post-spawning (from April on). Their length was from 34 to 70 cm, age from 3 to 17 years. The bulk of the catch comprised adult fish aged 8 to 10 years. Year classes of 1975-1978 predominated in the catch during the study period. Relatively small differences in mean lengths from year to year as well as high CPUE may indicate that catches made so far did not adversely affect pollock stocks in the open waters of the Bering Sea.

INVESTIGATION MATERIAL

In the open waters of the Bering Sea, fishing data and biological materials were collected from 1985 to 1988 from on board Polish commercial vessels. The study covered a period from autumn till spring (November-May), that is, the period of most intensive Polish fishing operations. Materials concerning the biological characteristics of these stocks come from that period while those characterizing Polish catches covered the whole period of Polish fishing operations in that area. Biological materials came from samples collected directly from on board the fishing vessels while those referring to catches were collected from fishing log-books. The total number of biological data gathered is presented in Table 1.

The biological investigations covered from 35 to 55% of successful hauls during the study period.

The length of fish by sex was measured in centimeters to the tip of caudal fin, to the nearest centimeter below. A single sample for length measurement comprised from 436 to 689 specimens. Samples for biological analyses consisted of the first and each fifths fish from all length classes. Sampling took into account the time of the day. The biological analysis covered the collection of such data on each specimen as length, weight, sex, gonads maturity stage, degree of stomach fullness, and age (otoliths).

Fish weight was determined with an accuracy of 5 g. Sexual maturity was determined on the basis of a five-grade scale applied in US for pollock (Nunnalee, Williamson, and Nelson 1982).

Stomach fullness was determined according to a five-grade scale, in which

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0 - means empty stomach,
1 - means stomach filled up to 1/4 of its volume,
2 - means stomach filled up to 1/2 of its volume,
3 - means stomach filled up to 3/4 of its volume,
4 - means stomach full and overflowing.

The data collected were subjected to statistical processing and presented in tables and figures.

FISHERY

Poland began fishing operations in the open waters of the Bering Sea in 1985. The main species caught in the area is walleye pollock; its aggregations do not mix with other species, hence no by-catch is present. For Polish vessels, the fishing season starts in October, November, or December and ends most frequently in May or June, although a few vessels continued fishing there through July and even August.

Size of catches

Data on Polish catches of pollock in the open waters of the Bering Sea are presented in Table 2.

It may be seen that Polish catches steadily increased from 115.9 thous. tons in 1985 to 230.3 thous. tons in 1987. A decline in catches in February and March is very typical. At that time pollock undergo spawning and their concentrations are quite mobile and quickly disappear, which results in a decrease in the mean weight of fish as well as a drop in CPUE. Catches and catch rates were much higher before and after that period.

Catch rates

It appears from the data presented in Table 2 that a decrease in catch rates coincided in time with an overall catch decline. In April-May, i.e., after spawning, catch rates were increasing again, reaching the same level as before the spawning period; in the months to follow they were different each year.

Such an irregularity of catch rates in the post-spawning period was caused by the pollock concentrations scattering over a vast area of the open waters and their considerable mobility. In the pre-spawning period, these concentrations were much more stable and concentrated over a smaller area, thus being more accessible to the fishery. The behavior of the post-spawning aggregations and a longer period of fish disappearance during the spawning period in 1986 and 1987 resulted in a decrease of mean CPUE in those years, as compared with 1985.

Distribution of catches

Distribution of catch of Polish fishing vessels is presented in Figures 1-2.

It may be seen, from the examination of these data that most catches were taken in the bottom part of the "triangle," up to latitude of 57^0 N. Northward of this parallel catches were sporadic. Since pollock were caught in the places of most dense concentrations, capture sites by month indicate directions of migration of this species. It may be said that commercial pollock aggregations exhibited a certain regularity recurring each year, that is, an anti-clockwise movement within the "triangle". Between March and May - when pollock occurred within a small area in the right-hand corner of the "triangle," concentrations of this species move towards north-west, most often from $56^0 30'$N to 57^0N. Then, in May and June, these shoals move south and south-east, reaching the southern boundary of the triangle at the turn of June-July. In October and November they are still in the western hemisphere, and in December, January they migrate along southern boundaries of the "triangle" to the eastern hemisphere. At that time the concentrations become more stable and congregate within a smaller area than before, thus being more accessible to the fishery. Since Poland did not conduct fishing operations from August to October there are no data covering that period. However, on the basis of regularity of fish occurrence in the same area each year one may suppose that in these months pollock was inhabiting the southern part of the triangle, west of the 180^0 meridian.

Features and depth of occurrence of pollock concentrations

In the pre-spawning period pollock formed quite dense concentrations, consisting of well separated congregations, with a thickness of 30-100 m. Along with gonads development and the approach of the spawning season fish formed densely-packed, ribbon-shaped layers with a thickness of 20-60 m. The aggregations of this type occurred in small areas of the "triangle", usually in its southern part, close to the 180^0 meridian, with a tendency to move eastward. Post-spawning fish occurred initially within a small area (March, Fig. 2b), in looser concentrations. With time these aggregations become more scattered, occurring as single, quite mobile shoals spreading over increasing areas.

Both premature and post-spawning concentrations underwent diurnal migrations: at night towards the surface, in the daytime-into deeper water layers. At night concentrations were scattered, forming loosely connected shoals with a thickness of 50-100 m, while in the daytime concentrations were more densely-packed and formed single patches or extended layers.

Mean depths of pollock occurrence ranged from 142 to 432 m. Fish exhibited distinct seasonal changes in the depth they inhabited. Towards the end of the summer season pollock concentrations occurred at shallower depths (about 200 m on the average) and with time they moved to much deeper waters (max. 500 m).

Vertical migrations of fish concentrations are most likely connected with a change in water temperature. Due to the cooling of water in winter, pollock concentrations migrate to deeper (warmer) waters while in the summer they occur at smaller depths. During the daytime pollock inhabit deeper waters than at night (from 60 to 120 m), which is a result of diurnal plankton migrations, followed by movement of small pelagic fish which constitute the food of pollock.

BIOLOGICAL CHARACTERISTICS

The biological analyses of pollock stocks from the open waters of the Bering Sea were based on materials collected form on board Polish fishing vessels in 1985-1988 (Table 1).

Length and age

Length and age distribution of pollock found in Polish catches taken in the open waters of the Bering Sea is graphically presented in Figures 3a-d. Length ranges and mean length and age of those fish are presented in Table 3.

The length of pollock specimens from Polish catches ranged 34-70 cm, their age being determined at 4-18 years. 4-year old specimens were found in small numbers in 1986 while 5-year olds and older fish were present in each year of the study period.

The bulk of the catches consisted of fish of 46-50 cm in length. Specimens of total length below 40 and more than 60 cm constituted only 1% of all pollock caught. In 1985, 1975-1978 year-classes predominated in the catch. As time elapsed, in the following years, the share of older year-classes diminished, first that of the year-class of 1975, then of 1976. Most abundant was 1978 year-class, which was one of the dominant ones during the three years of Polish fishing operations.

Weight

Weights of pollock, calculated from the formula $W=K*L^N$ (L = length of fish in cm, K,N = coefficients calculated by the least squares method. Regression coefficient "r" was over 0.9) are presented graphically in Figures 4a-d.

The weight of pollock ranged from about 200 to about 3,000 g; the bulk of the stock had a weight of 600-850 g. In the pre-spawning period the weights of fish reached their maximum value (Table 4). After the spawning lean specimens, differing considerably from pre-spawning fish, were found in the catches. Up to 45 cm in length, the weight of males and females was similar; above this length differences in the weight of the two sexes occurred: in the pre-spawning period, from December to February, the weight of females were greater than that of males. The same was found in March. On the other hand, in April, when the share of males was increasing and the feeding period began, males from larger length classes weighed more than females.

Condition

Fish condition, expressed as the percentage ratio of pollock weight to the cube of their length, is presented graphically in Figure 5.

A certain regularity may be observed in the condition of pollock from the open waters of the Bering Sea during the study period: they exhibited the best condition during the pre-spawning period, in November-December, i.e., two or three months before spawning. From this time on until spawning their condition steadily deteriorated, and then began to improve after spawning. Males attained the best condition more quickly, but also the deterioration of their condition began faster, which might reflect their faster sexual development.

Gonads maturity

Biological investigations conducted since 1985 covered pre-spawning periods (November, December, January), spawning periods (February, March), and post-spawning periods (April, May). Such a division was based on observations of development of gonads, which exhibited similar changes in the same months, year after year (Table 5).

Rapid sexual development of pollock takes place in January. Gonads at a premature stage (stage 3) were found in the majority of fish (in females in 21-97.7%, in males in 74.2-98.8%). In the third decade of January spawning specimens began to appear (1988-males). Females reached maturity somewhat later.

In February, except for 1985, the number of specimens at spawning stage increased considerably and post-spawning specimens began to appear. The situation was similar in March, the number of post-spawning specimens being higher. In April only a small number of pollock were at the spawning stage. Thus, the spawning period lasted from the third decade of January until April, with the peak in February, March.

Feeding

In the spawning period pollock practically did not feed (Table 6). Intense feeding began after spawning. In the stomachs of fish the following organisms were found: *Euphausidae*, *Copepoda*, shrimps, squid, lanternfish, and fish eggs.

In the pre-spawning period (from November until spawning) pollock gradually ceased feeding.

Sex ratio

In the pre-spawning period there were much more males than females in the stock of pollock from the open waters of the Bering Sea (Fig. 6). As spawning approached, the predominance of males diminished and at the end of the first decade of January the sex ratio was equal. In February and the first decade of March, i.e., during spawning there were more females than males in samples examined. After the spawning, in the third decade of March, the share of males in the stock increased.

In smaller length classes there were more males than females, in the 46-47 length class the sex ratio became equal, and in larger classes, the share of females increased.

Conclusions

The investigations as well as results of the Polish catches in the open waters of the Bering Sea in 1985-1988, have shown that mature pollock occur within the whole area of those waters from October to August.

Specimens found in the catches (1985-1988) were of 34 to 70 cm in length of 4 and 18 years old. The bulk of the catches consisted of fish whose length ranged 46-50 cm (70-74%), and age 8-9 years (62-70%). 4-year pollock occurred sporadically in 1986 while 5-year olds and older specimens were found in each year of the study period.

On the basis of gonads maturity, three periods in the biology of this species were distinguished:

1. Pre-spawning period (November, December, January).
2. Spawning period (February, March).
3. Post-spawning period (April, May).

There is no doubt that the remaining months may be considered as a feeding period for this species. This may be seen from the gonads development cycle, the shape of the curve of the condition coefficient, and the degree of stomach fullness of these fish.

This has also been confirmed by Japanese investigations in the same area (Keisuke Okada 1986).

Spawning of these fish takes place between the beginning of February and the third decade of March and may exhibit a certain shift in time (e.g. it took place earlier in 1986 than in 1988).

In the pre-spawning period, pollock do not feed, the condition coefficient curve slopes downward, and - at the same time - gonads mature rapidly. At that time, pollock congregate in the southern part of the "triangle", forming well separated, densely-packed aggregations changing later into dense, ribbon-like layers. Concentrations of this kind occur at increasingly greater depths (432 m in 1987) and within a shrinking area. At the same time they move eastward.

During spawning, pollock in the "triangle" area occur in separate concentrations, which quickly disappear, becoming difficult to catch. After spawning, feeding intensity increases, the condition of fish improves, and gonads are at spent stages. At that time pollock congregated into a number of separate feeding aggregations, very mobile and expanding over vast areas of the "triangle".

Poland has carried out investigations since 1985; this paper presents their results. It should be borne in mind, however, that the above conclusions are based on materials collected within a period of only three years and may thus constitute a basis for a discussion aimed at explaining the status of the pollock stock in the open waters of the Bering Sea, their migrations and spawning grounds, as well as the state of stocks, in order to manage them on a rational basis.

Catch rates attained, small differences in mean lengths in individual months of subsequent years, as well as permanent predominance of the same year classes of 1975-1978 in their age structure allows for a hypothesis that catches taken so far had no negative impact on the state of this stock.

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Table 1. Amount of materials collected

(specimens)

Study period	Mass measurements	Biological analyses
January-February 86	11 554	784
December 85-May 86	52 147	3 057
November 86-March 87	37 132	2 842
January-April 88	18 781	1 956

Table 2. Polish catches and catch rates of pollock in open waters of Bering Sea

Year	1985		1986		1987	
	catch (t)	CPUE (t/df)	catch (t)	CPUE (t/df)	catch (t)	CPUE (t/df)
January	3 407	48,7	32 290	59,1	41 107	54,1
February	16 954	55,8	21 169	45,5	32 146	44,1
March	10 031	42,3	18 937	41,3	13 715	26,8
April	18 456	51,4	26 644	62,8	31 292	57,4
May	30 855	63,9	17 852	46,4	30 338	49,9
June	18 161	50,2	4 939	26,7	24 512	45,8
July	94	47,0	339	21,2	16 157	68,5
August	–	–	6	6,0	–	–
September	–	–	–	–	–	–
October	–	–	2 201	44,9	–	–
November	–	–	13 514	41,2	13 342	47,8
December	17 916	58,9	25 358	45,4	27 709	39,5
Total	115 874	54,5	163 249	47,7	230 318	47,0

Table 3. Length ranges and mean lenght and age of pollock from the Polish catches in open waters of the Bering Sea in 1985-1988

Year	Month	Length (cm)						Age					
		range (from-to)			mean			range (from-to)			mean		
		males	females	total	males	females	total	males	females	total	males	females	total
1985	January	37-54	39-58	37-58	46,24	47,71	47,03	5-16	5-17	5-17	9,1	8,9	9,0
	February	39-56	38-59	38-59	46,39	47,78	47,13						
	December	39-56	40-60	30-60	45,85	47,21	46,49	5-17	4-17	4-17	8,4	8,7	8,6
1986	January	34-56	40-62	34-62	46,49	48,04	47,24	4-16	5-15	4-16	8,9	9,5	9,2
	February	38-57	36-60	36-60	47,10	48,70	47,94	5-16	5-18	5-18	9,9	10.1	10,0
	March	38-55	40-60	38-60	47,25	48,51	48,08	5-14	5-15	5-15	9,5	9,8	9,6
	April	30-56	39-70	38-70	45,96	47,25	46,68	6-14	6-17	6-17	9,0	9,0	9,0
	May	39-54	41-57	39-57	45,77	47,12	46,48	4-13	7-14	4-14	9,3	8,9	9,1
	November	41-57	42-58	41-58	47,39	48,76	47,89	5-16	6-14	5-16	9,0	9,5	9,2
	December	38-55	38-62	38-62	46,99	48,20	47,57	5-13	5-14	5-14	8,8	8,8	8,8
1987	January	38-55	38-50	38-53	46,48	47,70	47,11	5-13	5-14	5-14	9,4	9,5	9,5
	February	38-61	37-62	37-62	46,78	48,12	47,47	5-12	5-14	5-14	9,8	9,9	9,9
	March	37-53	39-60	37-60	46,89	48,06	47,37	5-11	5-14	5-14	9,2	10,3	9,8
1988	January	40-55	39-58	39-58	46,95	48,37	47,76						
	February	39-60	40-60	39-60	47,95	48,81	48,27						
	March	40-55	40-63	40-63	47,66	48,70	48,39						
	April	41-54	40-58	40-58	47,23	48,81	48,38						
		34-61	36-70	34-70	46,82	48,16	47,54						

Table 4. Mean weight of pollock caught in 1985-1988 open waters of Bering Sea

(g)

Year	1985		1986		1987		1988	
Month	males	females	males	females	males	females	males	females
January	623,0	755,0	671,8	768,8	638,1	742,1	673,8	773,9
February	655,0	770,0	666,3	786,9	611,1	739,2	661,7	777,0
March			602,5	728,2	584,1	764,2	650,1	722,9
April			568,7	643,0			633,8	698,7
May			570,4	602,0				
June								
July								
August								
September								
October								
November			738,3	809,3				
December	688,4	766,0	694,7	794,7				

Table 5. Gonads maturity in pollock from Polish catches in open waters of Bering Sea (1985-1988)

Males (%)

Year	1985					1986					1987					1988				
Maturity stage	2	3	4	5	n	2	3	4	5	n	2	3	4	5	n	2	3	4	5	n
January	2,2	98,7	-	-	138	0,6	98,8	0,6	-	360	25,8	74,2	-	-	271	5,3	79,7	14,5	0,5	207
February	2,5	97,5	-	-	202	1,8	69,8	24,8	3,6	278	5,5	89,7	4,8	-	272	12,2	47,8	30,0	10,0	303
March						22,4	4,1	37,4	36,1	219	15,0	10,0	67,5	7,5	40	24,9	6,9	9,5	58,7	189
April						87,6	8,8	-	3,6	193						17,5	-	7,0	75,5	57
May						98,1	1,9	-	-	106										
June																				
July																				
August																				
September																				
October																				
November						91,1	8,9	-	-	168										
December	1,4	98,6	-	-	294	78,0	22,0	-	-	142										

Females (%)

Year	1985					1986					1987					1988				
Maturity stage	2	3	4	5	n	2	3	4	5	n	2	3	4	5	n	2	3	4	5	n
January	7,4	92,6	-	-	162	1,5	97,7	0,8	-	392	53,8	46,2	-	-	334	79,0	21,0	-	-	286
February	3,2	96,8	-	-	281	2,0	71,0	26,3	0,7	304	9,0	86,6	4,4	-	367	42,4	55,9	0,5	1,2	406
March						48,6	4,6	35,8	11,0	282	8,6	54,3	28,4	8,7	81	37,0	11,5	2,3	49,2	384
April						96,8	2,3	-	0,9	219						35,7	-	2,6	61,7	115
May						98,2	1,8	-	-	112										
June																				
July																				
August																				
September																				
October																				
November						100,0	-	-	-	132										
December	3,4	96,6	-	-	298	99,2	0,8	-	-	253										

Table 6. Degree of stomach fullness in pollock from Polish catches in open wates of the Bering Sea (1985-1988)

Males (%)

Degree of stomach fullness	1985						1986						1987						1988					
	0	1	2	3	4	n	0	1	2	3	4	n	0	1	2	3	4	n	0	1	2	3	4	n
January	91,3	8,7	-	-	-	138	97,8	2.2	-	-	-	360	98,1	1,5	0,4	-	-	271	98,5	1,5	-	-	-	207
February	94,1	4,9	1,0	-	-	202	98,9	0,7	0,4	-	-	278	98,5	-	0,7	0,4	0,4	272	84,8	5,9	5,9	3,0	0,4	303
March							57,6	20,5	11,9	5,0	5,0	219	92,5	`2,5	5,0	-	-	40	64,5	19,6	10,6	3,7	1,6	189
April							31,6	34,8	26,9	6,2	0,5	193							73,7	24,6	-	1,7	-	57
May							50,0	24,6	17,9	5,6	1,9	106												
June																								
July																								
August																								
September																								
October																								
November							91,1	8,3	0,6	-	-	168												
December	98,0	2,0	-	-	-	294	96,7	2,9	0,4	-	-	142												

Females (%)

Degree of stomach fullness	1985						1986						1987						1988					
	0	1	2	3	4	n	0	1	2	3	4	n	0	1	2	3	4	n	0	1	2	3	4	n
January	88,9	9,3	1,8	-	-	162	96,1	2,5	0,8	0,3	0,3	392	97,6	1,2	0,3	0,3	0,6	334	93,0	6,6	-	0,4	-	286
February	90,7	9,3	-	-	-	281	99,0	0,3	0,7	-	-	304	98,1	0,8	0,6	0,5	-	367	81,4	8,6	7,1	2,4	0,5	406
March							44,7	28,7	17,7	7,1	1,8	282	92,6	1,3	1,2	3,7	1,2	81	54,6	29,2	8,5	6,9	0,8	384
April							20,1	42,9	27,4	8,7	0,9	219							64,4	23,7	6,9	5,1	-	115
May							24,1	39,3	22,3	9,8	4,5	112												
June																								
July																								
August																								
September																								
October																								
November							82,6	15.1	1,5	0,8	-	132												
December	92,4	7,0	0,3	0,3	-	298	87,7	10,3	0,8	1,2	-	253												

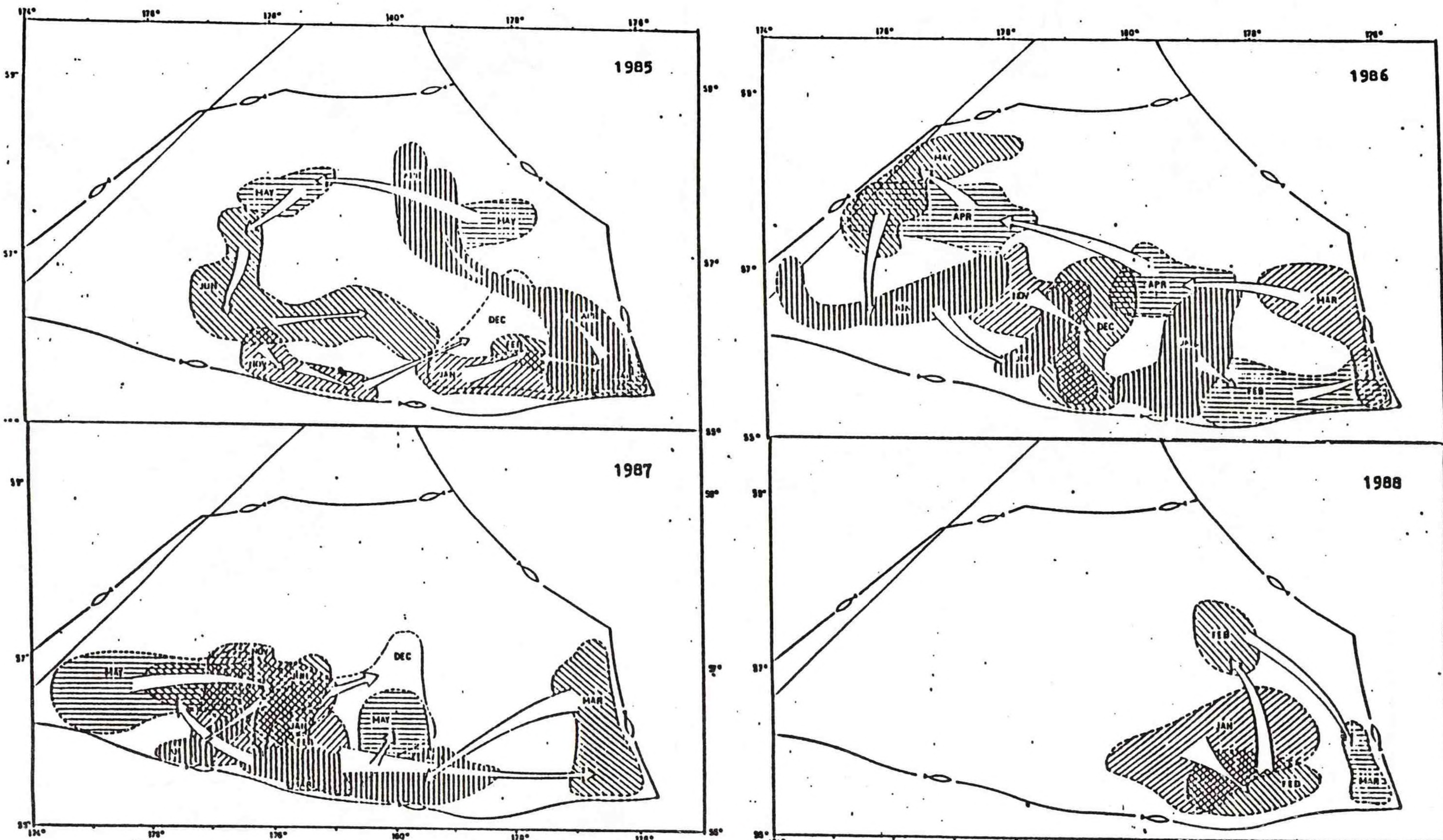


Figure 1. Directions of migrations of pollock concentrations on the basis of Polish catches in open waters of the Bering Sea in 1985-1988

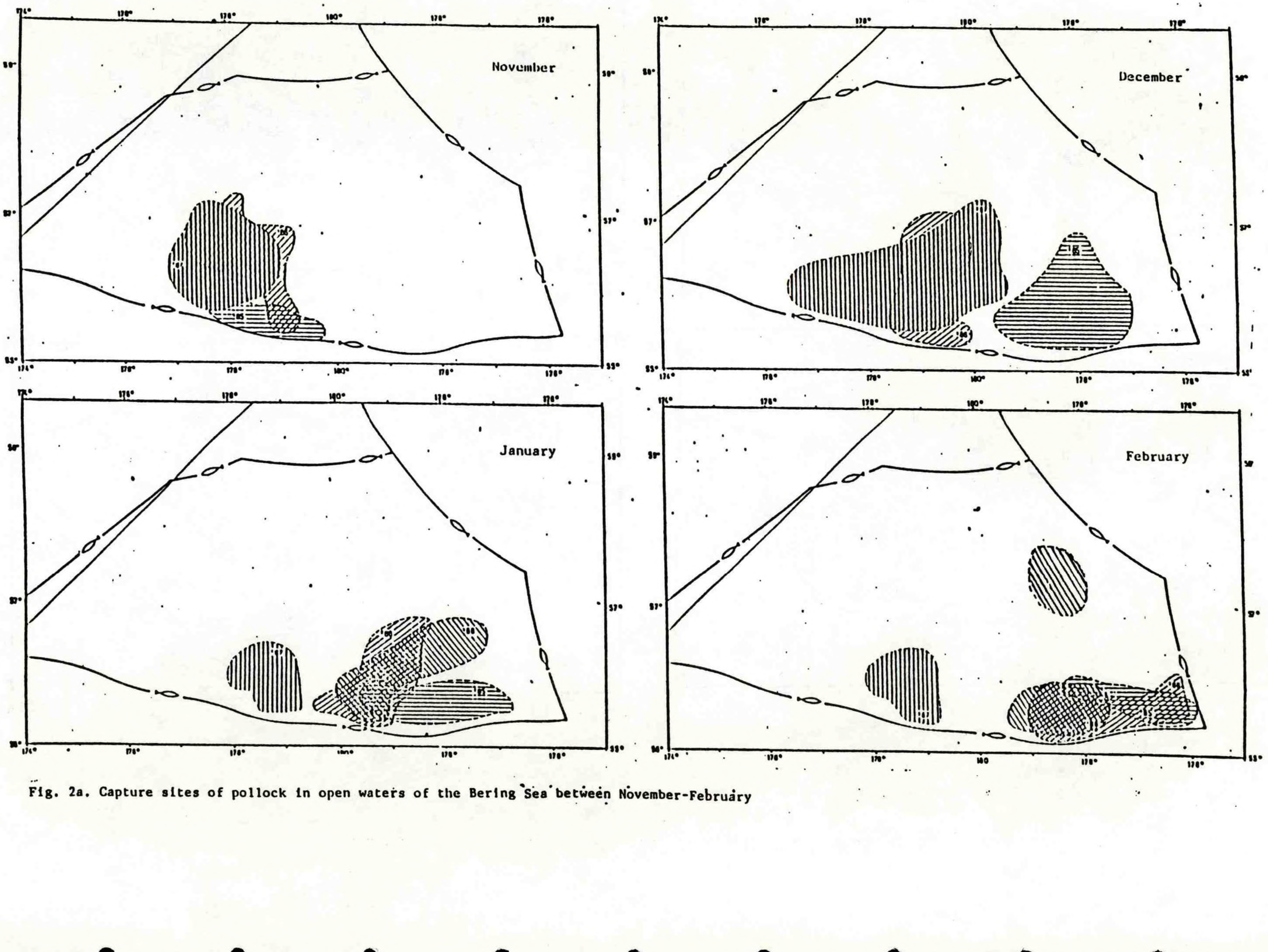


Fig. 2a. Capture sites of pollock in open waters of the Bering Sea between November-February

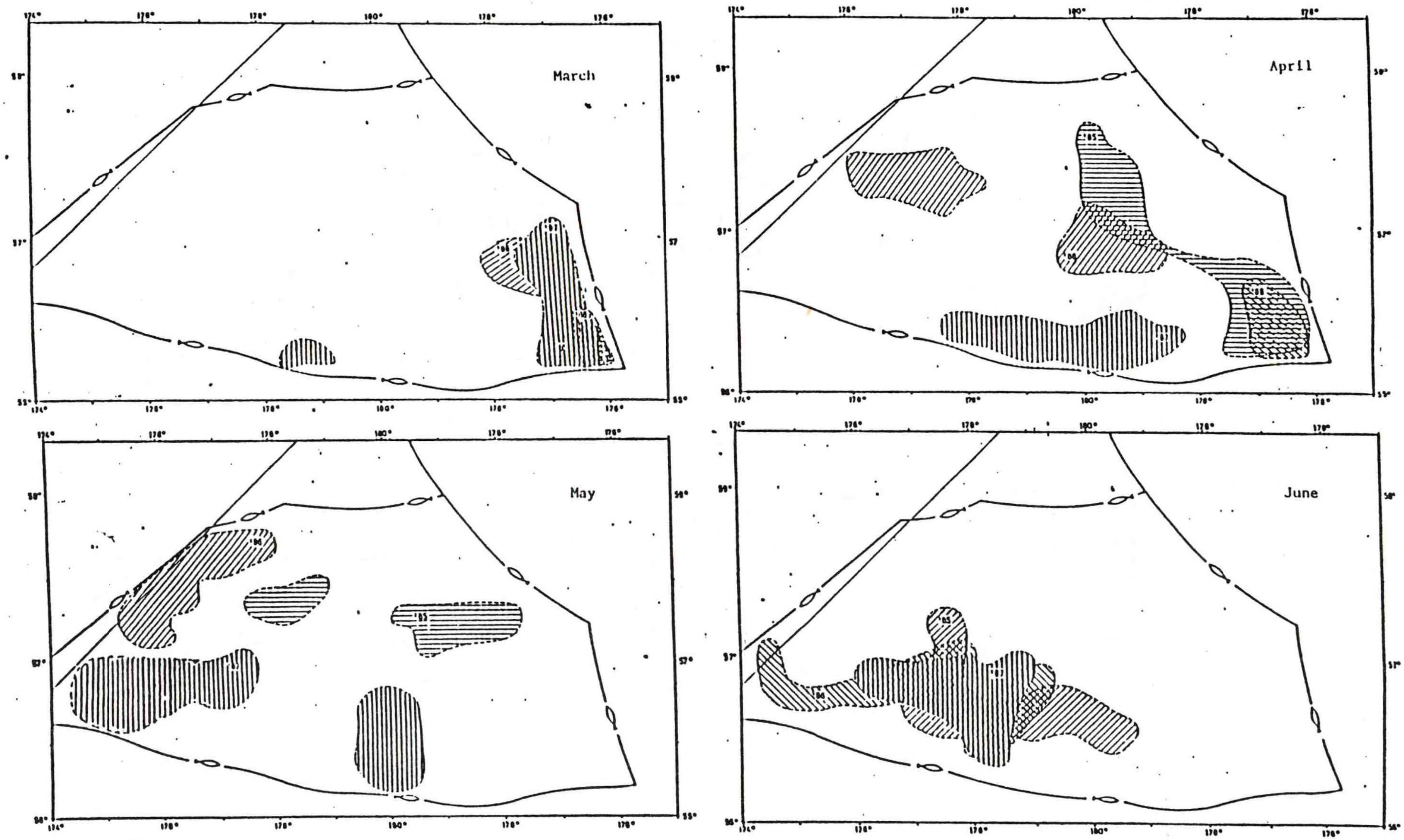


Fig. 2b. Capture sites of pollock in open waters of Bering Sea between March - June

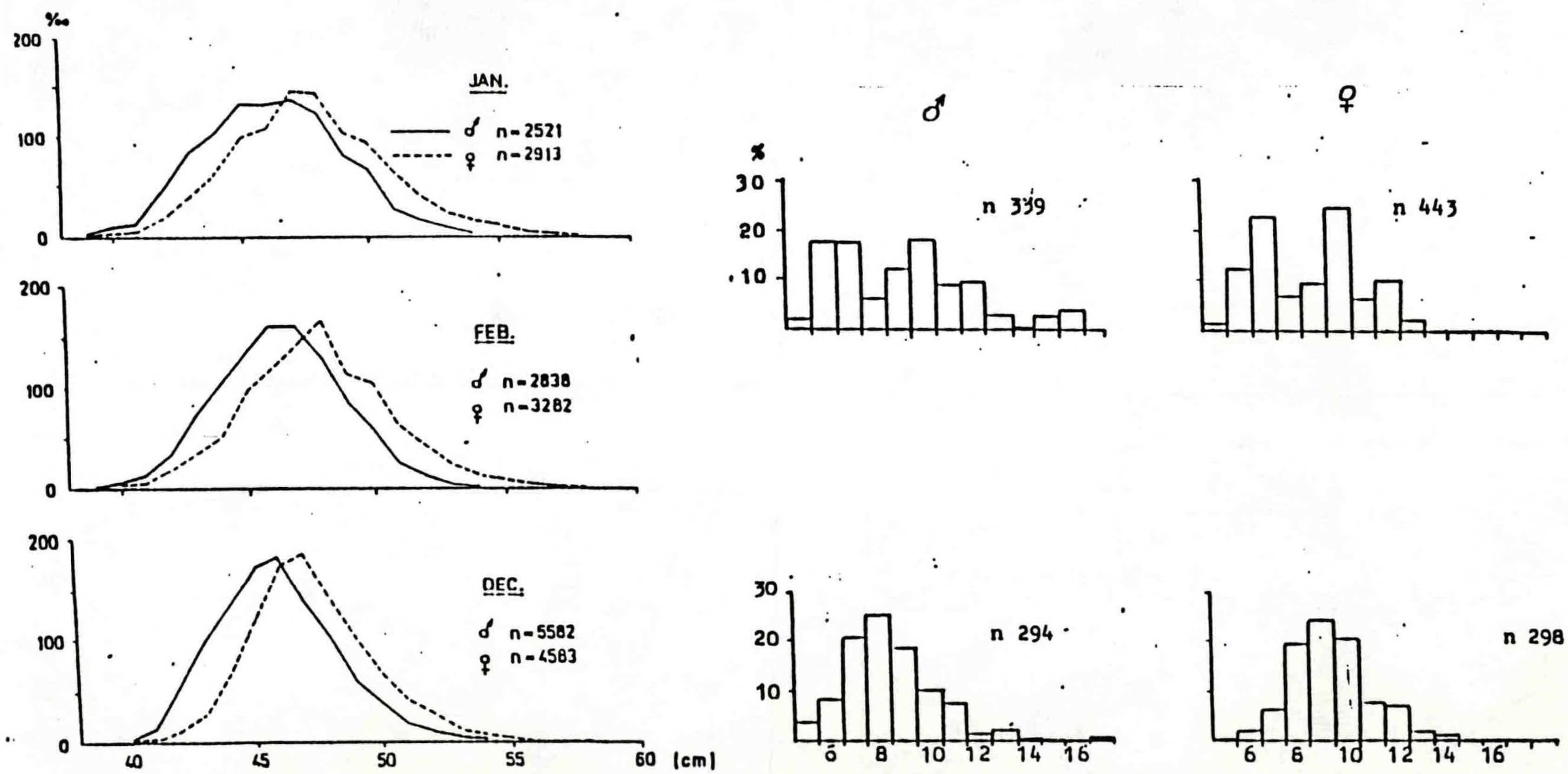


Fig. 3a. Length and age of pollock caught in open waters of the Bering Sea in 1985

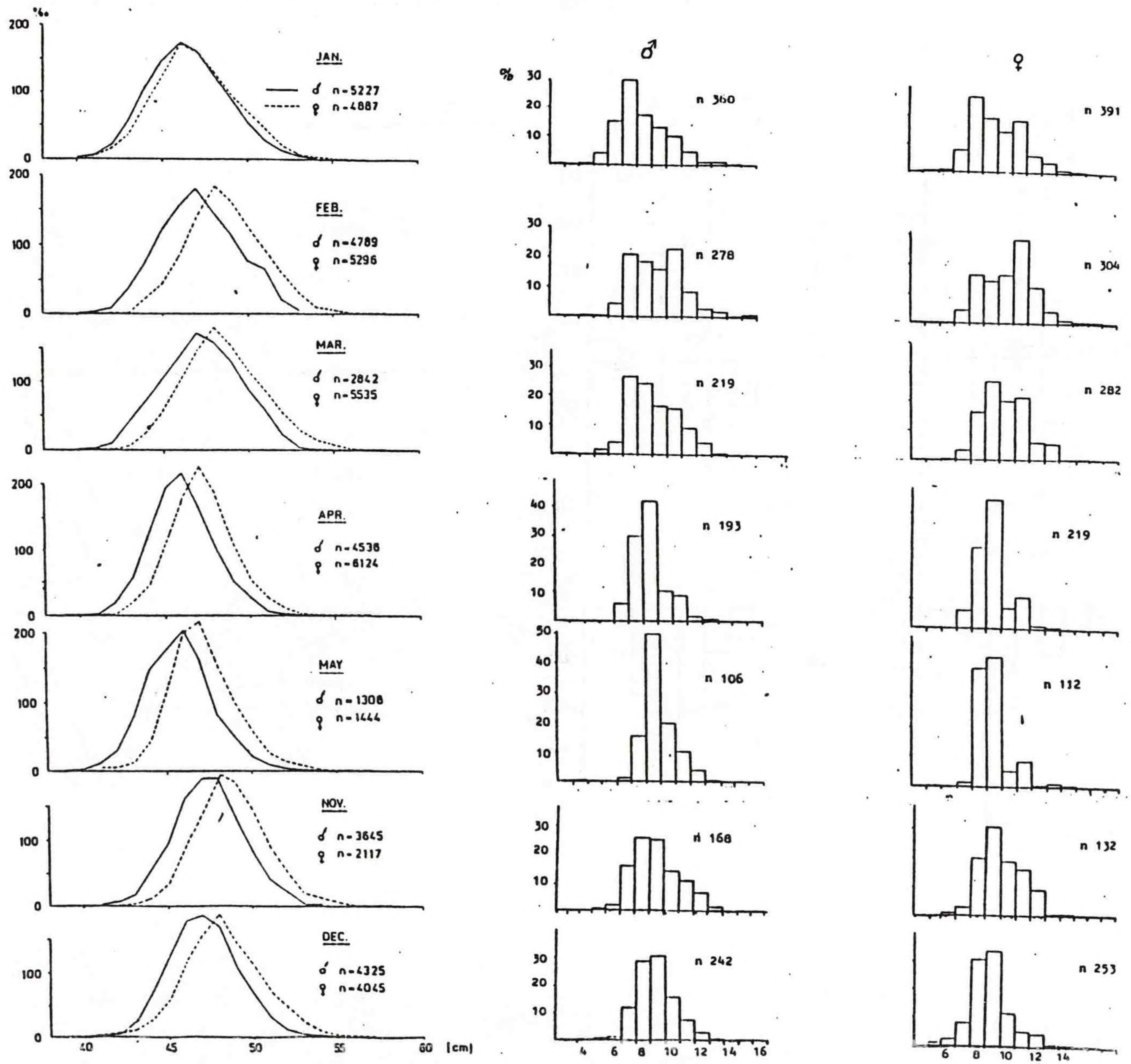


Fig. 3b. Length and age of pollock caught in open waters of the Bering Sea in 1986

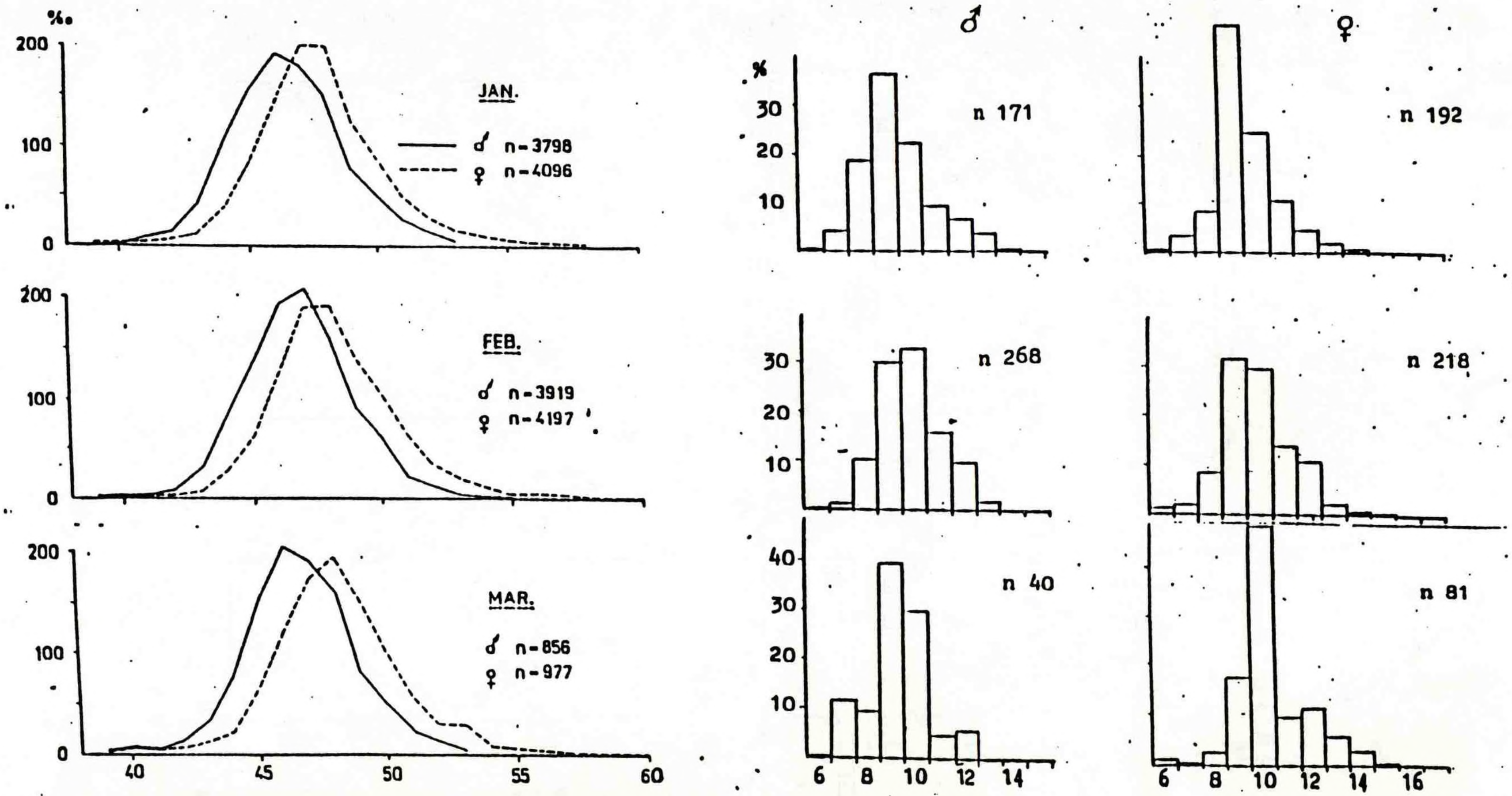


Fig. 3c. Length and age of pollock caught in open waters of the Bering Sea in 1987

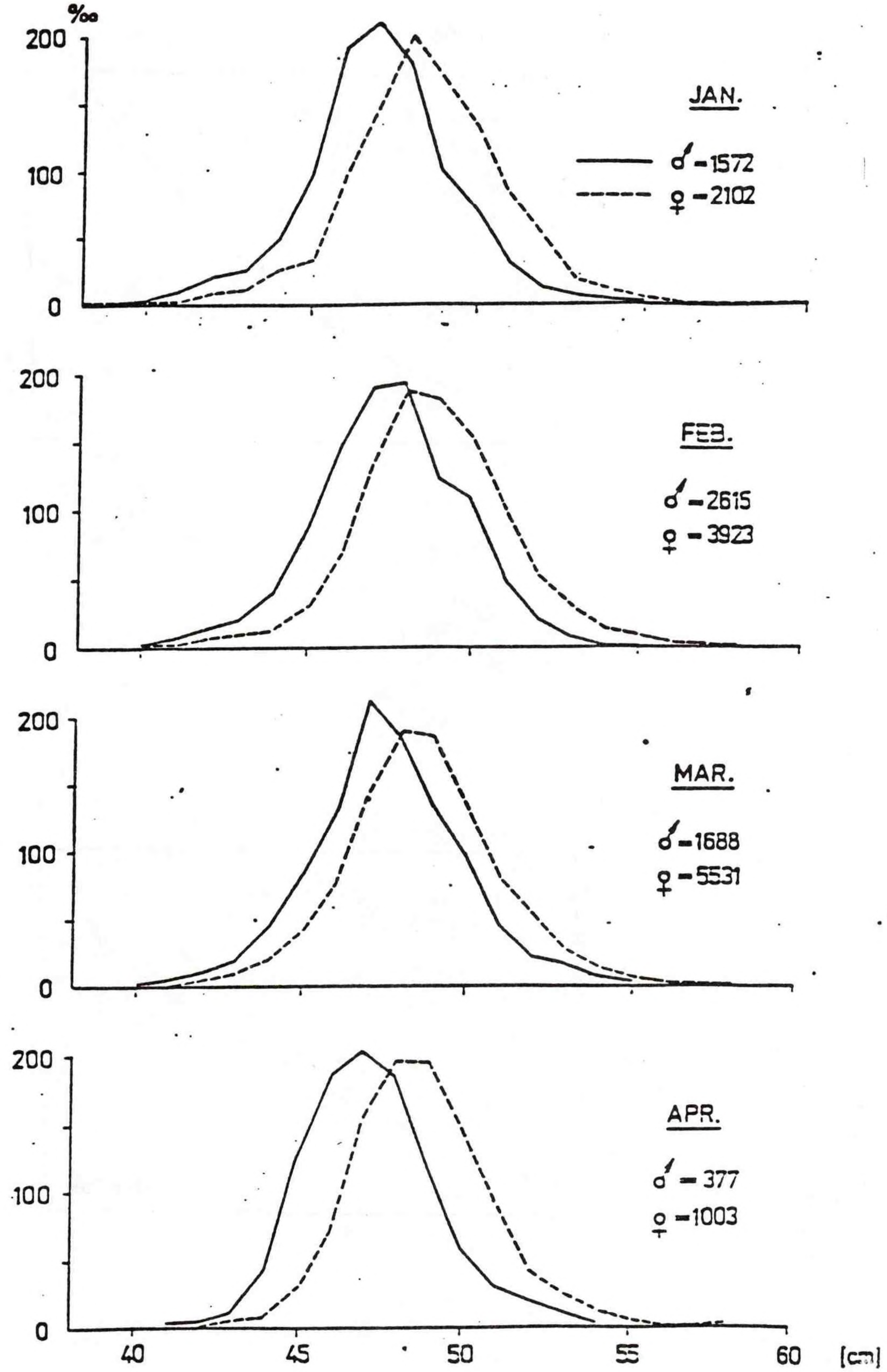
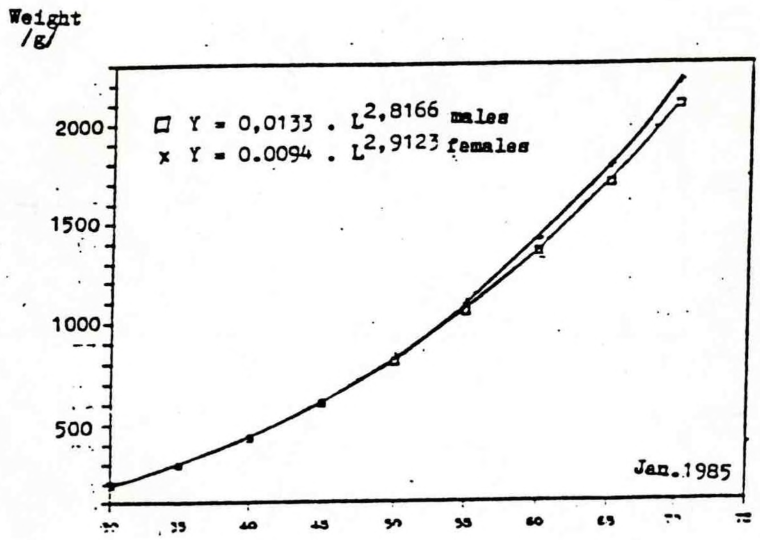


Fig. 3d. Length distribution of pollock caught in open waters of the Bering sea in 1988



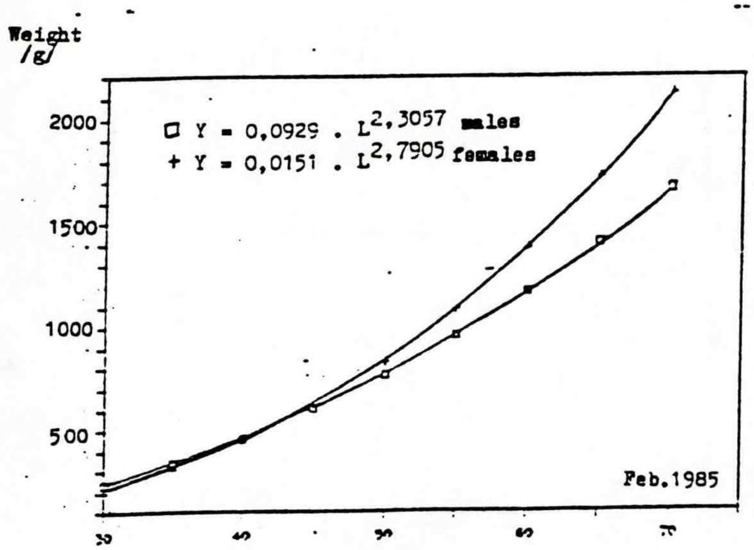


Fig. 4a. Weight of pollock from Polish catches in open waters of the Bering Sea / January, February 1985 /

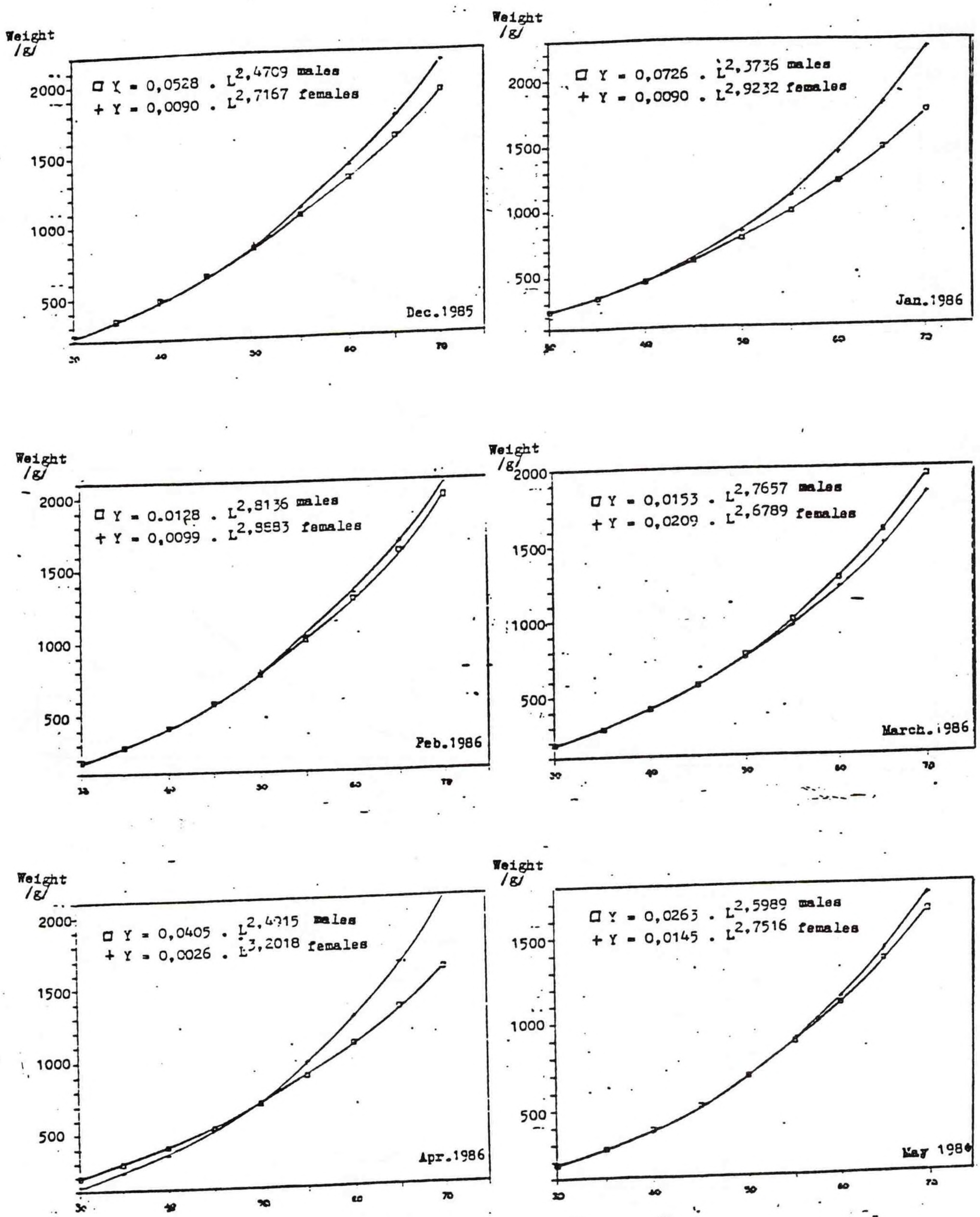


Fig. 4b. Weight of pollock from Polish catches in open waters o the Bering Sea
(December 1985, January-May 1986)

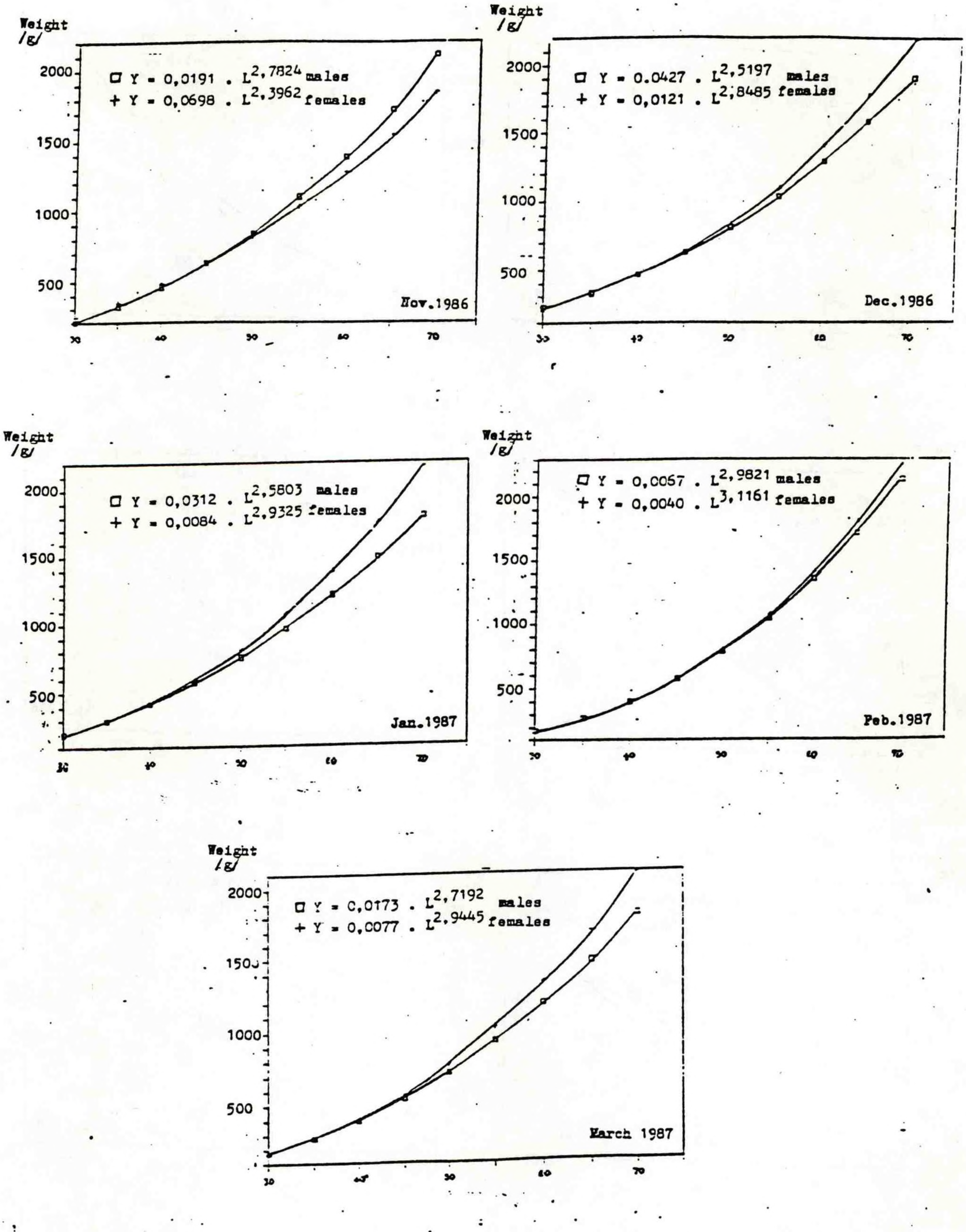


Fig. 4c. Weight of pollock from Polish catches in open waters of the Bering Sea (November, December 1986; January-March 1987)

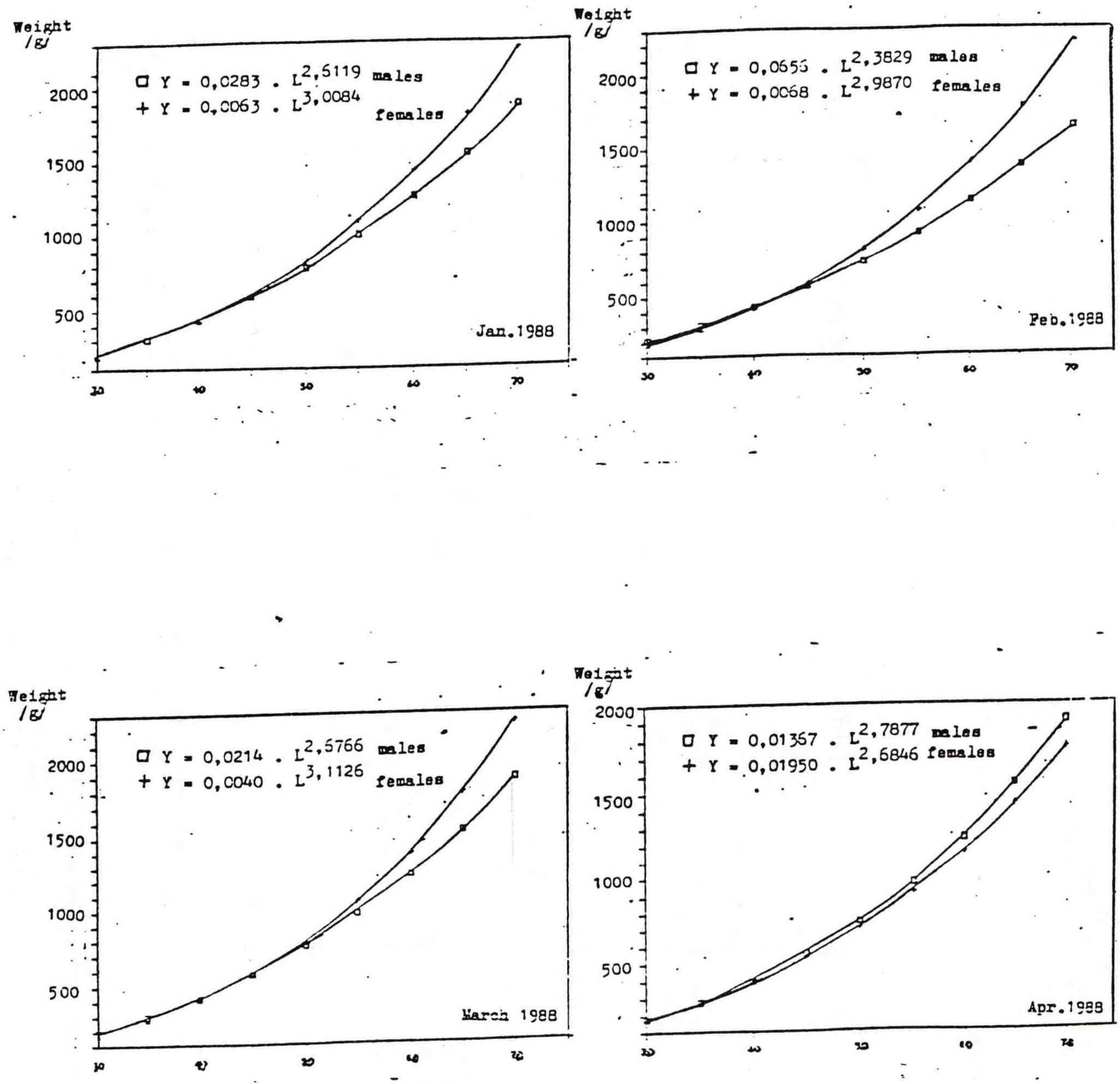


Fig. 4d. Weight of pollock from Polish catches in open waters of the Bering Sea / January, April 1988 /

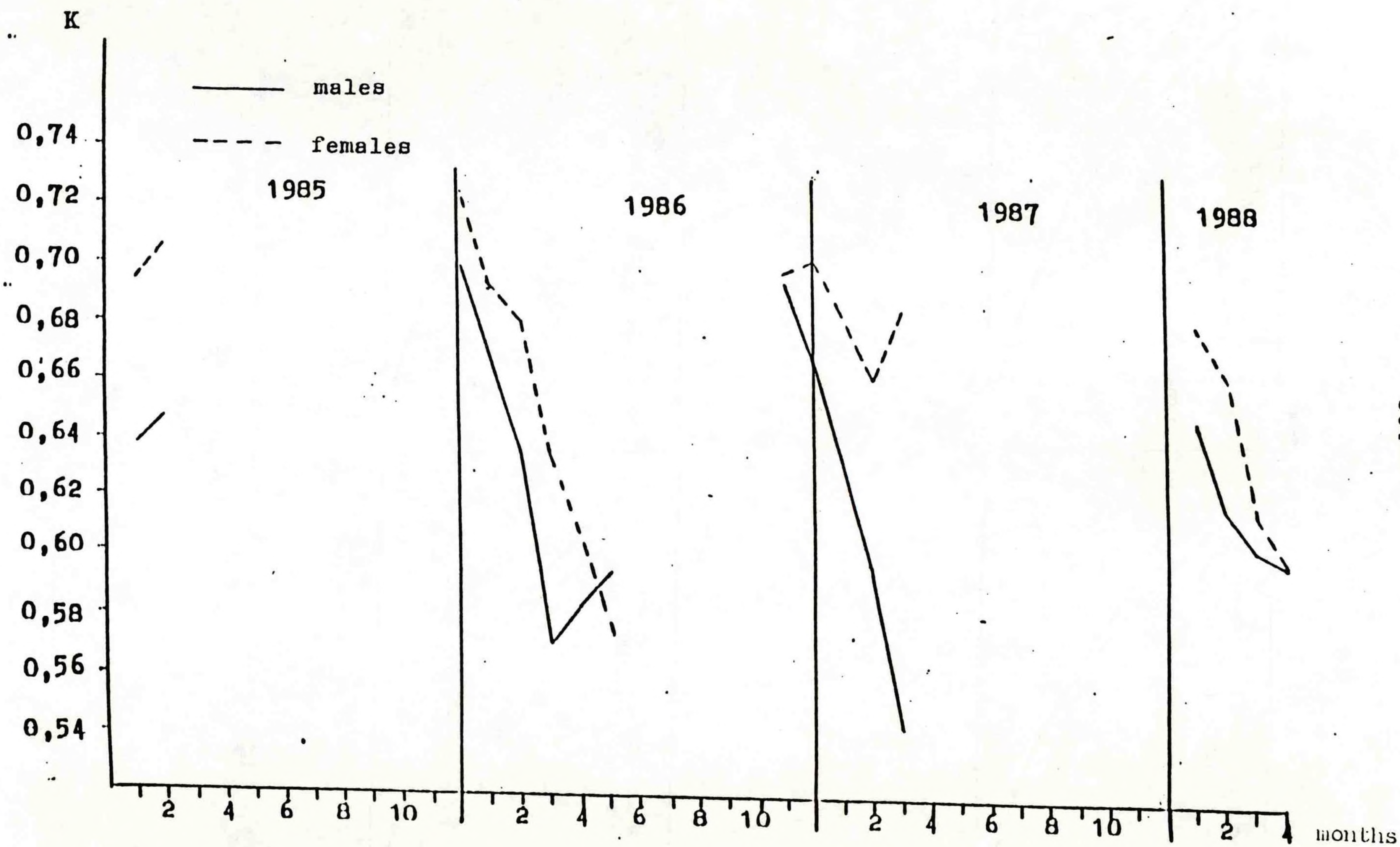


Fig. 5. Changes in condition coefficient / $K = \frac{W}{L^3} \times 100$ / in pollock from Polish catches in open waters of the Bering Sea /1985 - 1988/

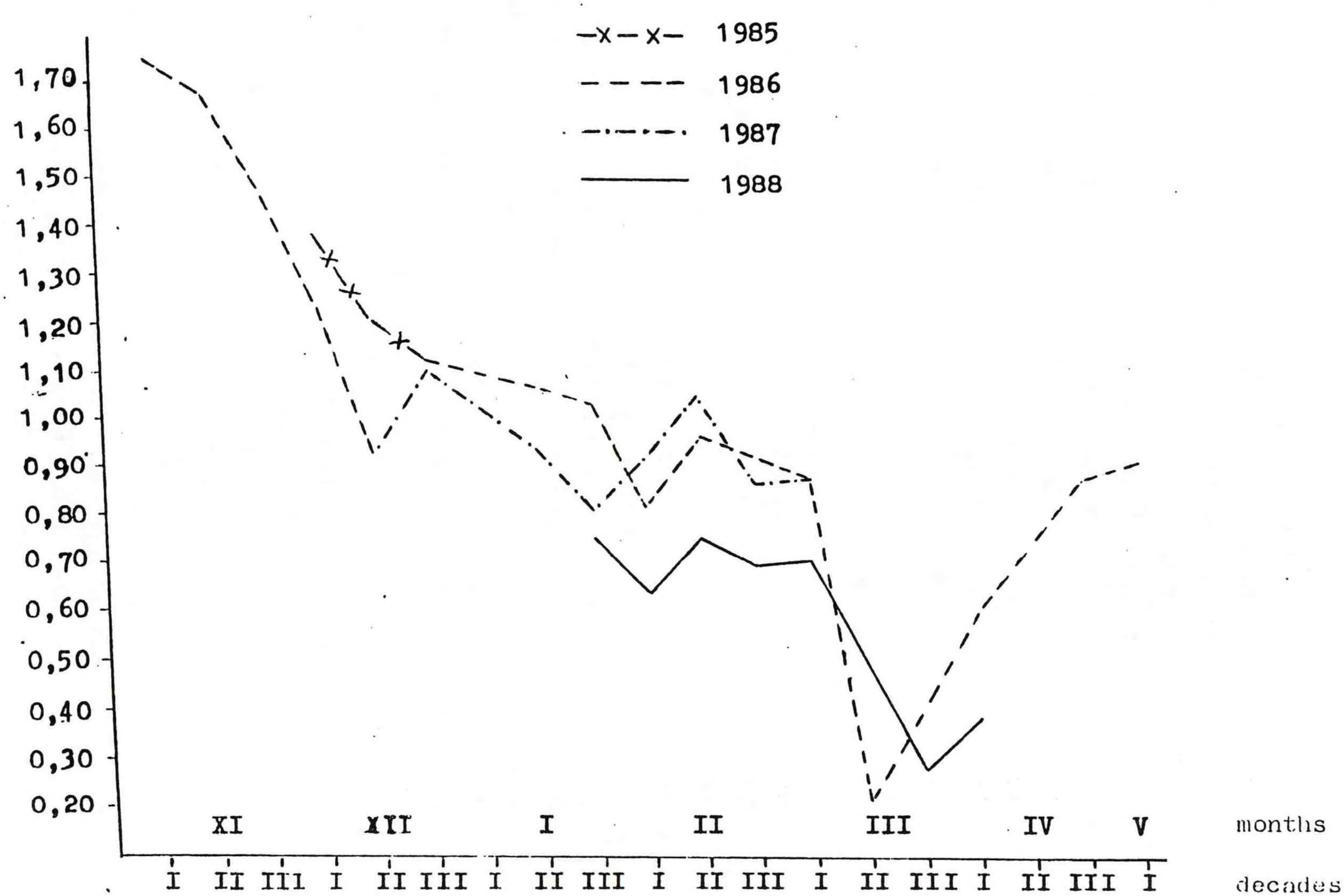


Fig. 6. Sex ratio of pollock from Polish catches in open waters of the Bering Sea / 1985 - 1988 /

DISTRIBUTION, BIOLOGY AND ABUNDANCE OF BLUE CRAB, PARALITHODES PLATYPUS IN THE BERING SEA

Slizkin A.G., Bukin S.D. TINRO

The complex investigations on the distribution, biology and abundance of crabs in the Bering sea have been started by TINRO in 1969 when the first survey of the entire shelf and the upper slope of the sea has been carried out. Within six years (1969-1974) we have accumulated the ample observation materials which essentially inlarged our knowledge of crabs (Slizkin, 1972, 1974, 1977, Kanarskaja, Slizkin, 1975). Almost in the same period the blue crab studies have been conducted by the other authors (Hoffman, 1968, Sasakawa, 1973, 1975 a, b) who described certain biology aspects of this species. Later on TINRO investigations were conducted only in the Western Bering sea.

The Bering sea is the habitat of the most abundant population of blue crabs. In the eastern part of the sea the blue crabs occur off the Aleutian Islands, Pribilof Islands , St.Matthew's and St. Laurence Islands. In the North they penetrate into the Bering Strait and the southern part of the Chukchi sea. In the Western Bering sea blue crabs are practically ubiquitous except the estuaries with the lower water salinity (Fig. 1).

Blue crabs have the heterotopic type of development, the life history of which subdivides into three stages: plankton stage - larvae (1), habitat of epifauna on hard grounds - juvenile (2), habitat over spatially extensive bottom areas - adult migrating animals (3). The conditions of existence are not the same for all three stages. The juvenile stage is the most critical for the species,responsible, after all, for the abundance and structure of the population. The proof for this thesis lies in the fact that nonmigrating juveniles can develop only if epifauna of sessile benthos is available. In the Bering sea the sessile bentos of high biomass occupy only selected areas limited in expanse (Makarov,1937, Lus, Kuznetsov, 1961, Vinogradov, Neiman, 1965).

The dredging surveys conducted in the Bering sea showed that aggregations of juveniles keep close to the shore (Fig. 1). They are observed here among hydroids, bryozoans, sponges, corals inhabiting the hard grounds (Slizkin, 1972, 1974a, Bukin et al., in press). In the habitat of the blue crab juveniles there are relatively high water currents velocities, the sediment deposits are

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washed away and the hard grounds with the high biomass of sessile benthos are formed (Neiman, 1963, Natarov, 1963, Arsenjev, 1967). These processes are characteristic for the Western Bering sea and the islands' coasts (Arsenjev, Shcherbinin, 1963, Vinogradov, Neiman, 1965, Slizkin, 1974 a,b). Preference of juvenile blue crabs to the grounds with the above characteristics is the main condition for the formation of the structure of the species population.

The king crab juveniles develop in the similar environment conditions. However the maximum concentrations of these two species are spatially isolated and the blue crabs occupy the northernmost coastal waters of the Far-Eastern seas with more unfavourable ambient conditions (Slizkin, 1977, Rodin, Myasoedov, 1982, Rodin, 1985). The biotopic preference of the juveniles and the spatial distribution of crabs related to it are most specific for blue crabs (Table 1).

The larval blue crabs cannot be selective to the environment conditions. Just as for the other species the favourable conditions (current directions, rough sea, temperature, chemical composition of water) contribute greatly to higher survival of larvae and formation of abundant generation. Accumulation of the postlarval juveniles on the shallow water shelf increases when larvae migrate nearby the shore, i.e. they have been released by females in this area.

The size composition of blue crabs from different areas of the Bering sea might greatly vary the evidence of which was given by investigations for many years including the survey of 1986 (Fig. 2). Difference in sizes of blue crabs from Olyutorskiy Bay, off Korjak coast, Anadyr-Navarinskiy area, St.Matthew's I. area might imply that abundant year-classes are not simultaneous in these areas. These peculiarities are attributed to the absence of the evident links between the subpopulations of blue crabs in the Bering sea. The idea of likeliness of existence of independent or semi-dependent populations in these areas was forwarded earlier (Slizkin, 1972). The population structures of crabs in the Anadyr-Navarinskiy and St.Matthew's I. areas are of certain interest. The complex system of currents in this part of the sea facilitates the distribution of larvae over the vast area. The huge flow of larvae born in the area of C.Navarin is carried by the currents to the North and North East into Anadyr Bay, to Chukchi Peninsula, St. Laurence I. and to the South West into Olyutorskiy Bay and the area off Korjak coast. In this sense the aggregation of blue crabs in the area of C. Navarin could be considered as an independent population and those to the North East and South West of C. Navarin as semi-dependent. The lack of mature crabs observed off the coast of Chukchi Peninsula might be the evidence of the sterile ~~immigration~~ zone of expatriation of crabs from Navarin and St.Matthew's I. populations. Hence the shelf area between C. Navarin and St.Matthew's I. might have essential if not the primary meaning in formation of the Bering sea blue crab population and its biomass. So the studies of crabs in the Navarin-St.Mathew's I. area should be further developed.

The ~~emergence~~ hatching of larval blue crabs[x] occurs like that of the other lithodids in the inshore waters following the migration of females to the shallow waters in spring. It was observed that it is eggs carrying females that are first to migrate to the shallow waters. This phenomenon was observed in the Olyutorskiy-Navarinskiy area of the Bering sea and off the Eastern Sakhalin (Bukin et al., in press). This behaviour of blue crabs differs from that of king crabs. The king crab females are only slightly ahead of their males in migrating over to the shallow waters. After the emergence of larvae the king crab females would moult, copulate with males in the shallow waters and ~~release~~ spawn new eggs (Vinogradov, 1969, Rodin, 1985). Biology of the king crab reproduction has the logical correlation with the corresponding spring migrations of mature crabs of the both sexes related to their participation in spawning.

Separation of major aggregations of blue crab males and females in spring and summer (Table 1) is attributed to the lack of necessity in spawning in the areas in question. The observed peculiarities do not, probably, contradict with the reproductive strategy of the species. At the time of investigations in the North Western Bering sea and off the Eastern Sakhalin in August-October when the larvae already emerged the authors observed the isolated abundant aggregations of mature females which did not release eggs or did not spawn. These females did not have any signs of disease. Based on these observations it was assumed that blue crabs would not spawn every year (Slizkin, 1972, Sasakawa, 1973, Somerton,Macintosh,1985).

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x - Females carry the fertilized eggs for about a year before the larvae emerge. The "spawning" is implied to include copulation, release of sperm and eggs, fertilization and fixing of eggs on the pleopods of females.

The studies of the blue crab gametogenesis have not yet provided any evidence to justify these observations.

The said peculiarities of biology and behaviour of blue crabs could be explained if to bear in mind that oogenesis of this species lasts for two years as that of king crabs (Fedoseev, 1982). There are two groups of blue crabs spawning in odd and even years, abundance of these groups in the population is, as a rule, different. In early 70s the emergence of larvae in the North Western Bering sea prevailed in odd years. It was observed that in July, 1969 62% of 480 mature females and in August, 1971 72% of 580 mature females were at the stage after the larval emergence. In other words, in these years about 70% of females did not spawn. And correspondently in the even 1970 (July) 77% of 772 mature females spawned while the rest (23%) females (after release of larvae) did not spawn. In the Eastern Sakhalin population in 1971-1975 and in the Western Kamchatka population in 1982-1986 we also observed females that did not spawn but their number in the study years was 30 to 40%.

The ratio of spawning and nonspawning blue crab females, is not, probably, the longterm characteristics of a population but is changed at elimination of the generations. Predominance of crabs spawning in odd or even years is related to the dominance in numbers of a specific abundant generation.

The blue crab fishery was first started by Japanese in the Western Bering sea in 1927 and was not conducted every year. The maximum catch of about 4 mln. crabs or 9,000 tons was in 1930 (as per Japanese data handed over at the bilateral meeting in 1968). In the post WW 2 period the blue crab fishery was resumed in 1956 when the harvest reached 1.255 mln. adult males. Further on until 1967 the catch did not exceed 1 mln. crabs a year. The maximum yield was taken 1958 when the total catch of both the Soviet and Japanese crabers reached 2.779 mln. crabs or about 7,000 tons. So intensive harvesting caused the drastic fall of crab stock abundance in the Western Bering sea that was proved by the results of the survey conducted here in 1969. Based on the trawl survey the estimate of the blue crab abundance has been made that showed at the trawl catchability coefficient equal to 1 the blue crab fishery stock was about 15,000 tons(Table 2). These calculations were laid in the basis of commercial fishing recommendations for further harvesting in quantities not exceeding 1,000 - 1,500 tons a year.

Table 1

Depths and Temperatures Ranges and Optimums of Blue Crab Habitats in Some Areas of the North Pacific from July to September (Data for 1969 - 1986)

Populations and sex/size groups	Nos. of obser-vations	Depths, m range	Depths, m optimum	Temperature, °C range	Temperature, °C optimum
Korjak population					
males over 130 mm	166	32-148	90	0.7 4.4	2.58
under 130 mm	134	61-166	113	-0.5 5.7	2.50
females mature	169	10-122	47	2.5 4.2	3.36
immature	170	55-153	107	-0.8 3.7	1.45
Anadyr-St.Matthew population					
males over 130 mm	14	57-104	100	-1.2 1.7	0.23
under 130 mm	30	30-104	87	-1.8 1.1	-0.39
females mature	6	52-132	95	-1.6 1.6	0.00
immature	14	25-110	65	-1.6 1.2	-0.50
West Kamchatka population					
males over 130 mm	147	20-320	97	-0.6 5.8	0.11
under 130 mm	179	20-200	88	-0.6 5.8	0.23
females mature	37	20-92	35	0.1 6.7	2.92
immature	15	15-45	52	0.5 5.8	1.37
North Okhotsk Sea population					
males over 130 mm	205	15-73	62	-1.7 3.4	0.00
under 130 mm	87	17-75	57	-0.8 4.7	-0.20
females mature	117	15-60	44	-1.5 1.9	0.40
immature	29	15-60	31	-0.8 2.0	-0.16
Eastern Sakhalin population					
males over 130 mm	276	35-290	97	-1.7 2.2	0.27
under 130 mm	72	25-80	49	0.0 2.0	0.41
females mature	31	25-100	68	-0.8 2.2	0.90
immature	181	25-100	61	0.0 2.0	0.55

In the period of 1972 to 1979 no blue crab fishery was conducted in the western Bering sea as a result of which the blue crab abundance restored to some extent. In 1979 the Japanese fishermen resumed the contract harvesting of crabs.

At present, as investigations of 1986 showed, the stocks of blue crabs notably decreased. The abundance of the Bering sea fishery stock was estimated to be around 4 to 5 mln. crabs (Table 2).

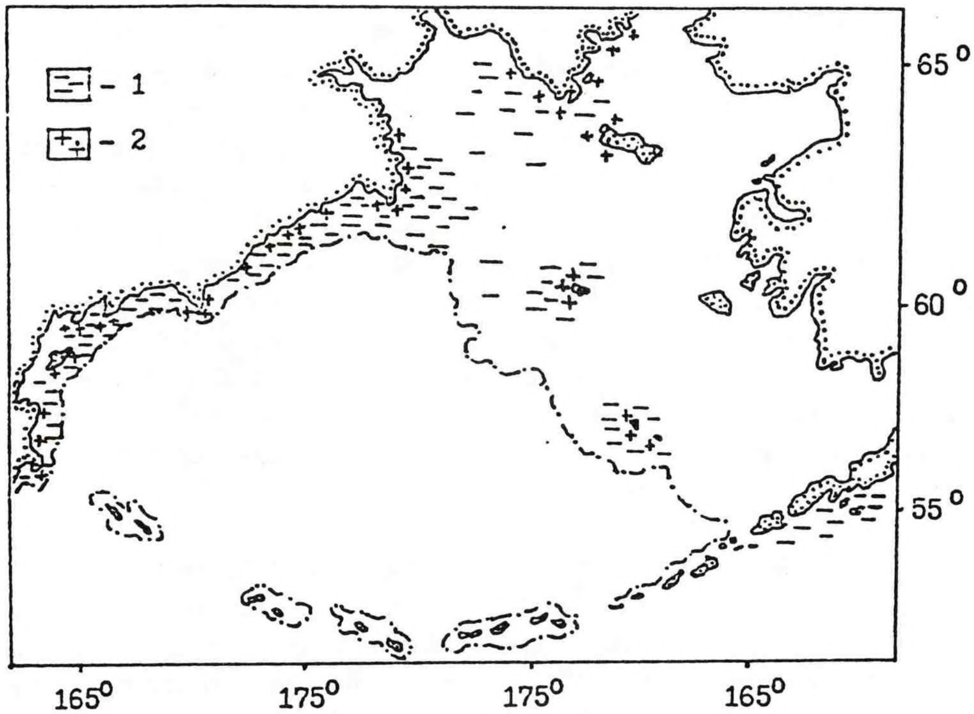

Fig. 1 Distribution of blue crabs in the Bering sea.
1 - migrating crabs, 2 - nonmigrating crabs

Table 2

The State of Blue Crab Stocks in the Western Bering sea (mln.crabs)

Areas and male sizes (mm)	1969	1970	1971	1972	1975	1986
Karaginskiy area - from C.Ozernoy to C.Govena						
100 to 130	0.11	0.16	0.28	0.02	-[x]	0.33
over 130	0.21	0.28	0.28	-	-	0.73
Olyutorskiy area - from C.Govena to C.Olyutorskiy						
100 to 130	0.04	-	0.12	-	-	0.20
over 130	0.24	0.14	0.08	0.09	-	0.81
Olyutorskiy-Navarinskiy area - from C.Olyutorskiy to C.Navarin						
100 to 130	3.26	3.31	2.08	1.80	2.35	0.20
over 130	8.60	4.17	4.09	3.30	3.44	2.70
Anadyr area - to the north of C.Navarin (USSR EEZ)						
100 to 130	0.50	0.52	-	1.62	-	-
over 130	0.26	0.08	-	0.22	0.05	-
Central area - to the south of 60°N, west of 174°W						
100 to 130	1.71	0.49	-	0.52	-	-
over 130	2.72	1.07	-	0.24	-	-

x - no investigations or no data

There is no doubt that within the 6-year period (1979-1986) of the sytematic fishery in the Bering Sea practically all blue crabs of the critical age have been removed from the population although their abundance was somewhat higher because of accumulation at the time of the direct fishery moratorium (1972-1978). The blue crabs just like the king crabs are known to live up to 20 years. After they reach the minimal fishery size of 130 mm in the carapace width the blue crabs live as long as about 10 years and their critical size at that age might be 200 to 220 mm. The new fishery or the fishery resumed after the lengthy moratorium get under the favourable conditions because of accumulation of fishable crabs in the stock. After the removal of the maximim size crabs from the population the catch should be stabilized at the level not exceeding the annual recruitment to the fishery stock.

The value of the yearly recruitment to the fishery stock has many terms. It is not the same for a population in terms of time as it varies along with the natural fluctuation of the population abundance and the recruitment rate is not the same even in the populations of the same species. The recruitment rate depends upon the geographical, latitudinal location of the fishery stock area and the food availability. What is most important for the reproduction of a population is the combination of favourable conditions.

Based on investigations of 1986 and the estimate of abundance and size structure of the blue crab population (Table 2) it is expected that approximately 10% of recruits recorded in 1986 would enter the fishery in 1987. Their numbers is 1.0 to 1.3 mln. crabs. This figure is considered to be rather high as the strong year-class of blue crabs would enter the fishery stock. The recruitments of 1988-1989 are expected to be much poorer than that of 1987 due to the low abundance of generations that would enter the fishery after 1987.

Thus on the basis of the above data it is necessary to bring the commercial fishery yield to terms with the recruitment to the fishery rate.

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DISTRIBUTION, BIOLOGY, POPULATION STRUCTURE & ABUNDANCE OF TANNER CRABS IN THE BERING SEA

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The regular studies of the tanner crabs were started in the Bering sea in 1969 and were every year conducted until 1975. Later on the research expeditions were sent there every 2 - 3 years. These investigations helped to collect comprehensive data on distribution, biology and abundance of crabs on the shelf and the upper slope of the Bering sea (Fig. 1, Table 1). In 1986 two surveys were conducted by R/V "Gidronavt" and R/V "Tamga" (the former with the submarine "TINRO-2") in the North-Western Bering sea. The materials of these surveys allowed to verify the present state of stocks, biology and behaviour of crabs.

In the recent years the great attention has been drawn to the studies of early stages of ontogenesis of tanner crabs including gametogenesis, embryonic and larval development, growth and survival of juveniles. Simulation models helped us to trace the changes of the population dynamics and to reveal the principal laws of formation of the spatial population structures (Slizkin, 1974a,b, ~~1974a~~, 1977, 1978, 1982; Kanarskaja, Slizkin, 1975; Fedoseev, 1982, 1983, 1986a,b ~~1986a~~; Fedoseev, Slizkin, 1986a,b ~~1986a~~). For the purpose of the longterm forecast and efficient fishery strategy for many years the comprehensive analysis of the entire life history of crabs is needed. These problems have been studied by many authors (Fedoseev, Rodin, 1985, 1986; Fedoseev, Slizkin, 1986a,b ~~1986a~~; Fedoseev, Rodin, Slizkin, 1987; Jamieson, 1986; Tester, Carey, 1986; Kanno, 1987; Incze et al., 1987).

Tanner Crab (Chionoecetes bairdi)

This species is found in the south-eastern and western parts of the Bering sea mainly in the central shelf and upper slope area (Fig. 2 - 6). The maximum frequency of adult mature crabs in the spring-summer period is observed at depths 60 - 120 m at water temperature 1.5 - 2.5°C (Fig. 12, Tables 2 and 3). The junior age groups and the postlarval juveniles are distributed at the greater depths and higher water temperature (Fig. 4, 6, 12) than adult crabs. This species of tanner crabs is the typical representative of the lower sublittoral fauna complex (Vinogradov, Neiman, 1985). Reproduction of Ch. bairdi takes place in the lower part of the shelf and the slope. The juveniles concentrate on the grounds enabling (Fig. 13) them to hide under the layer of silt from their predators.

Preference of Ch. bairdi to inhabit the lower shelf where the warm intermediate layer (WIL) influence is very essential establishes the limits of their distribution in the Bering sea. The maximum concentrations of this species are found in the Bristol Bay. In the areas to the West of Pribilof Isls they occur in smaller aggregations and practically disappear near C. Navarin. Off the Asian coast the maximum concentrations of this species have been observed along the Korjak shore and in Olyutorskiy Bay. Slizkin (1974, 1977, 1982) determined the population structure of this species on the basis of analysis of materials on distribution, size composition and reproduction. The stocks of Bristol Bay, Korjak shore and Olyutorskiy Bay are considered to be self-reproductive populations. The aggregations of tanner crabs from the area between Pribilof Isls and C. Navarin are characterized as semi-dependent populations due to recruitment at the larval stage from the Bristol population.

In 1969-1971 the older age groups dominated in all the populations of Ch. bairdi (Fig. 14, 15). The most homogeneous in size were the crabs of Bristol population (Fig. 14) where the mean size of males and females was 143 mm and 91 mm respectively. In Olyutorsko-Navarinskiy area the crabs were smaller: 108 mm and 67 mm (males and females, Fig. 15). However the crabs of these sizes have not been found in either of the above populations afterwords, as in late 60s - early 70s the intensive commercial harvesting of tanner crabs started.

Tanner Crab (Chionoecetes opilio)

This species is practically distributed over the entire shelf of the Bering sea. At the same time concentrations of different size and sex groups are not uniform in distribution (Fig. 7 - 11). The mature crabs inhabit predominantly the lower shelf with flat grounds (Fig. 7, 10). Adult crabs in their migrations prefer to move into the zone of warm intermediate layer on the bottom. In this regard the adult crabs of both species Ch. opilio and Ch. bairdi prefer the similar environment (Fig. 12, 13). It is most typical for tanner crabs of Olyutorskiy-Navarinskiy area where the environment conditions gradients for adult crabs of the both species are less evident than those in Pribilof-Bristol area (Tables 2, 3).

The juveniles and immature crabs behave in the different way. The postlarval young crabs Ch. opilio form aggregations in the zone of low temperatures on the bottom (Table 3, Fig. 12). Therefore the juveniles are distributed in farther to the North areas than adult crabs and prefer the zone of cold intermediate layer in contact with the bottom (Fig. 4, 6, 9, 11).

The farther from the shelf edge to the North and at changing of temperatures from above 0 to below $0^{o}C$ the sizes of crabs Ch. opilio diminish. It is apparent in the case of Anadyr Bay (Fig. 16). It is worth noting that in the northernmost areas of this species distribution in the Bering sea and even in the Chukotskoe morje (Chukchi sea) the mature crabs (females with fertilized eggs) have been observed. But the size of carapace (both males and females) does not exceed 70 mm in these waters. This means the high tolerance of this species to low water temperatures. Therefore the species Ch. opilio is referred to the Subarctic-boreal biogeographical complex of animals (Slizkin, 1974b).

Ch. opilio male sizes do not exceed 160 mm (crapace width) in Pribilof-Bristol area, 150 mm in Olyutorskiy-Navarinskiy area and 120 mm in Anadyr- St.Matthew's area (Fig. 14, 15, 17).

As Ch. opilio crabs are widely distributed in the Bering sea there is every possibility of interpenetration between the subpopulations of this species. However a sole population cannot exist without dividing into the structures of lower levels on so vast expanse.

The postlarval juveniles of Ch. bairdi occupy in concentrations the smoothed bottom, frequently close to their brood stock habitat, while those of Ch.opilio are found on the relatively remote shelf areas in the zone of stationary water gyrals. The larval belt habitat of tanner crabs is very broad as it covers the entire expanse of the sea (Takeuti, 1972; Kanarskaja, Slizkin, 1975). This is attributed to the fact that larvae emerge in all the areas where mature females occur. In other words, the tanner crabs do not perform the spawning migrations. Their observed movements are attributed to their selectivity of the environment conditions.

Bearing this in mind it is difficult to judge of the population structure of Ch. opilio in the Bering sea in view of poor isolation of the structure's elements. The maximum frequency in occurrence was observed in the Pribilof-Bristol population (1) and the Navarin-St.

Matthew's population (2) having the vast vegetative zone in the Anadyr Bay. The Korjak (3) and Karaginskaja (4) populations are much less abundant.

The populations 1, 2 and 4 are practically independent stocks having the vast reproductive areas (Fig. 8, 9, 11). The Korjak population depends to a great extent on the Navarin population because reproductive condition for Ch. opilio crabs in this area are worse than on the other areas and this species is replaced here by Ch. bairdi crabs.

Discussion of Results

The high abundance of the tanner crabs' populations depends upon all stages of the reproductive process (Fig. 18) including the stages of gametogenesis, fertilization, embryonic and larval development. The critical stages could be different in different years. Therefore in the analysis of spawning and abundance of year-classes it is necessary to take into account the impact of various biotic and abiotic factors upon all the links of the reproduction process. The critical factors for the tanner crabs at the stages of gametogenesis and embryonic development of eggs are the temperature regime, depths of habitat and food availability for the spawners.

On the basis of conducted studies it was found (Slizkin, 1974, 1982) that the maximum aggregations of Ch.opilio juveniles of the Navarin-Anadyr area area mainly concentrated in the zone where the cold intermediate layer nucleus contacted the bottom. The water flow of the Bering sea trough transfers the pelagic larvae of tanner crabs into Anadyr Bay and the central part of the Bering sea shelf from the area adjacent to the continental slope, the habitat of the brood stock. There the larvae settle upon the silt or silt-sandy grounds resulting in formation of high concentrations of tanner crab juveniles (Fig.9). The size composition of juvenile settlements decreases the farther to the North of Anadyr Bay they move (Fig. 16).

The larval survival depends on their drift, hydrological characteristics of water masses and the settling conditions.

The juvenile survival is related to the grounds where they find food and shelter.

The development of juveniles until their maturity occurs at frequent moulting resulting in the higher mortality due to predators.

The existence of adult crabs and the formation of the spatial structure of their population is greatly influenced by the character of grounds, sufficiency of space and the food supply.

Taking into account all the stages of the reproduction process makes it possible to obtain the adaptation model of the crab population reproduction and to increase accuracy of the longterm abundance forecasts (Fedoseev, Rodin, 1985, 1986; Fedoseev, Slizkin, 1986 a, б) ~~1986a)~~.

The same pattern of formation is followed by the self-reproductive populations of Ch. opilio in the other areas of their distribution. Adaptation of pelagic larvae and juveniles of Ch. bairdi to the environment conditions is different. The postlarval juveniles are tolerant to the lower shelf biotops and the above 0^{o} temperatures of water. Contrary to that of Ch. opilio the vegetative areas of Ch. bairdi are located in the viscinity of their spawners' aggregations.

It is worth noting that such inherent features of the tanner crabs' biology as the high rate of spermatogenesis, the constant formation of spermatozoa and spermatophores not depending on a season of a year, the capacity of a female to copulate with several males, the usage of the sperm reserve by a female for a few years, the extention of the spawning period, etc. enable the tanner crabs to efficiently adapt to the boreal environment, to reach the high abundance in the natural biocenosis and to retain the stable reproduction under the intensive fishing pressure (Fedoseev, 1983, 1986; Fedoseev, Slizkin, 1986).

The Condition of Stocks and Fishery

The direct fishery of tanner crabs in the Western Bering sea was started by the Japanese crabers in 1966. The size composition of commercial catches ranged from 82 to 155 mm (the carapace length measured). The mean size of the measured crabs (29,540 measurements) was 109.2 mm and the mean weight 653 g. In 1966 - 1968 the major fishery was conducted in Olyutorskiy Bay where 85% of crabs were harvested and 15% were taken in the area to the south east of C. Navarin. The maximum harvest of tanner crabs in the Western Bering sea was recorded in 1968 when Japan caught 16,433 mln. tanner crabs or 10,700 tons. In 1969 -1971 the yield of tanner crabs greatly diminished and the fishery was completely stopped until 1979.

As a result of the yield exceeding 10,000 tons a year the resources of tanner crabs have been decreased. The detailed trawl survey carried out in the Western Bering sea in 1969 made it possible to estimate the numbers of crabs. The males of 100 mm size (carapace width measured) numbered around 25 mln. crabs or in weight about 16,200 tons. By 1972 the resources of tanner crabs fell down to 15 - 17 mln. crabs. In view of the low abundance of tanner crabs and blue crabs their fishery was ended off in early 70s.

The crab fishery was resumed on the basis of the contracts with the Japanese in 1979. Within 6 years (1972 - 1978) in the absence of the direct fishery the numbers of tanner crabs essentially restored. At the resumption of the fishery the abundance of crabs was estimated on the basis of investigations performed in 1975.

The estimate included the data on the probable recruitments entering the fishery. Based on this estimate the recommended harvest of tanner crabs in the North-Western Bering sea was about 6,500 tons a year. Our survey conducted in 1982 has proved in principle the correctness of 1975 estimate. But it was noticed even in 1982 that percentage of tanner crabs of commercial sizes diminished in the population.

The investigations conducted in 1986 revealed that the total numbers of males of over 100 mm size (carapace width measured) in the Western Bering sea reached 5.1 mln.crabs (Table 4) or 4,080 tons provided the sampling trawl catchability coefficient was 0.75.

While calculating the recruitment of tanner crabs to the fishery we implied that males of 90 to 100 mm sizes (recruits) would moult within a year and enter the fishery in 1987. Based on data of the trawl survey the percentage of recruits reaches 37.7% in some areas. It is related to Ch. bairdi crabs of the Olyutorskiy-Navarinskiy area where the abundance of the crabs of minimum size has notably reduced under the impact of the present fishery.

The commercial fishery resource of tanner crabs including the recruits is estimated to be 6.6 mln. crabs or 5,300 tons.

Thus the results of investigations carried out in the last years bear witness of the changes in the population of tanner crabs in the North-Western Bering sea resulted in significant reduce of of their abundance. The reduction of abundance of crabs of commercial sizes demands the revision of the recommended yield on one hand, and the further analysis of available biological and fisheries data , on the other hand, with the purpose to determine the optimal sustainable yield that would not affect the reproduction of tanner crabs.

Table 4

The Condition of Tanner Crab resources

Species	Males of commercial sizes		Recruitment		Biomass
	'000 Nos	'000 tons	'000 Nos	'000tons	'000 tons
	OLYUTORSKIY-NAVARINSKIY AREA				
Opilio	665.1	0.53	204.8	0.16	0.69
Bairdi	2247.1	1.78	847.1	0.68	2.46
	OLYUTORSKIY AREA				
Opilio	468.8	0.38	165.0	0.13	0.51
Bairdi	1376.3	1.10	308.3	0.25	1.35
	KARAGINSKIY AREA				
Opilio	335.4	0.27	-	-	0.27
Total:	5092.7	4.06	1525.2	1.22	5.28

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Table 1

The Number of the Trawl Stations Conducted during Research Surveys in the Bering Sea from 1969 to 1986

A r e a s	Depths, m				Total
	under 50	51 - 200	201 - 500	501 - 750	
Pribilof-Bristol	147	655	35	17	854
Anadyr-St.Matthew's	208	1357	146	76	1787
Olyutorskiy-Navarinskiy	625	1105	193	77	2000
T o t a l :	980	3117	374	170	4641

Table 2

Bathymetric Distribution of Tanner Crabs in Some Areas of the Bering Sea Based on Research Data Obtained in 1969-1974

Area and sex & age groups of crabs	No. of observations	Maximum frequency, m	Range, m	
			Observed	theoretical $\pm 1.5\sigma$
Pribilof-Bristol Area		<u>Chionoecetes bairdi</u>		(May - June)
males adult[x]	3910	121		5 - 238
young	840	168	41 -	123 - 213
females mature	9206	81	430	9 - 154
immature	611	119		11 - 228
Pribilof-Bristol Area		<u>Chionoecetes opilio</u>		(May - June)
males adult	385	95		7 - 200
young	1400	60	41 -	0 - 129
females mature	2554	106	430	64 - 148
immature	384	47		0 - 98
Anadyr-St.Matthew's Area		<u>Chionoecetes opilio</u>		(June - July)
males adult	448	135		60 - 211
young	3900	76	48 -	31 - 115
females mature	1787	98	315	48 - 148
immature	2316	85		53 - 117
Olyutorskiy-Navarinskiy Area		<u>Chionoecetes bairdi</u>		(August-September)
males adult	180	66		11 - 174
young	178	61	22 -	5 - 174
females mature	82	118	415	10 - 256
immature	116	72		0 - 232
Olyutorskiy-Navarinskiy Area		<u>Chionoecetes opilio</u>		(August-September)
males adult	136	150		64 - 236
young	814	97	23 -	0 - 234
females mature	53	218	415	20 - 336
immature	718	77		0 - 166

x - The adult males were considered to have 100 mm carapace width and over.

Table 3

Distribution of Tanner Crabs in Relation to Water Temperature in Some Areas of the Bering Sea based on Research Data Obtained in 1969 - 1974

Area and sex & age groups of crabs	No. of observations	Maximum frequency, (°C)	Range (°C) Observed	Range (°C) Theoretical +/- 1.5 σ	
Pribilof-Bristol Area *Chionoecetes bairdi* (May - June)					
males adult	3910	1.48		-0.77	3.73
young	840	2.70	-1.6 -	-0.17	5.57
females mature	9206	1.55	4.4	0.65	2.45
immature	611	2.90		1.35	4.45
Pribilof-Bristol Area *Chionoecetes opilio* (May - June)					
males adult	385	1.07		-1.00	3.04
young	1400	-0.31	-1.6 -	-1.80	2.92
females mature	2554	0.49	3.9	-1.80	3.09
immature	384	-0.33		-1.80	2.11
Anadyr-St.Matthew's Area *Chionoecetes opilio* (June - July)					
males adult	448	0.79		-0.75	2.29
young	3900	-0.45	-1.8 -	-1.51	0.61
females mature	1787	-0.01	3.4	-1.80	0.99
immature	2316	-0.30		-1.56	0.96
Olyutorskiy-Navarinskiy Area *Chionoecetes bairdi* (August-September)					
males adult	180	2.35		1.45	3.25
young	178	2.48	-1.1 -	1.49	3.47
females mature	82	2.48	4.1	0.63	3.93
immature	116	2.33		0.47	4.19
Olyutorskiy-Navarunskiy Area *Chionoecetes opilio* (August-September)					
males adult	136	0.18		-1.41	1.77
young	814	-0.35	-1.1 -	-1.80	1.37
females mature	53	1.24	3.4	-0,50	4.33

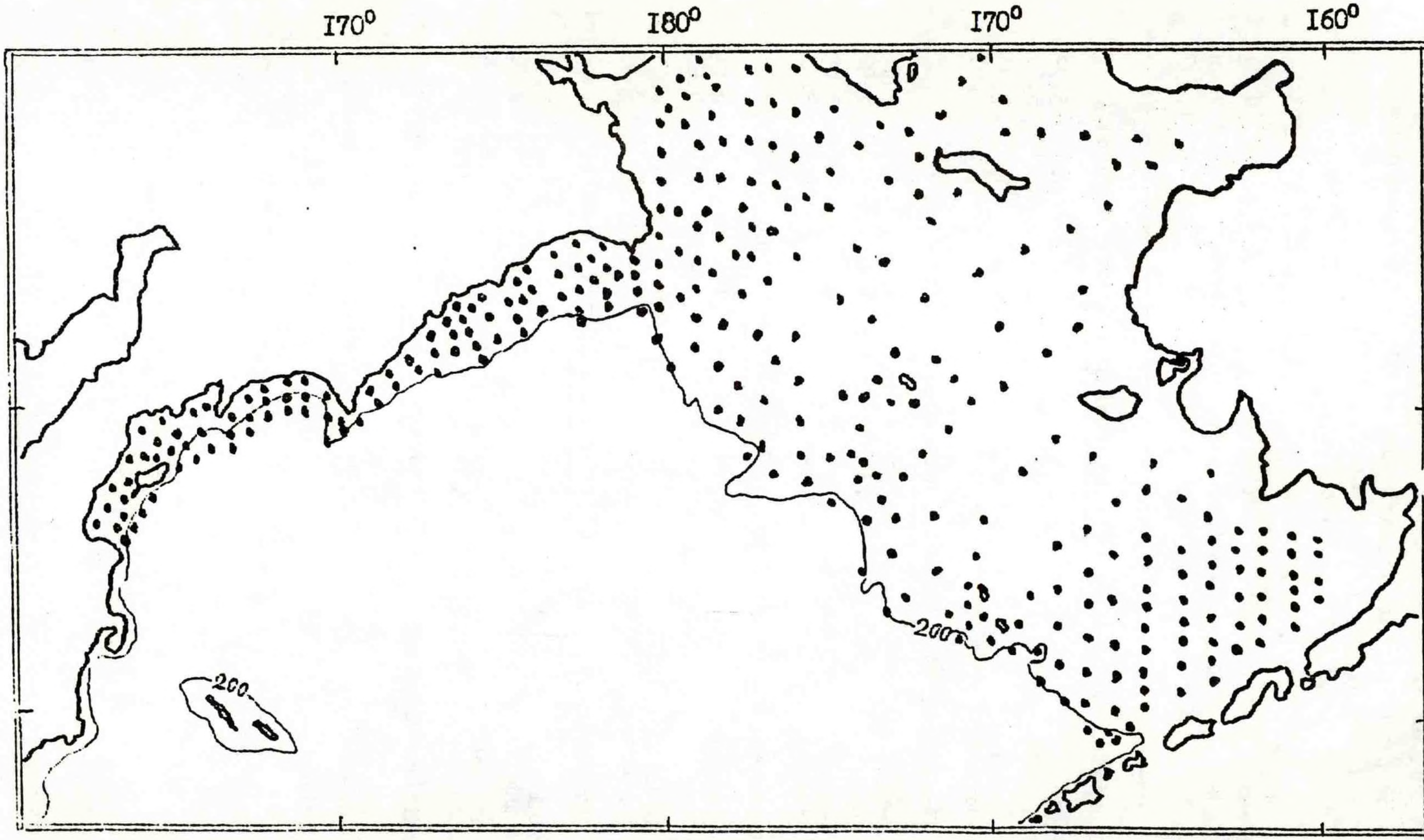

Fig. 1 The Scheme of Trawl Stations in the Bering Sea in 1969-1986

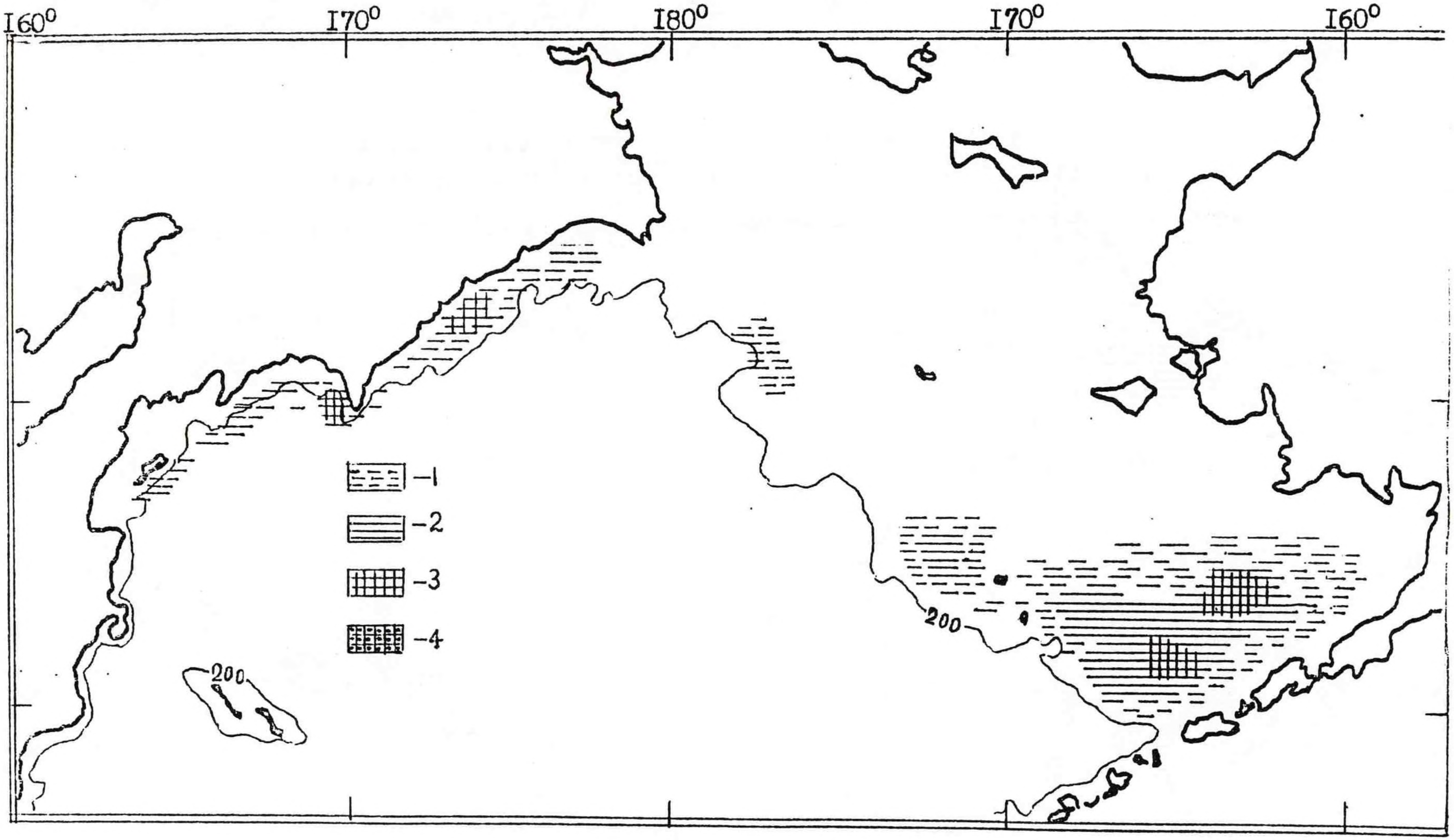

Fig. 2 Distribution of Chionoecetes bairdi males over 11 cm in carapace width in the Bering Sea. Catch per trawling in numbers: 1 - 1 to 10, 2 - 11 to 100, 3 - 101 to 1000, 4 - over 1000

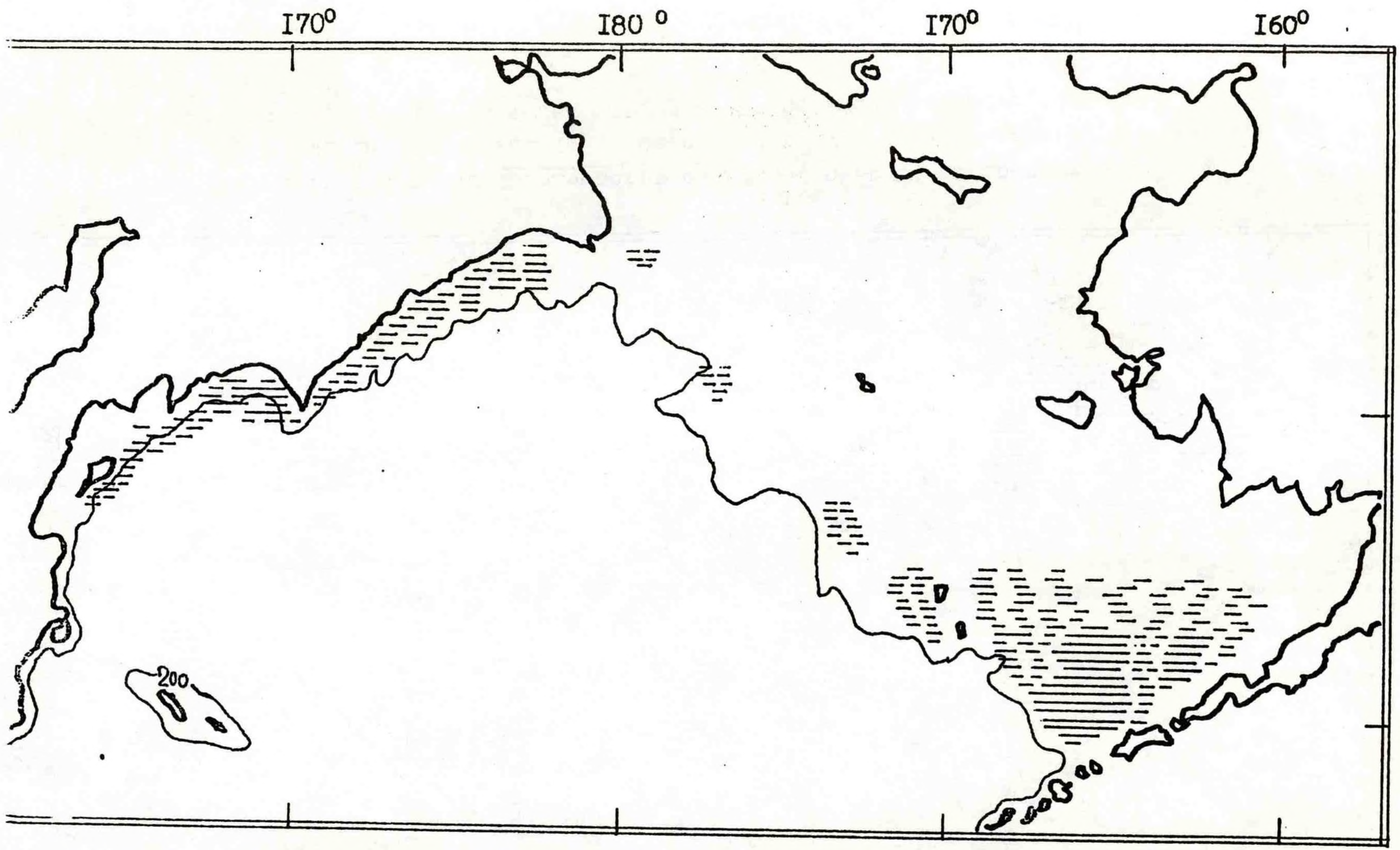

Fig. 3 Distribution of Chionoecetes bairdi males of 8 to 11 cm in carapace width in the Bering Sea. Legend is as in Fig. 2

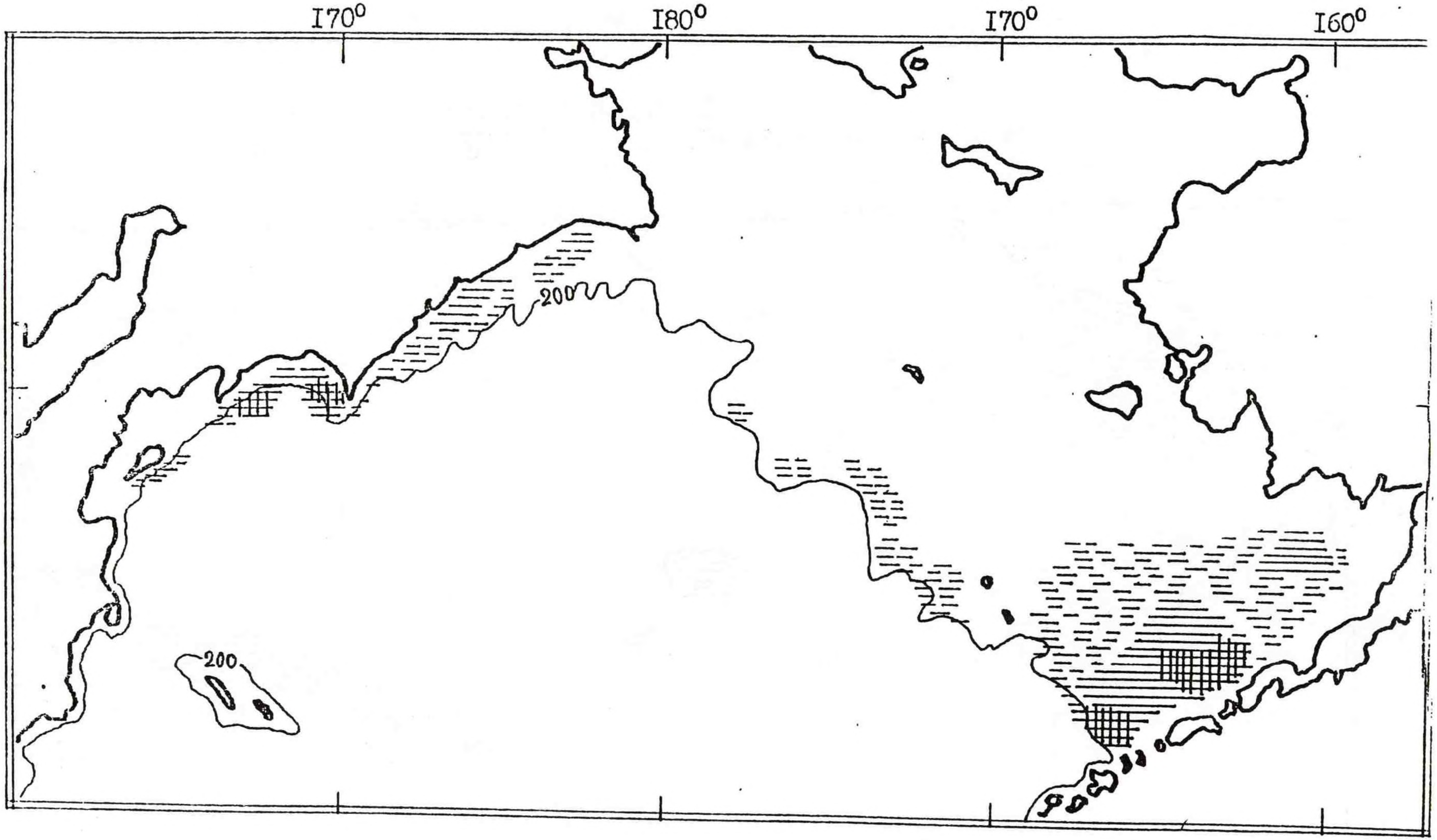

Fig. 4 Distribution of Chionoecetes bairdi males of under 8 cm in carapace width in the Bering Sea. Legend is as in Fig. 2

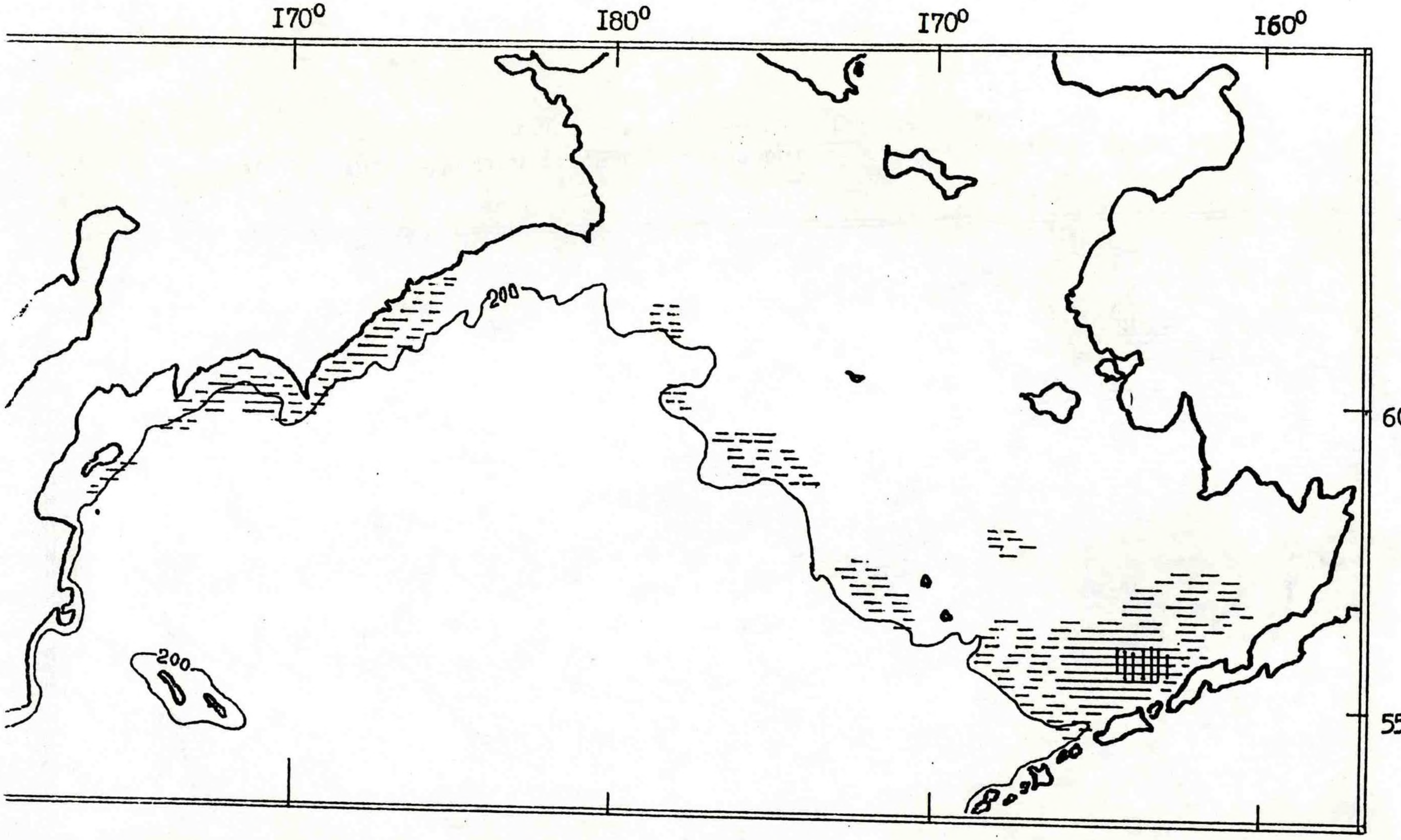

Fig. 5 Distribution of Chionoecetes bairdi mature females in the Bering Sea. Legend is as in Fig. 2

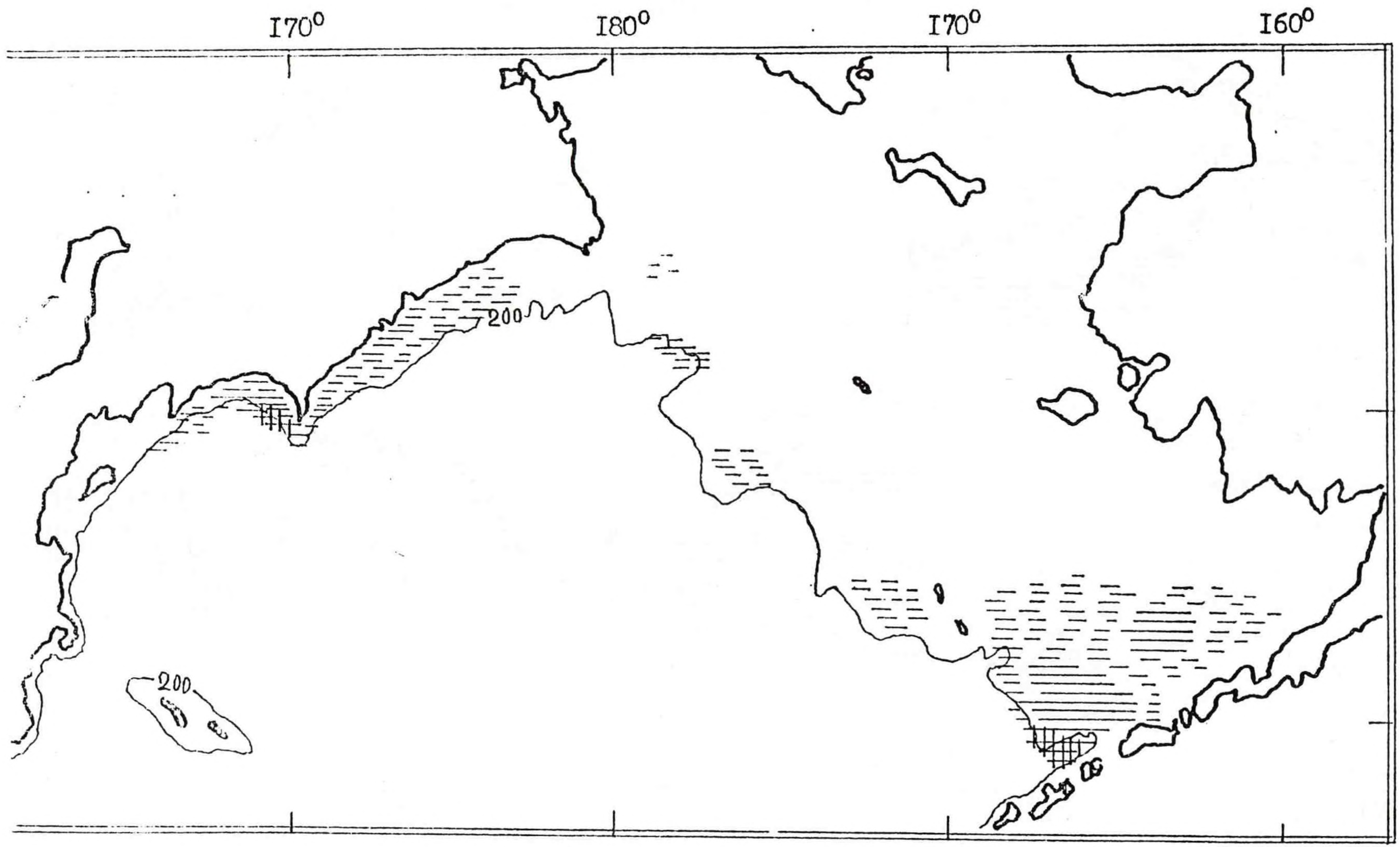

Fig. 6 Distribution of <u>Chionoecetes bairdi</u> immature females in the Bering Sea. Legend is as in Fig. 2

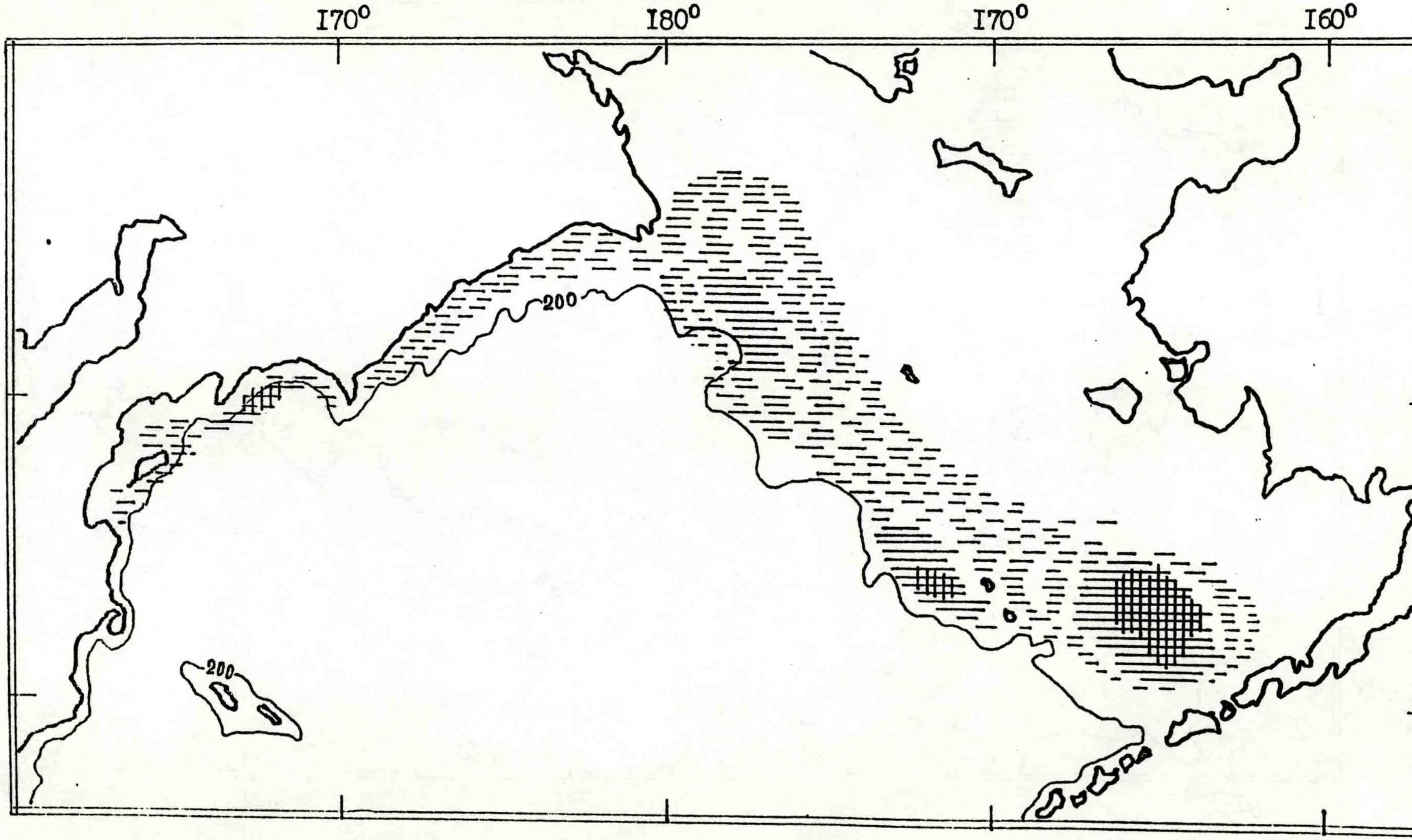

Fig. 7 Distribution of Chionoecetes opilio males of over 10 cm in carapace width in the Bering Sea. Legend is as in Fig. 2

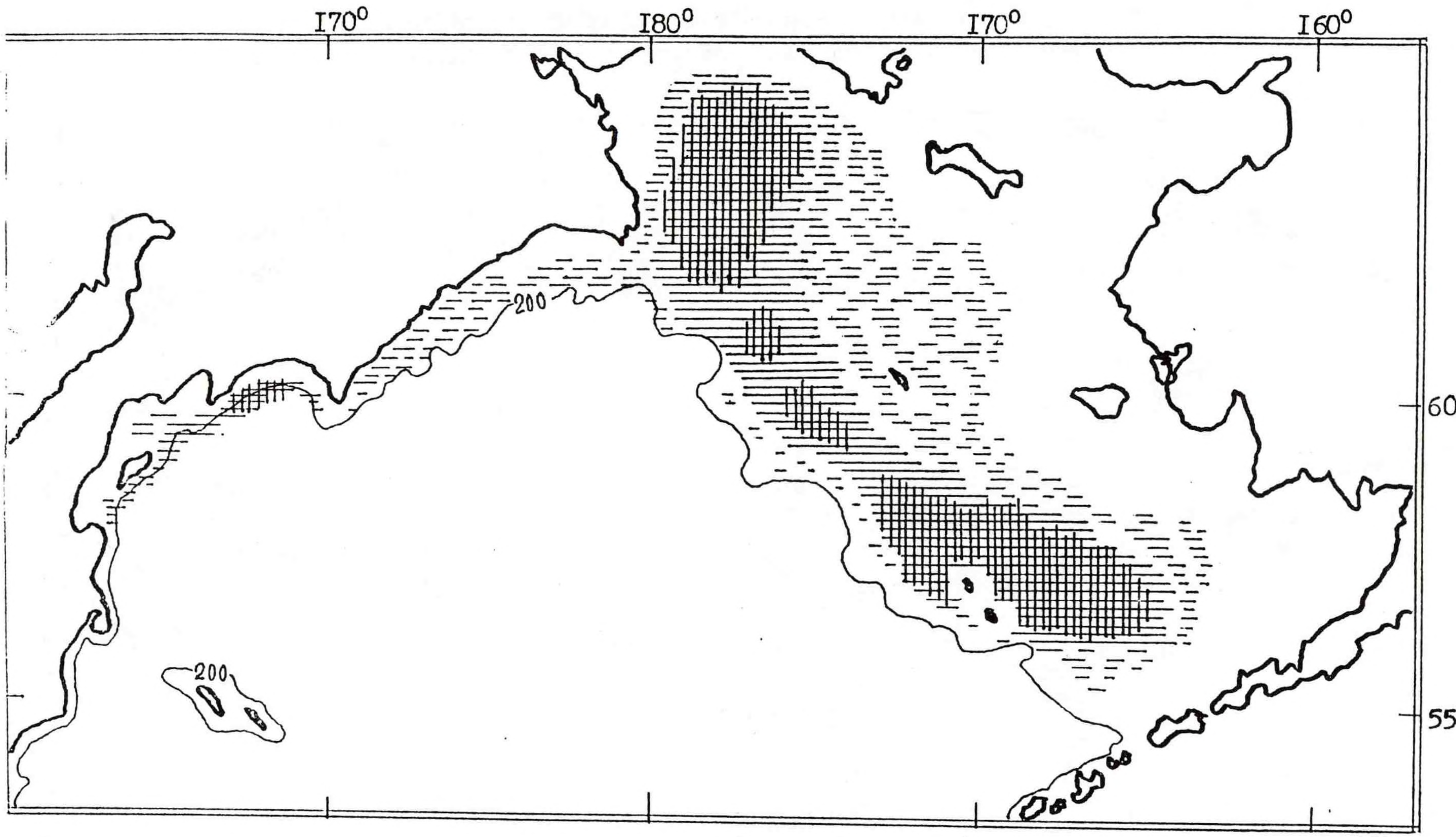

Fig. 8 Distribution of Chionoecetes opilio males of 6 to 10 cm in carapace width in the Bering Sea. Legend is as in Fig. 2

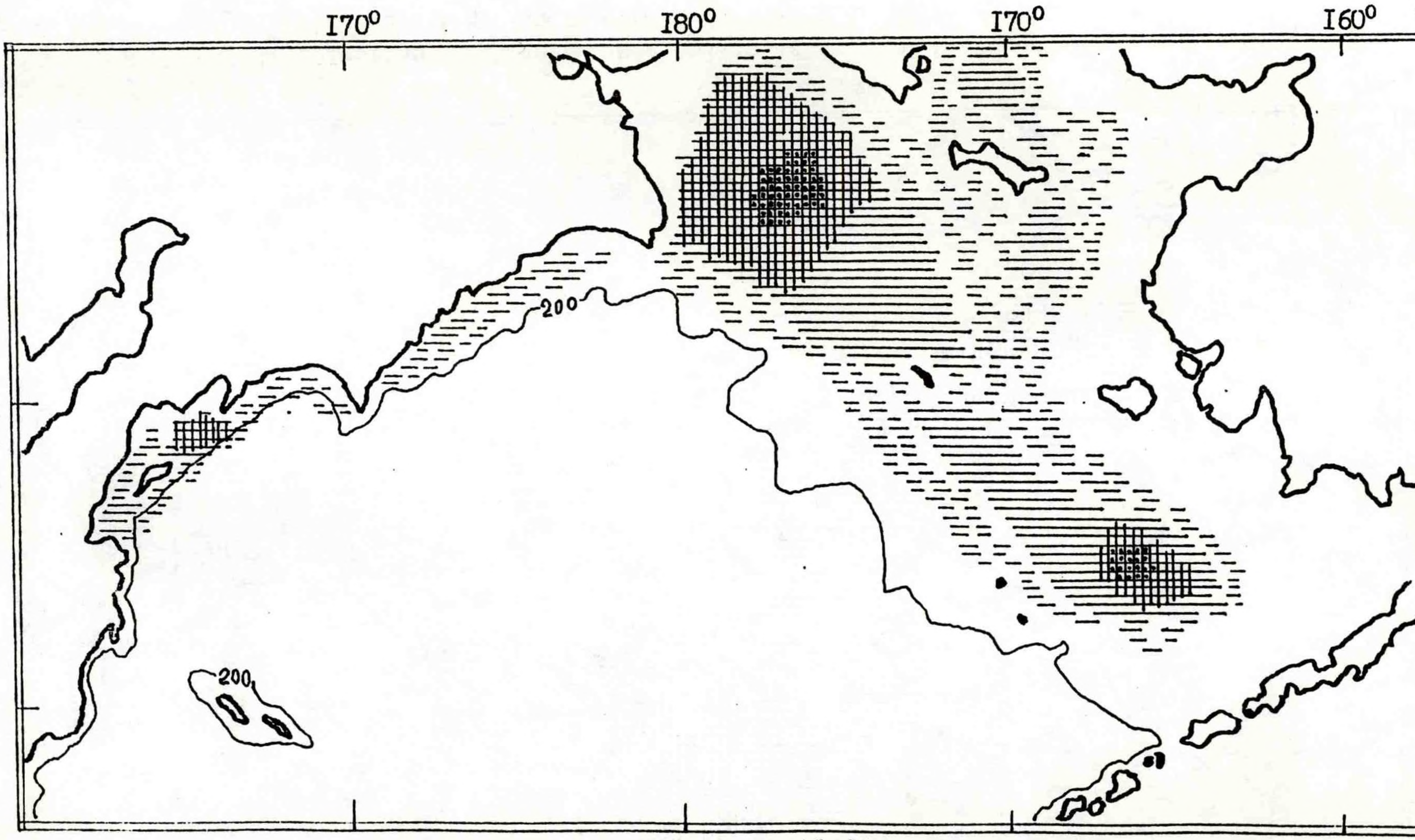

Fig. 9 Distribution of Chionoecetes opilio males of under 6 cm in carapace width in the Bering Sea. Legend is as in Fig. 2

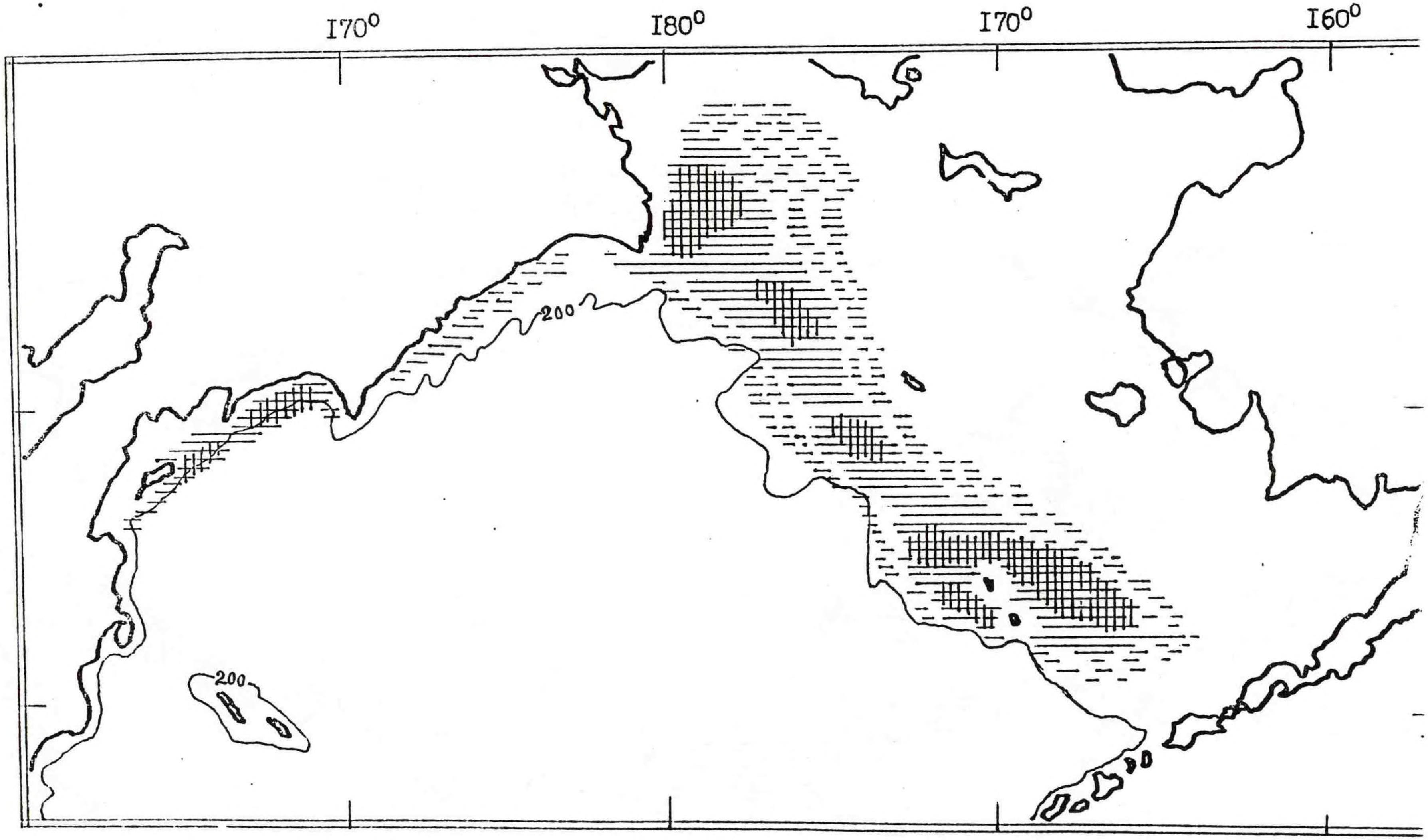

Fig. 10 Distribution of Chionoecetes opilio mature females in the Bering Sea. Legend is as in Fig. 2

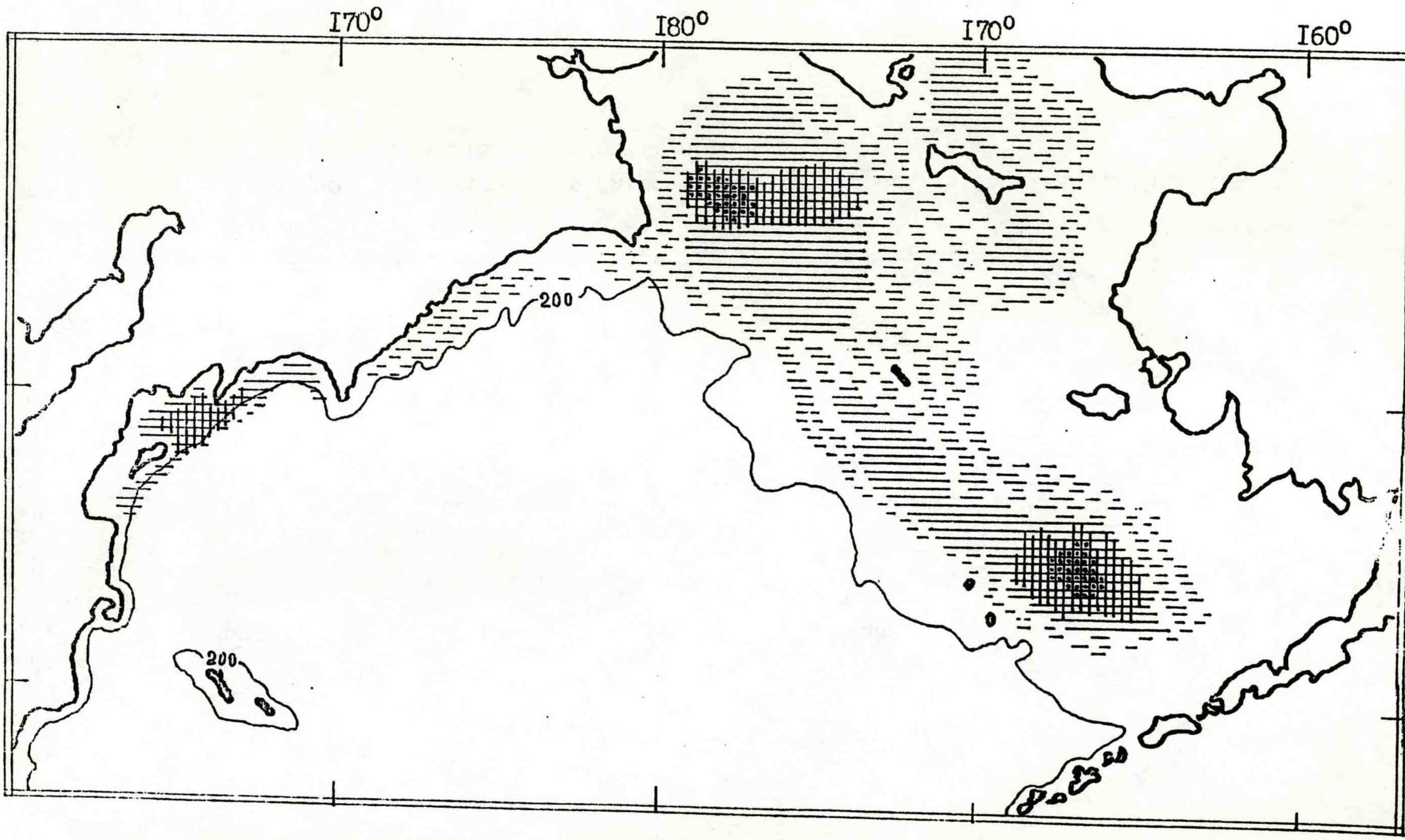

Fig. 11 Distribution of Chionoecetes opilio immature females in the Bering Sea. Legend is as in Fig. 2

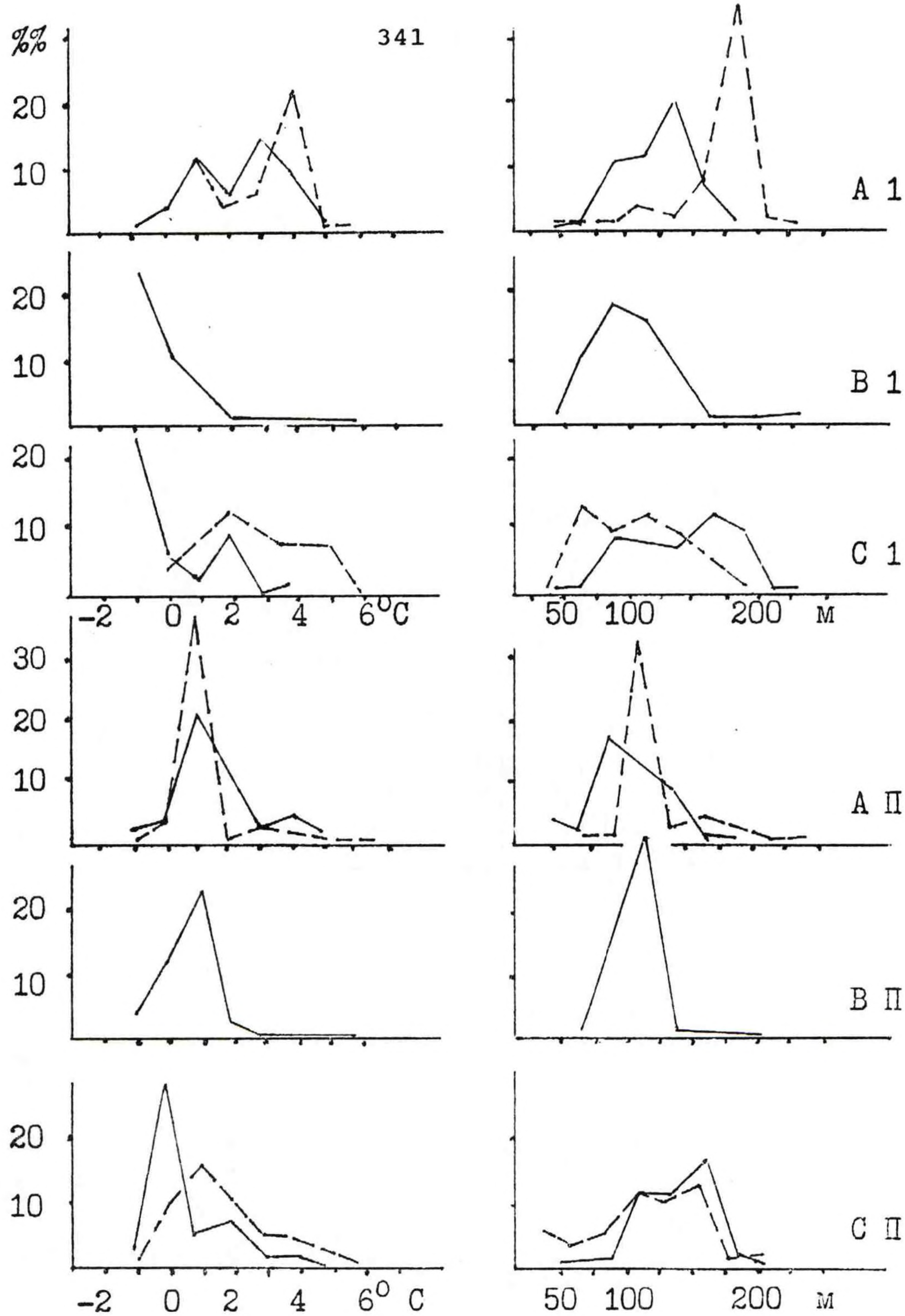

Fig. 12 Distribution of Tanner crab Chionoecetes opilio (solid line) and C. bairdi in relation to depths and water temperatures in the Bering Sea based on studies data of 1969-1974. A - Pribilof-Bristol area, in spring; B - Anadyr-St.Matthew area, in spring; C - Olyutorskiy-Navarinskiy area, in summer.
1 - immature crabs, II - mature crabs.

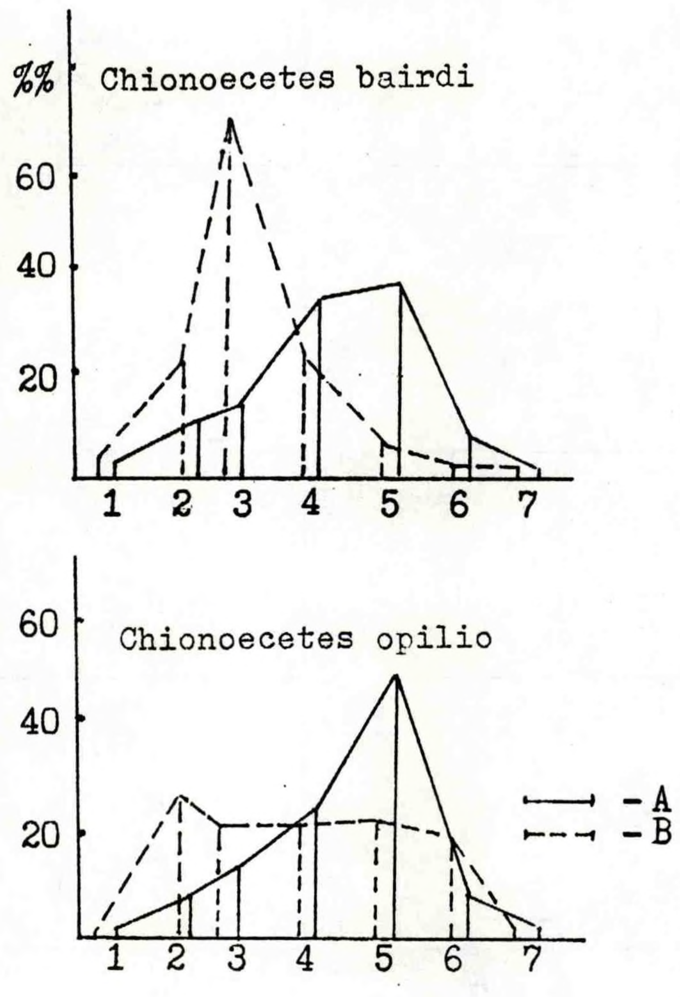

Fig. 13 Distribution of Tanner crabs in relation to the ground characteristics in Olyutorskiy Bay (Bering Sea).
1 - silt, 2 - sandy silt, 3 - silty sand, 4 - sand, 5 - grainy sand, 6 - gravel, stone, 7 - stone, rock.
A - mature crabs, B - immature crabs

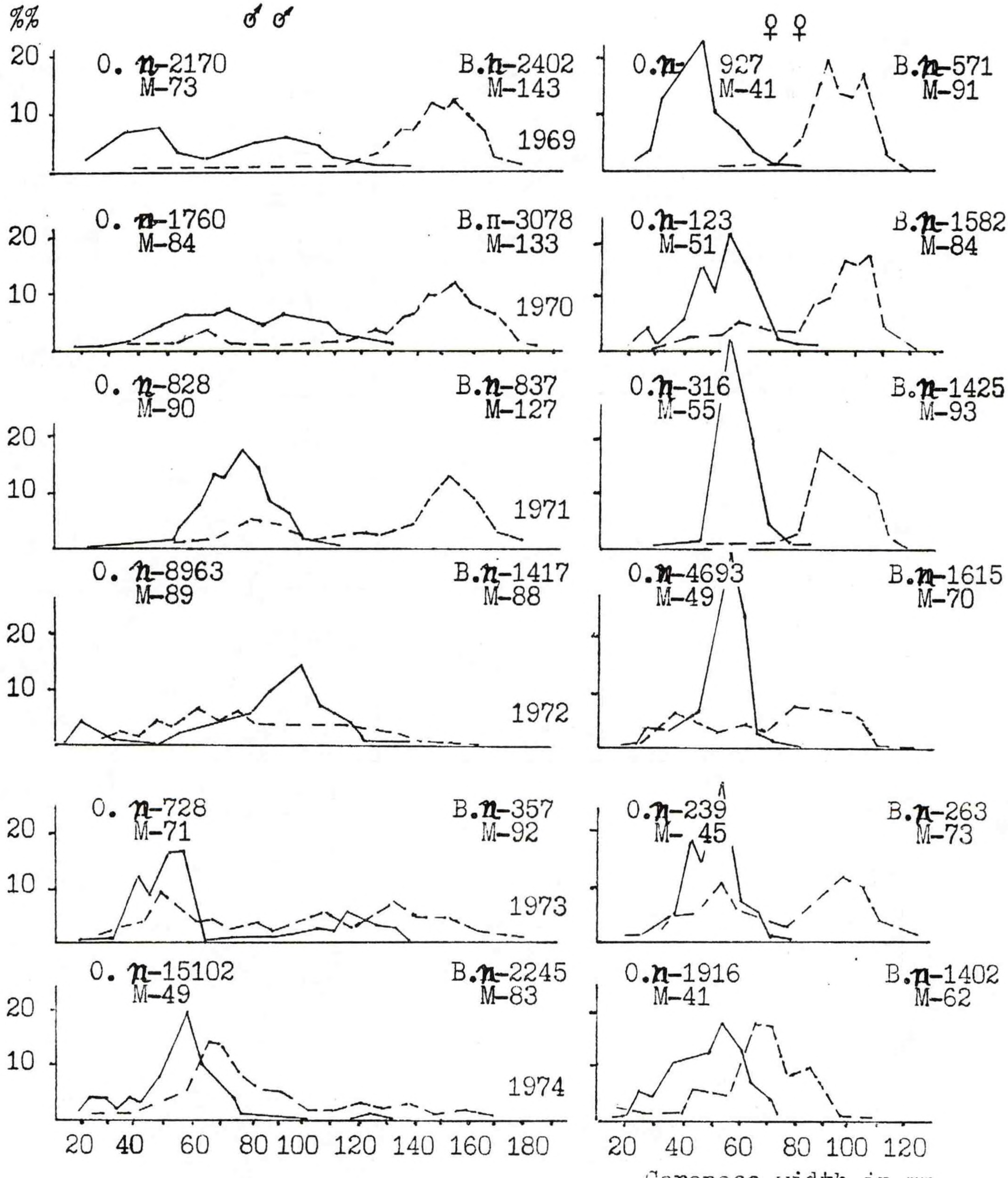

Fig. 14 Size composition of Tanner crabs Chionoecetes opilio (O) and C. bairdi (B) in Pribilof-Bristol area of the Bering Sea. Solid line - C.opilio, dotted line - C. bairdi, n - number of crabs in a sample ~~(pieces)~~, M - mean size of crabs in mm

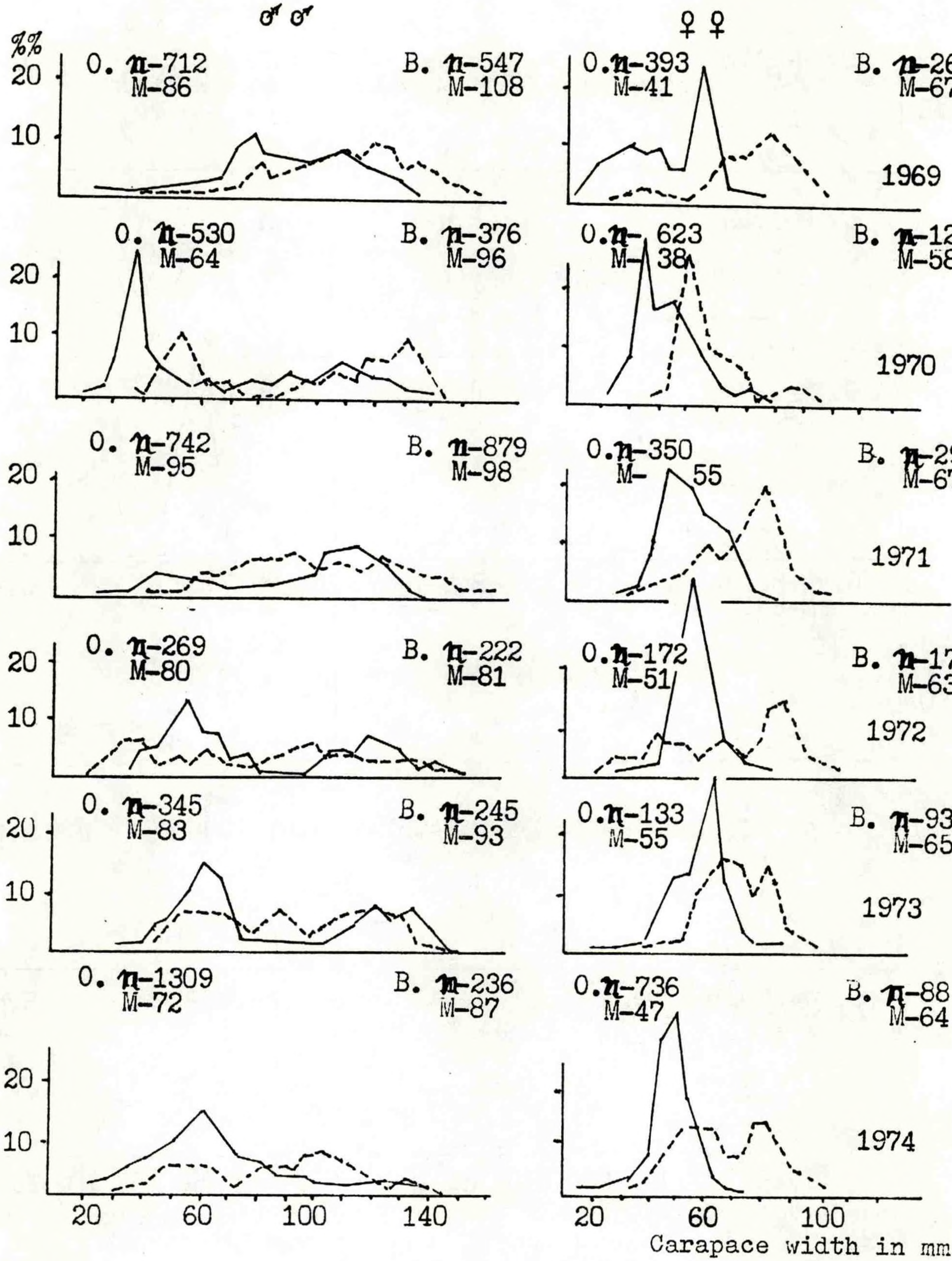

Fig. 15 Size composition of Tanner crabs Chionoecetes opilio (O) and C. bairdi (B) in Olyutorskiy-Navarinskiy area.
Solid line - C. opilio, dotted line - C. bairdi,
n - number of crabs in a sample (pieces), M - mean size of crabs in mm

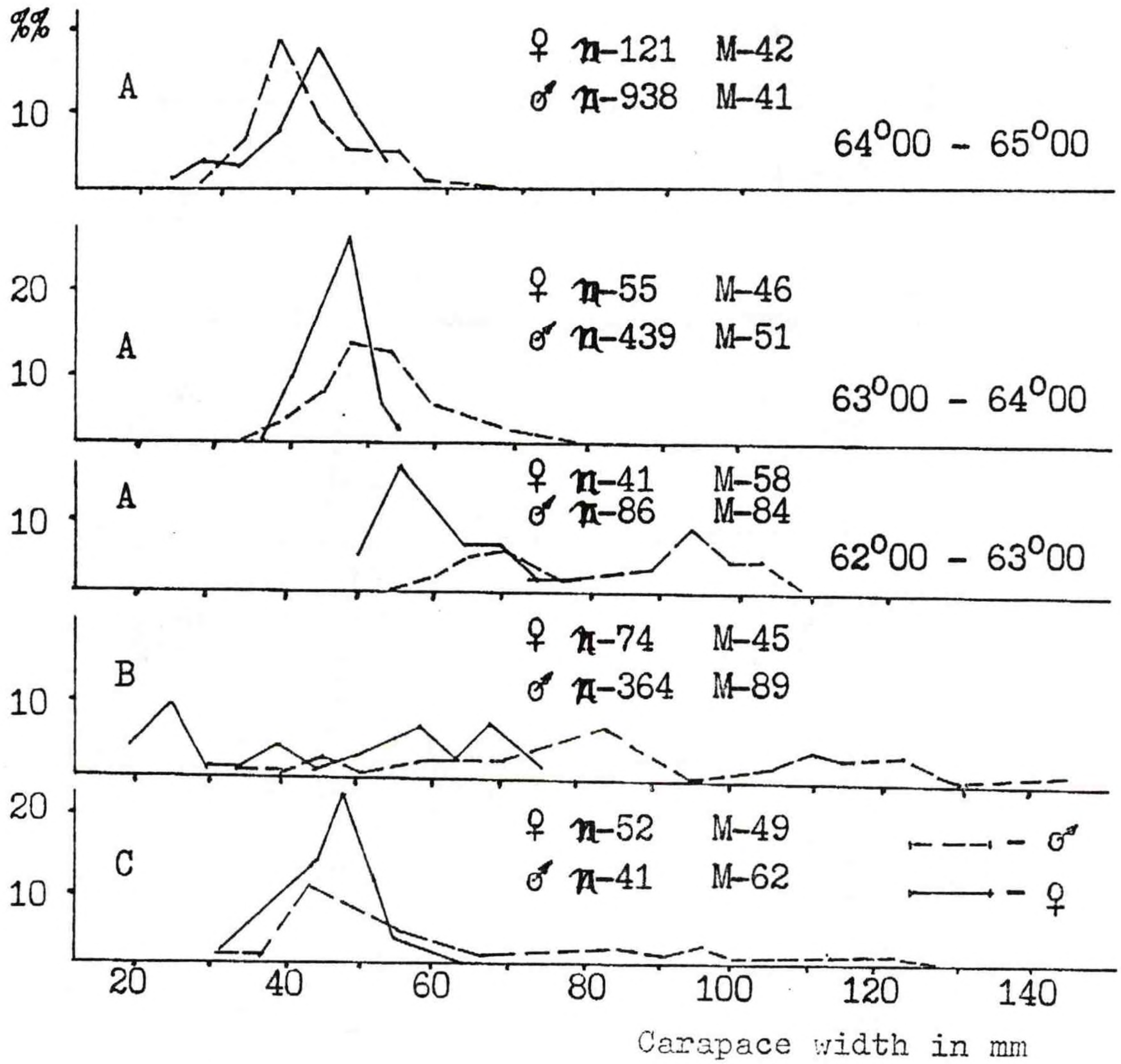

Fig. 16 Size Composition of C. opilio in the north western Bering Sea based on studies data of 1982.
A - Anadyr Bay, B - Korjak coast, C - Olyutorskiy Bay, n - number of crabs in a sample (pieces), M - mean size of crabs in mm

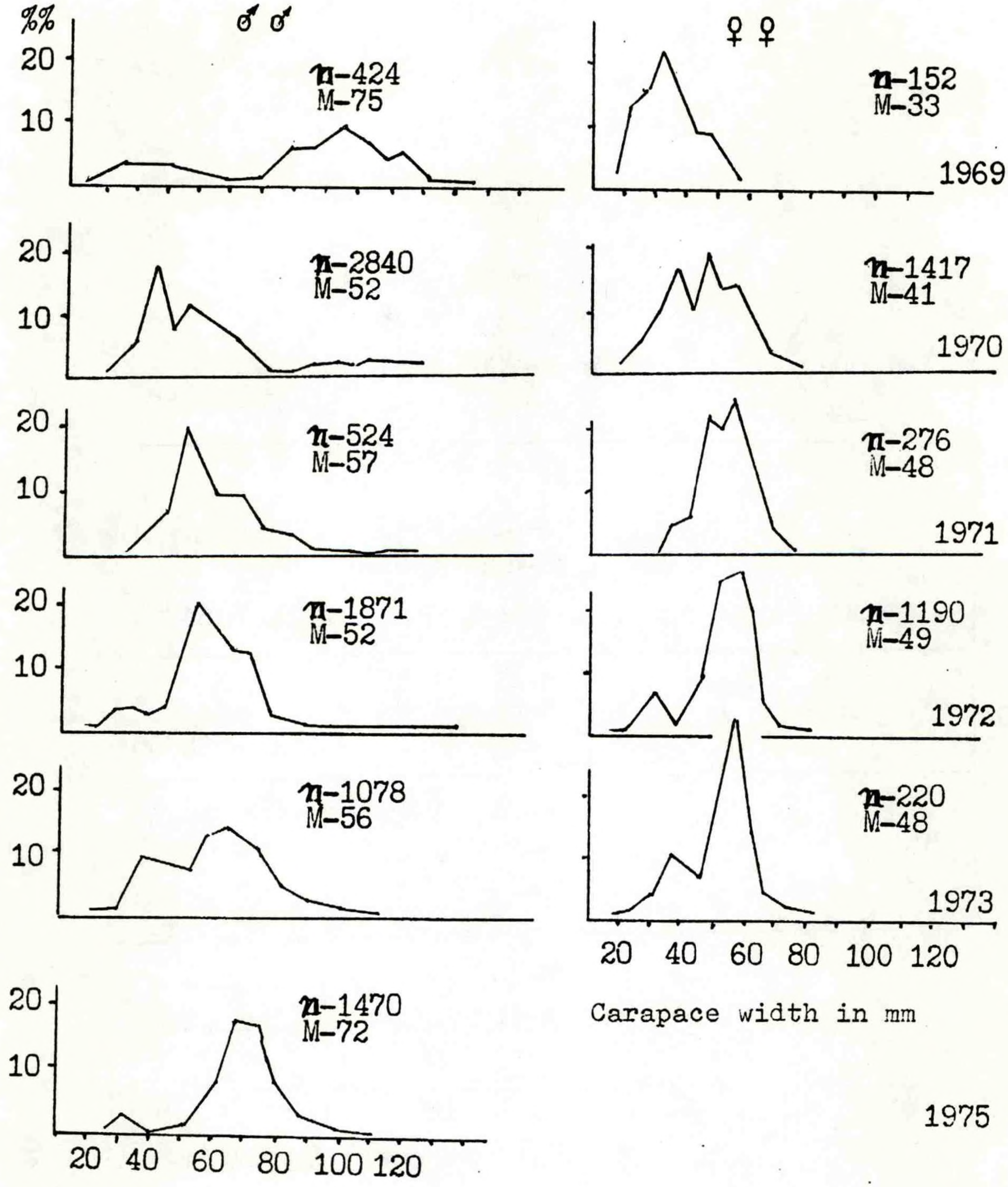

Fig. 17 Size composition of Tanner crabs Chionoecetes opilio in Anadyr-St.Matthew area.
n - number of crabs in a sample (pieces), M - mean size of crabs in mm.

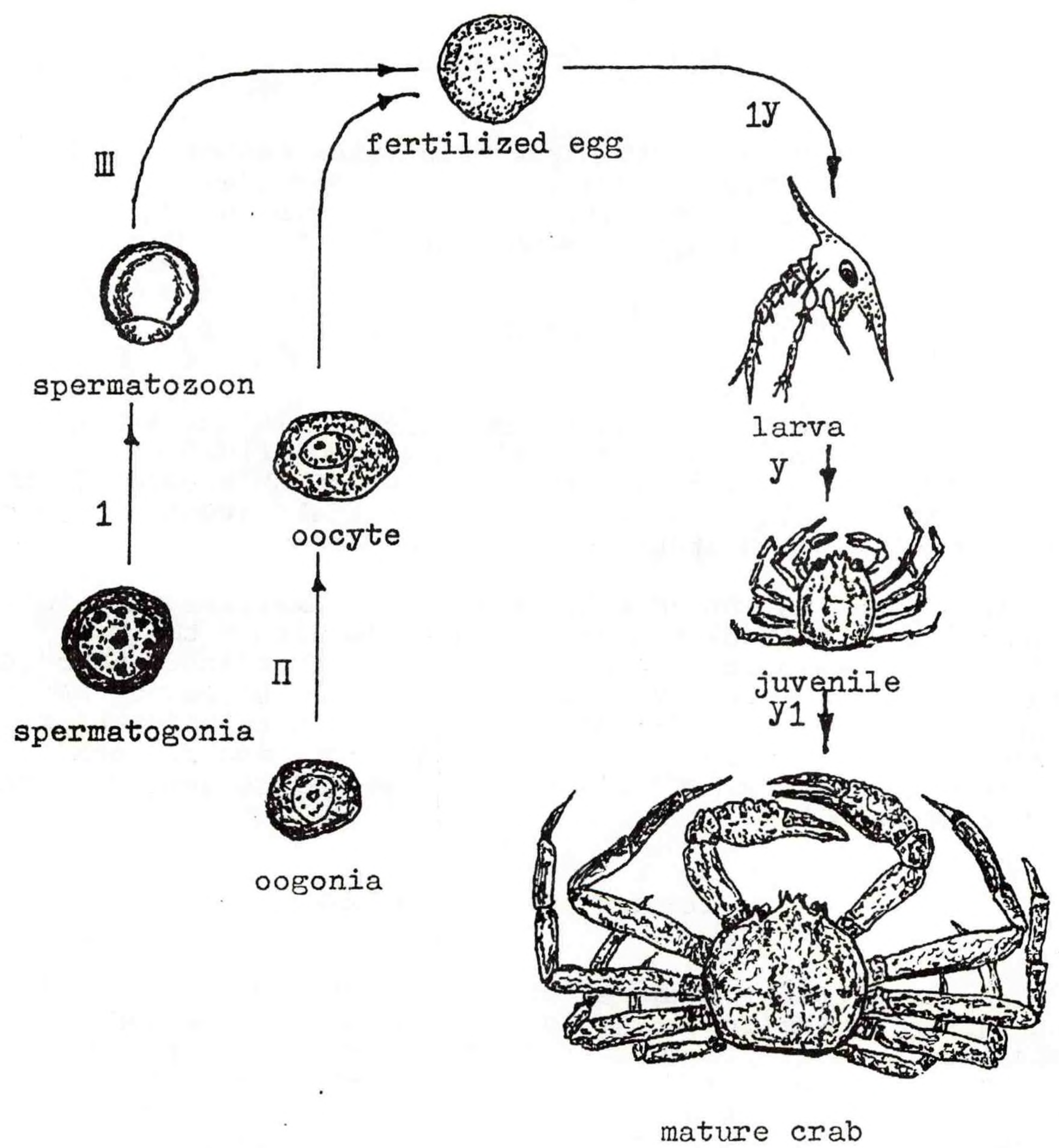

Fig. 18 The scheme of the Tanner crab reproductive process: 1 - development of spermatozoon (84 days), 2 - oogenesis (2 years), 3 - fertilization, 4 - embryonic development of larva (1 year), 5 - postembryonic development of larva (2 months), 6 - growth and development of crab until maturity occurs (around 6 years).

ABUNDANCE AND YIELD OF WALLEYE POLLOCK ON THE EASTERN BERING SEA AND ALEUTIAN ISLANDS SHELF AND IN THE ALEUTIAN BASIN

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INTRODUCTION

Walleye pollock, Theragra chalcogramma, is the single most abundant fish species in the northeastern Pacific Ocean, comprising 80% of the total catch of groundfish species (Bakkala et al. 1986). Walleye pollock range completely around the Pacific rim, from Washington State to the Sea of Japan.

This paper is intended to review and summarize the available information on pollock abundance and yield within the U.S. Exclusive Economic Zone (EEZ). Also, some abundance and catch information from international waters within the Bering Sea is presented along with a discussion of possible relationships between the harvest in the international zone and pollock abundance in the U.S. EEZ and research needed to resolve current uncertainties.

COMMERCIAL UTILIZATION

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

Catches in the Aleutian Island area have historically been much less than the harvest in the eastern Bering Sea. However, since 1980 the catch in this area has increased (Table 2). Part of the growth has been due to the development of off-shelf fisheries in the Bowers Ridge area. Additionally, increasing catches of pollock are reported from the international zone in the central Bering Sea. Some of this off-shelf catch may be derived from Aleutian Island stock, such as the harvest just outside the EEZ near Bowers Ridge. The catch beyond the U.S. EEZ has not been officially reported, and is not included in Table 2.

ESTIMATED ABUNDANCE IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS

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

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

Research Vessel Survey Assessments

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

Annual trawl surveys instituted in the early 1970s focused on crab and only surveyed a portion of the pollock range until 1975 when the survey was expanded to encompass most of the range of pollock. Since 1979, the Northwest and Alaska Fisheries Center (NWAFC) survey has been conducted annually in the expanded area with vessels fishing standard groundfish bottom trawls (Bakkala et al. 1985b). Pollock CPUE rates were reported in the crab-groundfish surveys, and estimates of biomass were not made because of the limited area surveyed. All abundance estimates obtained from bottom trawl surveys reported here are for a standardized area (Fig. 2) and may differ slightly from abundance estimates reported prior to 1986 (Bakkala et al. 1987b).

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

Survey efforts have not been as extensive in the Aleutian Islands as in the eastern Bering Sea. Bottom trawl surveys have been conducted in 1980, 1983, and 1986. Estimated biomass from these surveys were 397,362 t in 1980, 822,063 t in 1983, and 527,074 t in 1986. These estimates do not include midwater pollock and represent only a portion of the biomass. The population in this area is probably in excess of one million t if the on-bottom/off-bottom distribution is similar to that in the eastern Bering Sea.

Relative Abundance Indices

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

Age-Structured Models

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

Input data to age-structured stock assessment models consist of catch-at-age data (in numbers) and an estimated rate of natural mortality. If there are several exploited age groups in a cohort, then one can be reasonably confident of obtaining reliable estimates of the size of the year class when it recruited to the fishery.

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

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

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

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

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

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

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

RECRUITMENT TRENDS

Estimates of recruitment were examined to project future abundance trends and potential yield. Estimates of recruitment were obtained from the annual groundfish survey. Based on age 1 estimates derived from the 1987 survey results (Fig. 4), for which age estimates were not yet available, pollock smaller than 20 cm were assumed to be age 1. These recruitment estimates were compared to the number of age 3 pollock estimated from cohort analysis (Fig. 5). The comparison of survey-based estimates of age 1 with cohort analysis estimates of age 3 resulted in a linear relationship. This relationship was used to project age 3 recruitment in 1987-89 (Fig. 5).

Cohort analyses estimates of age 3 pollock entering the population have varied from a high of 15.1 billion in 1981 to 1.8 billion in 1984, and have averaged 7.58 billion since 1981. The following table of the recruitment trend shows that since the very strong 1978 year class, recruitment has been near average except for a very weak 1981 year class. Projected recruitment is estimated to be low in 1986 and 1989, but slightly above and below average in 1987 and 1988, respectively.

Year class Year age 3	1978 1981	1979 1982	1980 1983	1981 1984	1982 1985	1983 1986	1984 1987	1985 1988	1986 1989
Age 1 est.[a]	8.2	--	1.0	0.8	3.7	0.3	4.0	2.2	0.3
Age 3 est.[b]	15.1	5.7	7.4	1.8	7.9	[2.2]	[8.4]	[5.4]	[2.2]

a From survey data
b From cohort analysis

Based on these recruitment trends it is anticipated that pollock will decrease slightly in abundance as the 1978 year class dies off and is replaced by weaker year classes.

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

MAXIMUM SUSTAINABLE YIELD AND CURRENT POTENTIAL YIELD IN THE EASTERN BERING SEA AND ALEUTIAN ISLANDS AREA

Eastern Bering Sea

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

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

The model results are most sensitive to the spawner-recruit relationship (Fig. 6). The Ricker model was used to fit the pollock spawner-recruit data because this relationship occurs in situations where cannibalism is an important population regulating mechanism. Cannibalism is believed to be an important source of mortality in the eastern Bering Sea pollock population.

A Beverton-Holt model was also fit to the pollock spawner-recruit data, but this model did not fit the data as well as the Ricker model, R = 0.51 vs. R = 0.81, respectively. Figure 7 shows that MSY occurs at the point of maximum recruitment which is 8.4 billion age 3 pollock produced from a spawning population of 5.2 billion pollock (4.7 million t).

An additional important factor in the determination of pollock MSY is the selectivity pattern. Pollock fishing mortality exhibits a dome shaped curve, which indicates that pollock selectivity increases to a maximum at ages 4-5 and then decreases with age. This pattern is believed to be due to a combination of catchability and availability (Wespestad and Megrey 1989). Therefore, to calculate the level of fishing that produces MSY, two sets of possible selectivity patterns were examined: 1) the average selectivities computed from the F values obtained in cohort analysis; and 2) a pattern based on data presented by Smith (1981), where age 3 is only partially available, but older ages are fully selected.

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

The acceptable biological yield for eastern Bering Sea pollock was evaluated at the MSY, replacement (fishing = recruitment) and $F_{0.1}$ fishing rates. The predicted yield and biomass levels resulting from fishing at these levels in 1988-90 are shown in Figure 7. The projections were derived from the Walters (1969) model with input consisting of 1985 cohort analysis estimates, cohort analysis-trawl survey recruitment projections, and the 1985-87 catches.

The projections indicate that the biomass of eastern Bering Sea pollock in 1988 is expected to be above the level that will produce MSY. However, if estimated recruitment in the near future is correct, biomass is expected to decrease. How much the biomass decreases depends on future exploitation and recruitment. The fit of pollock recruitment to the Ricker model is fairly good (Fig. 6). For the most part, observed recruitment is close to expected and the large deviations have primarily been due to greater than expected recruitment. Although the fit is reasonably good, there are many sources of error and bias in the relationship, which warrant judicious use of the spawner-recruit relationship (Walters and Ludwig 1981).

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

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

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

Aleutian Islands

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

In the Aleutian Islands region, the status and dynamics of pollock are not as well understood as in the eastern Bering Sea. Since quantitative data are sparse and abundance estimates are based on limited observations, Acceptable Biological Catch (ABC) should be set as low as possible until better data become available. The ABC for 1988 should be set at 200,000 to 240,000 t. This level of harvest is derived by applying the eastern Bering Sea $F_{0.1}$ exploitation rate ($F = 0.31$) to the estimated 1 million t biomass.

ESTIMATED ABUNDANCE AND YIELD WITHIN THE ALEUTIAN BASIN

In the Aleutian Basin (that portion of the Bering Sea where depth exceeds 2,000 m), Japan has conducted three summer surveys (1977, 1978, and 1979) and one winter survey in 1983 (Okada 1986). The Japanese surveys found pollock to occur pelagically at low density in the deep waters of the Aleutian Basin (Okada and Yamaguchi 1985). In 1978, a biomass estimate was obtained by mid-water trawl density estimates combined with echo sounder estimates of pollock distribution. The 1978 survey covered the U.S. portion of the Aleutian Basin and the international zone; the estimated biomass within this area was 1.3 to 5.4 million t (Okada 1986).

A NWAFC hydroacoustic-trawl survey in 1988 covered the southeastern portion of the Aleutian Basin, the southern edge of the international zone, and an area west of Bowers Ridge. This survey found only small amounts of pollock outside of the southeastern basin. Most of the pollock found were concentrated in the Bogoslof Island area; preliminary estimates are that approximately 1 million t of spawning pollock occurred there.

Pollock have been harvested within the U.S. EEZ portion of the Aleutian Basin and the international zone since 1980. Catches within the U.S. EEZ portion of the Aleutian Basin have been small relative to the catch taken on the shelf. However, in 1987 and 1988, U.S. joint venture and domestic fisheries concentrated on pollock near Bogoslof Island. The fisheries harvested 328,000 t and 219,000 t, respectively, based on preliminary estimates.

Pollock catch within the international zone was minimal until 1984 when the combined catch of Japan and Korea reached 181,000 t (Table 5.). Catches continued to increase to approximately 800,000 t in 1986.

Japanese catch per unit effort within the international zone increased along with increases in catch. Sasaki and Yoshimura (1987) attribute this increase to a move within the fishery to larger midwater nets and improvements in electronics and their use. The CPUE data collected by U.S. observers indicate that CPUE has been higher than that estimated by Japan, but observer sample sizes in the international zone are small and may not be indicative of the actual situation. Comparison of Japanese and U.S. international zone CPUE with catch rates on the shelf shows that CPUE in the international zone is at best one-half to one-third the CPUE on the shelf, which suggests that pollock abundance in the international zone is much less than abundance on the shelf.

The available data suggest that pollock biomass in the Aleutian Basin may be relatively large. However, the limited amount of survey data suggests that distribution of abundance may vary considerably each season. There are insufficient data to determine if pollock remain within the basin or follow some sort of migratory pattern within the Aleutian Basin and surrounding shelf waters.

At the present time there are insufficient data to determine absolute levels of abundance or yield within the Aleutian Basin with any degree of confidence.

SALMON AND HERRING BYCATCH IN THE ALEUTIAN BASIN POLLOCK FISHERY

Pollock is the principal species found in the Aleutian Basin, and catches are usually greater than 99% pollock. Lumpsuckers (Cyclopteridae) are the principal bycatch species.

Four species of Pacific salmon have been reported present in the basin: chinook (Oncorhynchus tshawytscha), chum (O. keta), sockeye (O. nerka), and pink (O. gorbuscha). Observations available from fisheries in the Aleutian Basin indicate that chinook salmon is the principal bycatch species. Observer estimates of salmon bycatch from 1982 to 1987 show that the bycatch of salmon is variable (Fig. 8). Some of the observed variability may be due to annual variation in the number of hauls sampled. The highest salmon bycatch rate observed was in 1983 when approximately 19 salmon were taken per 1,000 t of total catch and the lowest observed was in 1986 when 1-2 salmon were taken per 1,000 t of total catch. Overall, the incidental catch of salmon in the international zone is lower than the incidental catch in on-shelf fisheries.

Pacific herring (Clupea pallasii) are found throughout the eastern Bering Sea shelf and occur incidentally in trawl catches. However, this species has not been encountered in the Aleutian Basin in surveys or in fishery samples.

INTERRELATIONSHIP OF INTERNATIONAL ZONE POLLOCK CATCH TO EEZ YIELD

Several hypotheses have been postulated to explore the relationship between pollock in the international zone and those found within the U.S. EEZ. The currently available data do not support or refute any one of the several proposed hypotheses. Without any clear indication of interrelationships, any attempt to estimate the effects of harvests on abundance and yield within the U.S. EEZ is purely speculative.

Until recently, it was thought that most of the pollock in the basin resulted from migration of mature fish from the eastern Bering Sea shelf, and these fish did not return or contribute to the population. However, the recent finding of a large spawning biomass in the Bogoslof area, consisting primarily of the 1978 year class, suggests that basin fish may contribute recruits to the shelf population. Information from the fishery in the international zone suggests that the pollock in the Bogoslof Island area may have moved there from the international zone. If this is so, then fisheries in the international zone and the EEZ are harvesting the same fish. Information presented by Sasaki and Yoshimura (1987) suggests that pollock may also be moving into the international zone from Cape Olytorsky along the Shirshov Ridge in the western Bering Sea.

RESEARCH NEEDS

The amount of information on pollock in the Bering Sea now available is sufficient only to cause confusion. Bits and pieces are coming in which are often contradictory. If yield estimations and management measures are to be formulated, then a comprehensive research effort must be developed.

The number one priority is to define the distribution of pollock spawning biomass within the entire Bering Sea. A comprehensive survey during the spawning period would provide data on possible stock structure and interrelationships between subregions. Biological samples collected during this survey could also provide information on stock structure.

Data are also needed to discern whether significant migration occurs between different areas. Japanese observations and reports from Polish vessels suggest pollock move out of the international zone into the southeastern Bering Sea and that some pollock may migrate from Soviet waters into the international zone. Collection of biological materials from surveys and fisheries may shed some light on migrations, but it is likely that a large-scale tagging program will have to be initiated to resolve the question.

Reliable catch data and biological samples are needed from all segments of the fishery in order to quantify fishery removals and determine the resulting status of the stock or stocks. The data provided by the U.S. observer program over the past 10 years have greatly enhanced our knowledge of the dynamics and yield structure of the eastern Bering Sea shelf pollock population. Observer coverage in the Aleutian Islands region has not been as extensive, primarily due to the relatively lower levels of harvest, and observations from the international zone extremely sparse. Complete and comprehensive coverage of all segments of the Bering Sea pollock fishery would at the very least provide an accurate accounting of harvest and could help to resolve some of the questions on stock structure and migration.

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Table 1.--Annual catches of walleye pollock (t) in the eastern Bering Sea.[a]

Year	Japan	U.S.S.R.	R.O.K.[b]	Taiwan	Poland	F.R.G.[c]	Other non-U.S. fisheries[d]	Joint ventures[e]	U.S.	Total
1964	174,792									174,792
1965	230,551									230,551
1966	261,678									261,678
1967	550,362									550,362
1968	700,981		1,200							702,181
1969	830,494	27,295	5,000							862,789
1970	1,231,145	20,420	5,000							1,256,565
1971	1,513,923	219,840	10,000							1,743,763
1972	1,651,438	213,896	9,200							1,874,534
1973	1,475,814	280,005	3,100							1,758,919
1974	1,252,777	309,613	26,000							1,588,390
1975	1,136,731	216,567	3,438							1,356,736
1976	913,279	179,212	85,331							1,177,822
1977	868,732	63,467	45,227	944						978,370
1978	821,306	92,714	62,371	3,040						979,431
1979	749,229	58,880	83,658	1,952	20,162					913,881
1980	786,768	2,155	107,608	4,962	40,340	5,967		10,479		958,279
1981	765,287		104,942	3,367	48,391	9,580		41,938		973,505
1982	746,972		150,525	4,220		1,625		52,622		955,964
1983	654,939		170,007			10,038		146,467	912	982,363
1984	626,335	12,268	167,887		46,900	8,304	48	230,314	6,727	1,098,783
1985	584,484	1,504	160,735		22,696			370,257	38,084	1,178,759
1986	256,178		76,313		3,616		1,043	804,842	47,363	1,189,355

[a]Catch data for 1964-79 as reported by fishing nation (except 1967-76 R.O.K. catches which were based on U.S. surveillance reports). Non-U.S. and joint venture catch data for 1980-85 from U.S. observer estimates. U.S. catches from Pacific Fishery Information Network (PACFIN), Pacific Marine Fisheries Commission, 305 State Office Building, 1400 S.W. 5th Ave., Portland, OR 97201.
[b]Republic of Korea.
[c]Federal Republic of Germany.
[d]Portugal and People's Republic of China.
[e]Joint ventures between U.S. fishing vessels and R.O.K., Japanese, Polish, F.R.G., and U.S.S.R. processors.
[f]Fish caught and processed by U.S. operations.

Table 2.--Annual catches of walleye pollock (t) in the Aleutian Islands region.

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

*Federal Republic of Germany, Republic of China (Taiwan), and People's Republic of China.

Table 3.--Biomass of eastern Bering Sea walleye pollock (million metric tons) as estimated by various assessment methods, 1963-85. CAGEAN biomass estimates are expressed as means and 95% confidence intervals.

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

[a]Cohort analysis (Pope 1972) for ages 2-9 tuned to hydroacoustic trawl survey based estimates for years 1979, 1982 and 1985.
[b]CAGEAN model (Deriso et al. 1985) for ages 2-9 tuned with hydroacoustic trawl survey estimates for years 1979, 1982 and 1985; M=0.3; means and confidence intervals based on 50 bootstrap replications.
[c]Resource survey included midwater, shelf bottom trawl and slope bottom trawl components.
[d]Resource survey included shelf bottom trawl component only.
[e]Resource survey included shelf and slope bottom trawl components.

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

	Eastern Bering Sea Method			International Zone	
Year	Japan (t/h)	U.S. (t/1,000 hp/h)	INPFC (percent)	Japan (t/h)	U.S. (t/h)
1964	3.1	9.5			
1965	6.0	18.3			
1966	7.4	23.6			
1967	8.1	21.3			
1968	11.2	23.8	130*		
1969	14.3	31.5	132		
1970	12.1	18.7	145		
1971	11.2	14.2	152		
1972	12.2	14.2	184		
1973	10.2	8.6	164		
1974	10.1	9.9	115		
1975	9.1	9.2	100		
1976	9.2	10.0	98		
1977	9.2	8.7	97		
1978	9.7	9.2	100		
1979	9.8	9.9	103		
1980	9.3	9.7	92	0.4	
1981	9.6	6.4	95	0.3	
1982	10.9	6.0	100	0.5	5.5
1983	11.5	9.3	121	1.0	7.5
1984	14.6	9.2	173	4.0	7.3
1985	14.6	9.9	155	4.8	5.3
1986				8.6	4.5
1987					5.3

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

International Zone CPUE:
Japan from Sasaki and Yoshimura 1987.
U.S. from Foreign Fisheries Observer observations in the International Zone.

Table 5.--Reported walleye pollock catch (metric tons) in the Bering Sea international zone by nation and total compared to the U.S. Exclusive Economic Zone (EEZ) catch, 1880-1984.

Year	International Zone				Total	U.S. EEZ
	Japan	Korea	Poland	China		All Nations
1980	2,401	12,509			14,910	958,279
1981	221	0			221	973,505
1982	1,298	2,934			4,232	955,964
1983	4,096	66,558			70,654	982,363
1984	100,899	80,317			181,216	1,098,783
1985	136,475	63,821		1,599	201,895	1,178,759
1986	697,967	128,414	163,249	3,218	992,848	1,189,355
1987 *	NA	183,991	118,200	NA		

NA = not available

* Korean catch Jan-Oct., Poland Jan-Apr., Japan and China catches in 1987 estimated to be near 1986 levels.

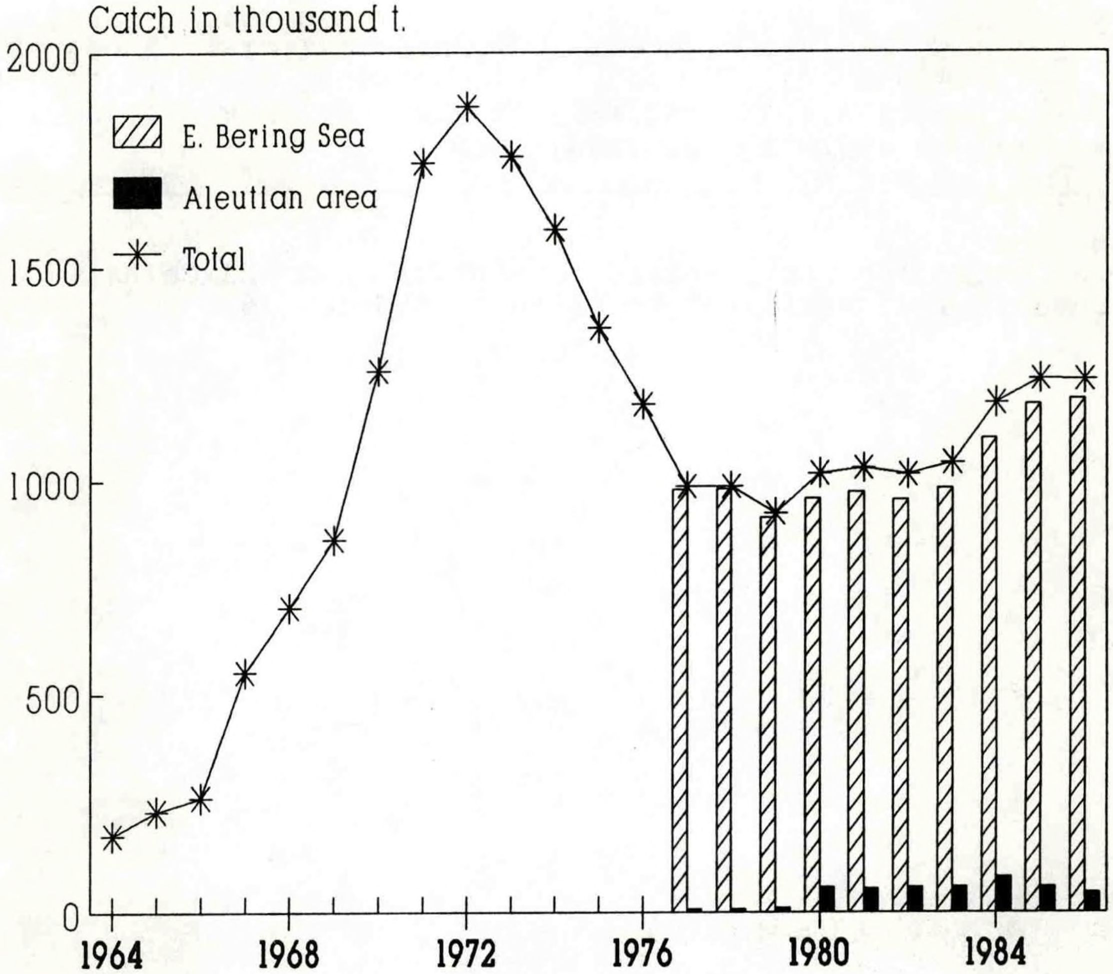

Figure 1.--Pollock catch in the eastern Bering Sea and Aleutian Region, 1964-86.

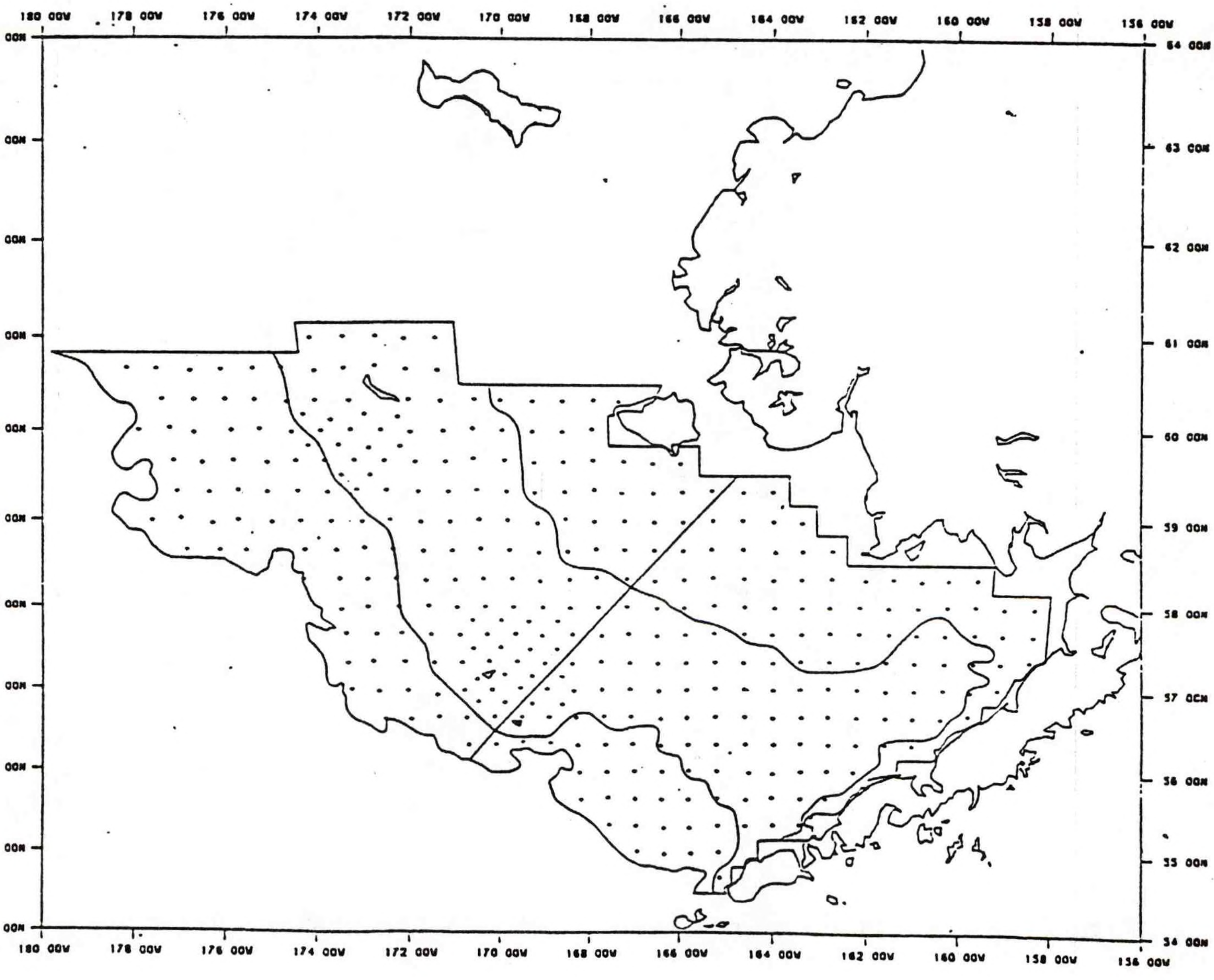

Figure 2.--Standardized survey area on the eastern Bering Sea continental shelf sampled during Northwest and Alaska Fisheries Center bottom trawl resource assessment surveys in 1975 and annually since 1979. Stratification of the survey area used in analyses of assessment data is also shown.

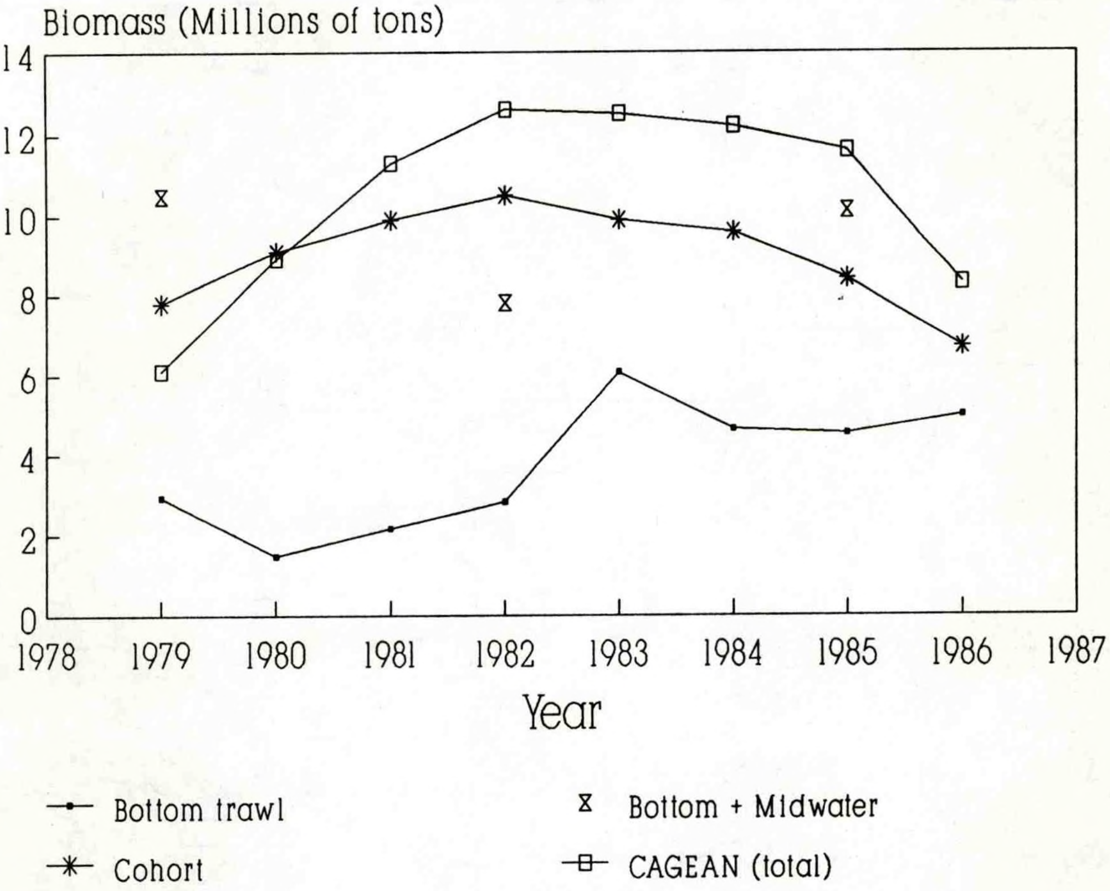

Figure 3.--Estimates of pollock biomass in the eastern Bering Sea.

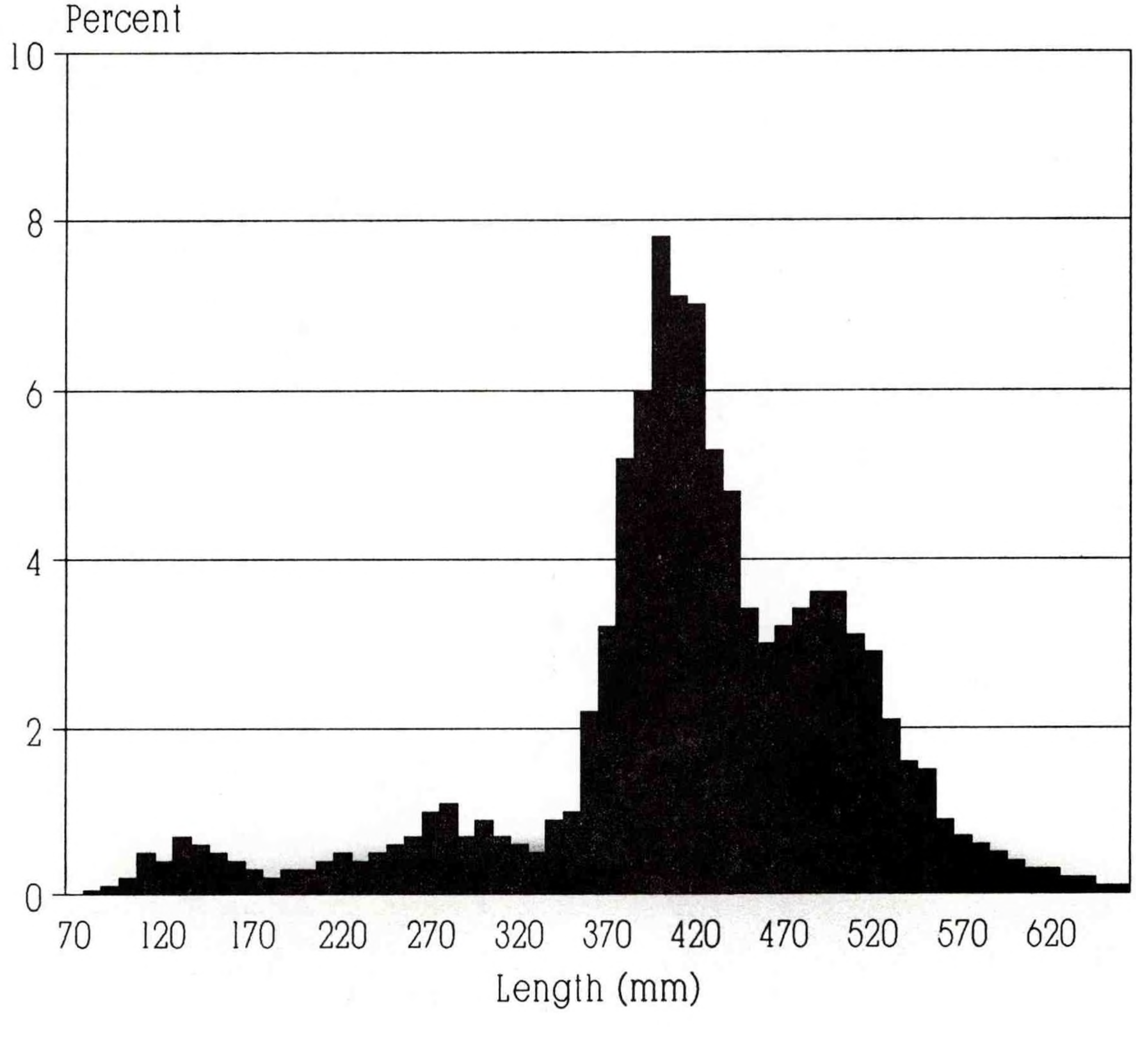

Figure 4.--Size frequency of eastern Bering Sea pollock captured in the 1987 Northwest and Alaska Fisheries Center bottom trawl survey.

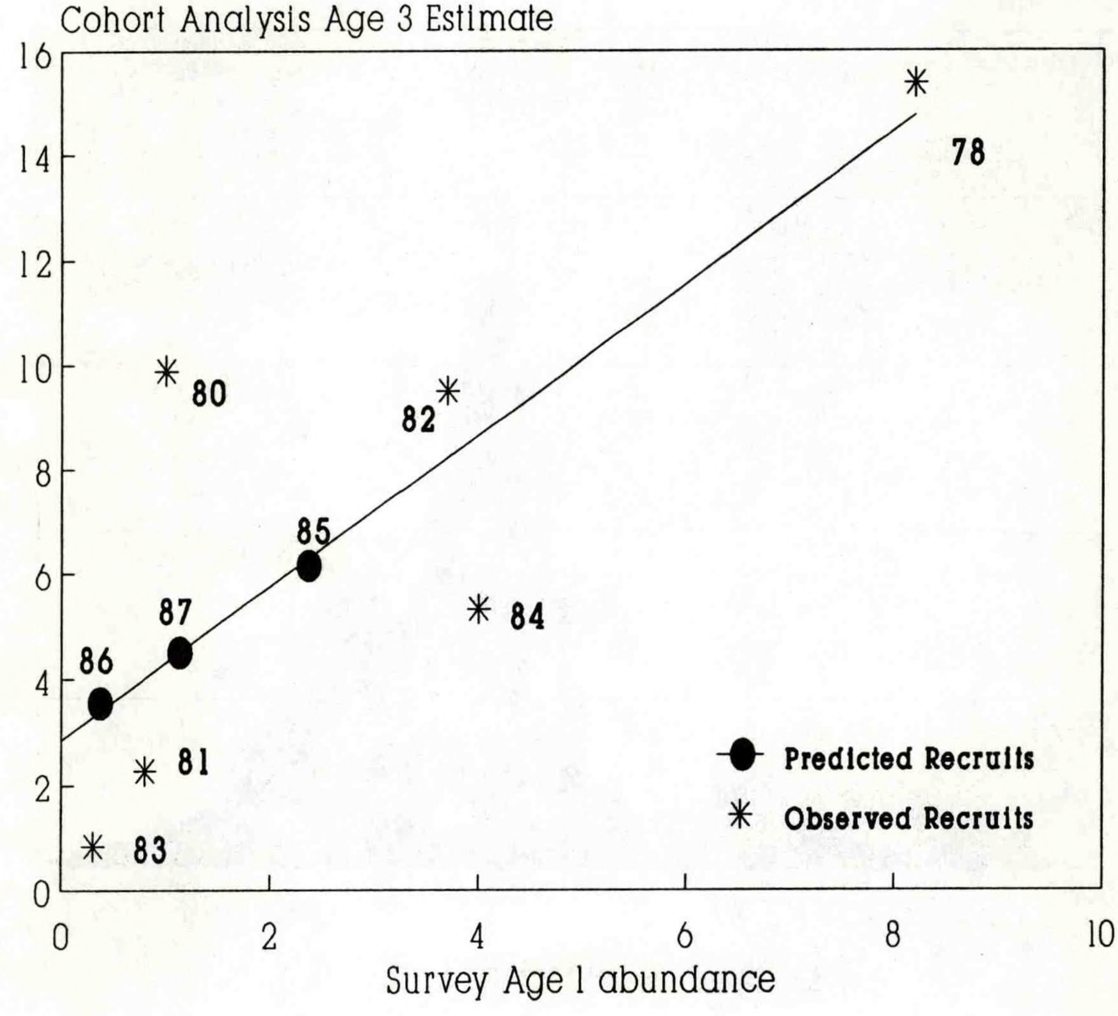

Figure 5.--Relationship between survey estimates of age 1 and cohort analysis estimates of age 3 pollock in the eastern Bering Sea.

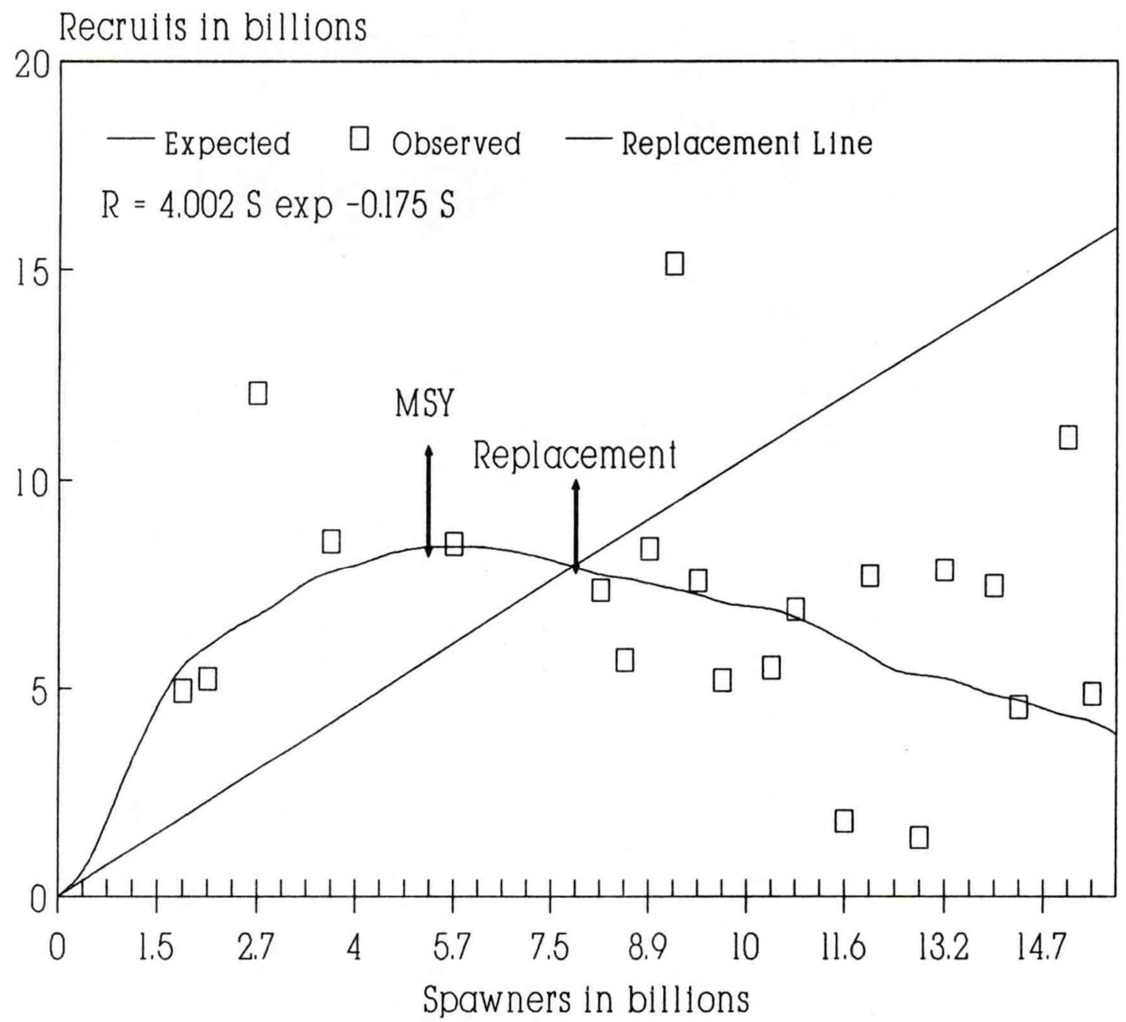

Figure 6.--Spawner-recruit relationship for eastern Bering Sea pollock.

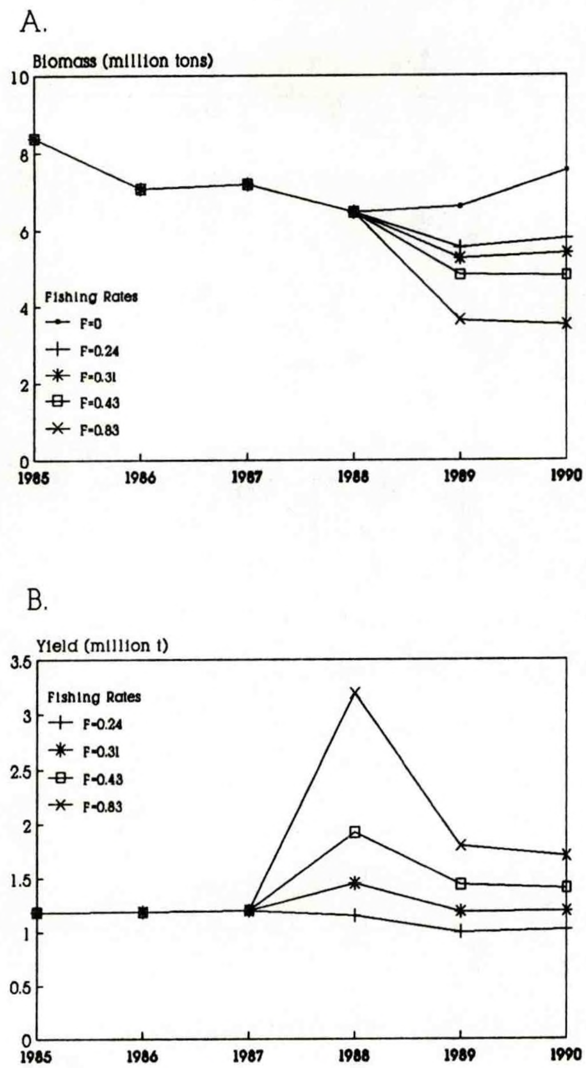

Figure 7.--Predicted biomass and yield of walleye pollock in the eastern Bering Sea at various fishing mortality rates.

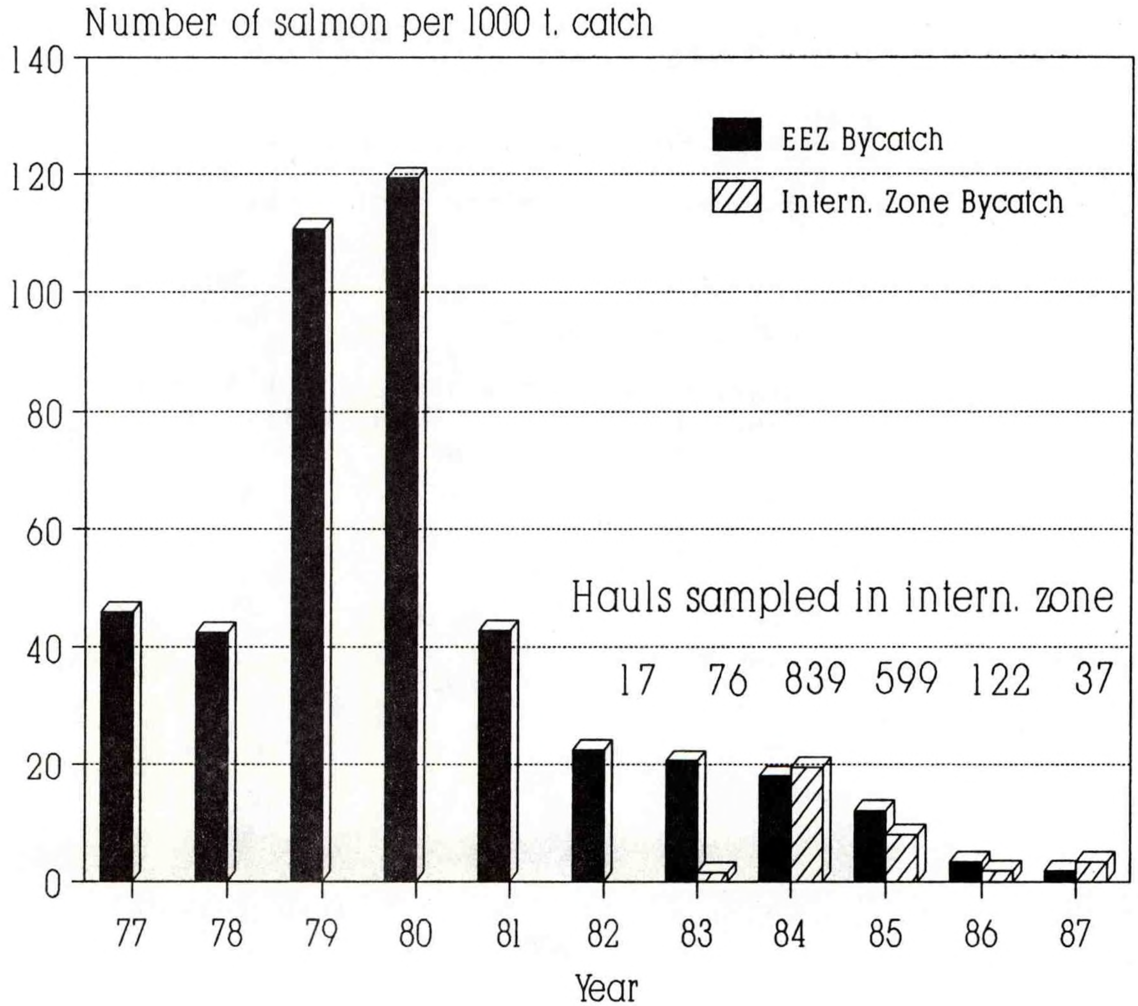

Figure 8.--Salmon bycatch in the foreign trawl fishery in the U.S. EEZ and the international zone, 1977-87.

ABUNDANCE INDEX FOR ALASKA POLLOCK BY KOREAN TRAWLERS IN THE BERING SEA

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ABSTRACT

Annual changes in catch per unit of effort(CPUE) by geographical area of Alaska pollock were analyzed as a measure of abundance through the standardization of fishing effort of korean trawlers in the Bering sea for the period of 1982 to 1987.

Fishing effort was standardized by vessel size classes, based on relative fishing power. This fishing power was measured by comparing the CPUE of each vessel size class to that of a standard vessel size class in the outer continental shelf/slope of the eastern Bering Sea and high seas of the Aleutian Basin.

Vessel size, as a combination of vessel tonnage class and horsepower class, positively influenced vessel efficiency in both the continental shelf/slope and the Aleutian Basin.

The annual standardized CPUE has increased continuously in the eastern Bering Sea from 1982 to 1986.

In the Aleutian Basin, seasonal variation of CPUE was apparent. CPUE was higher in autumn through winter and lower in spring through summer. Annual changes in CPUE were compared for the winter season for January which appeared to be the main fishing season for Korean trawlers. Overall CPUE was stable during 1984 to 1986 and increased in 1987.

Bottom trawl nets has been used in the continental shelf/slope, and midwater trawl nets in the Aleutian Basin.

CPUEs were higher in the high seas of Aleutian Basin in the main fishing season than in the continental shelf/slope of the eastern Bering Sea. However,the differences in CPUEs do not simply reflect difference in pollock density because different fishing gears were used in those areas.

INTRODUCTION

The annual catch of Alaska pollock by Korean trawlers in the eastern and Aleutian Basin of the Bering Sea, 1980 - 1987, is shown in Table 1. Annual total catch for Alaska pollock in the eastern Bering Sea and Aleutian area within US EEZ is 1.0 -1.2 million tons recently. The proportion of the Korean catch to total catch in this region ranged about 17% to 6%.

In the eastern Bering Sea, Alaska pollock was the main target species since the beginning of the Korean trawl fishery and represented around 63 to 84 percent of annual total catch. Yellowfin sole was also targetted occasionally. Other groundfish, such as Pacific cod and flatfishes other than yellowfin sole, and squids were caught incidentally.

The fishing gear used by Korean fishery in the eastern Bering Sea was traditionally bottom stern trawl.

A midwater trawl fishery has been developed to catch Alaska pollock, mainly in the Aleutian Basin including the southeastern Basin (within the US EEZ) and high seas, during the winter season since 1980. Annual total catch for high seas increased sharply from 1986 and showed 1.0 to 1.3 millian tons in 1986 and 1987 by Japan, Korea, Poland, and China. Catches from the high seas area by Korea have increased continuously since 1983, and 241,870 mt were caught in 1987 (Table 1). The catch for Korea from the southeastern Basin within the US EEZ has declined from a peak of 31 thousand tons in 1982. Alaska pollock has been the only species caught by Korean trawlers in the Aleutian Basin.

Geographical distribution of catch of Alaska pollock in the Bering Sea by Korean trawlers by statistical block (lat. 1/2° * 1° long.) from 1982 to 1987 are shown in Fig.1. In the eastern Bering Sea, catches were recorded mainly in the outer continental shelf/slope region. In the Aleutian Basin, the fishing grounds were the southeastern Aleutian region within the US EEZ and the eastern and southern parts of high seas at the beginning of the exploitation; this area was extended to high seas of south of 59°N.

The size of fishing vessels of Korean trawlers ranged from 900 GRT to 5,800 GRT and 2,000 Hp to 6,000Hp.

Catch and effort data from commercial fishery operations provides one of the most readily available sources of information that can be used to assess the condition of fish stock. for this purpose, fishing conditions and vulnerability of the stock to fishery will have to remain constant.

There were some changes in the fishing grounds and fishing season used by Korean trawlers for Alaska pollock in the Aleutian Basin and the eastern Bering Sea. Therefore, it is necessary to standardize the fishing efforts of Korean trawlers in the Bering Sea. This paper examined the annual changes in CPUES for Alaska pollock by geographical area as a measure of pollock abundance through the standardization of the unit fishing effort of Korean trawlers in the Bering Sea from 1982 to 1987.

MATERIAL AND METHODS

The raw data collected from Korean trawlers by the National Fisheries Research and Development Agency were daily fishing location, catch, and effort statistics by species by individual fishing vessels. Catch and effort data were summarized for each vessel by statistical block (lat. 1/2°* 1° long.) by month. Factors considered for the standardization of fishing efforts for Alaska pollock are summarized in Table 2.

Qualification level

The eastern Bering Sea data used here comes from the fishery activities which targetted Alaska pollock, in which the catch of pollock was 50% greater than that of any other species. In the Aleutian Basin, Alaska pollock was the only species caught by Korean trawlers.

Fishing area and time

Initially, we separated individual fishing grounds considering geographical characteristics of the Bering Sea with distribution patterns of pollock, its life history feature, and the fishing pattern of Korean trawlers. However, except for the outer continental shelf /slope of the eastern Bering Sea, south of 57°N, and high seas of the Aleutian Basin, catches by Korean trawlers were minimal. Therefore, we considered three fishing areas(Fig.2) :

1) Outer continental shelf/slope: From December to May, some areas are prohibited from fishing. We therefore confined the data to the period of June to November, which is considered to be the feeding season of pollock (Low & Ikeda,1980).

2) High seas: Monthly distribution and amounts of fishing effort were quite different seasonally. We considered each month as a time cell.

3) Southeastern Aleutian Basin within the US EEZ: Catch and effort were concentrated in February, while those in other months were minimal. We used only effort data from February.

Fishing gear

The gear used by Korean trawlers are bottom trawls in the continental shelf/slope, and midwater trawls in Aleutian Basin. Therefore, we considered that they were constant within the same fishing area, and different between the continental shelf/slope and Aleutian Basin areas.

Vessel size class

Both horsepower and tonnage of fishing vessel are likely to be related to the fishing power of Korean trawlers for Alaska pollock. We therefore classified vessels in this study into twelve vessel size classes through a combination of tonnage and horsepower classes (Table 2).

Estimation of relative fishing power and standardized effort

relative fishing power for a vessel size class can be measured against the standard fishing unit by comparing their CPUE (Gulland, 1956).

$$\bar{P}_i = 1/n_i \sum (U_{ij} / U_{sj})$$

where $\bar{P}_i$ = relative fishing power for vessel size class
U_{ij} = CPUE for vessel size class i, in jth peiod
U_{sj} = CPUE for standard vessel size class in jth period
n_i = time unit for comparison for vessel size class i (year or month)

$$f_{sj} = \sum (\bar{P}_i * t_{ij})$$

$$CPUE^s_j = C_j / f_{sj}$$

where fs_j = standardized fishing effort in jth period
t_{ij} = nominal fishing effort of ith vessel in jth period
$CPUE^s_j$ = catch per standardized unit effort
c_j = catch in jth period

Vessel size class E5 (3500-4000GRT, 4500-5000 HP) was used as standard in this study because the annual variation is low and this class covers the whole season in both areas.

RESULTS AND DISCUSSION

Relative fishing power

The estimated mean relative fishing power and coefficient of variation between years by vessel size classes, and the regression coefficient of vessel size class in each fishing area in this study are represented in Table 3 and Figure 3.

Vessel size, the combination of gross tonnage with horsepower, was an important variable influencing fishing efficiency in both the eastern Bering Sea and high seas areas. As vessel size increases, relative fishing power tends to increase and within the same vessel tonnage class fishing efficiency was increased in vessels having larger horsepower classes. However, within the same horsepower class, smaller tonnage class vessels were more efficient, especially in the high seas area.

In the southeastern Aleutian Basin within the U.S. EEZ, annual variations in relative fishing power were relatively high as the coefficient of variation 25%-72%. It seems that not the fishing power but the other factors such as patterns of the concentration of pollock influence the catchability in this area. Therefore we did not standardized by fishing power for this areas.

The regression slope was greater for the high seas than the continental shelf/slope. Thus, the estimated relative fishing power of smaller vessel size classes (less than 2000 GRT and 3500 HP) was more efficient in the continental shelf/slope than the high seas. Conversely, larger trawlers were more efficient on the high seas.

In the high seas area, the relative fishing power for the same vessel size class apparently varied by season (Figure 4). In the winter season from October to February, vessel sizes influenced fishing efficiency positively, although in the spring and summer seasons vessel sizes did not seem to influence fishing efficiency. Different density of pollock stock by season in the high seas area of the Bering Sea affects the relative fishing power of the vessels. Therefore, effort standardization was done by month in the high seas area..

Effort standardization and adjusted CPUE

Based on the relative fishing power of each vessel size class to the standard vessel, fishing efforts of Korean trawlers for Alaska pollock were standardized within the fishing area-time cell. Adjusted CPUE was calculated from the standardized effort and catches in each fishing area-time cell.

Eastern Bering Sea

Adjusted and unadjusted effort and CPUE are presented in Table 4. On the whole, adjusted effort was lower than unadjusted effort in all years. This is because a vessel class having a high fishing efficiency was used as the standard. Unadjusted and adjusted effort exhibited the same trends. However, the reatio of unadjusted (N) and adjusted (S) effort and CPUE were not consistent by year. N/S ratios of fishing effort declined year by year and reflected that the fishing efforts of the smaller vessels have increased in the eastern Bering Sea recently. Trends in adjusted and unadjusted CPUE were similar, but unadjusted CPUE was underestimated in 1985 and 1986. The adjusted CPUE of Korean trawlers has shown a continuous increase during the study period.

High seas

The adjusted and unadjusted monthly catch, effort and CPUE are shown in Table 5 and Figures 5 and 6. The fishing season of Korean trawlers in the high seas has lengthened each year. At the beginning of the exploitation, fishing was limited during January to April, with a peak in January and February comprising about 85% of the total annual catch. Recently, the fishing season has extended almost the whole year around, and catches were high in the period from October to January.

Monthly changes in CPUE in 1987 increased from October to February, declined from April, and showed the lowest value in August. The trend in adjusted CPUE showed that relative pollock abundance in January, the main fishing season through the years, was relatively stable during 1984 through 1986 and increased in 1987.

Comparison of adjusted CPUE between the eastern Bering Sea and the high seas of the Aleutian Basin

The CPUE in the high seas of the Aleutian Basin in the main fishing season was higher than in the continental shelf/slope area of the eastern Bering Sea during the years studied (Table 6). The fishing gear used by Korean trawlers in the two areas is different; midwater trawl is used in the high seas and bottom trawl is used in the continental shelf region. Therefore, the differences in CPUEs between the two areas seem to reflect not only the differences in pollock density of the two areas, but also the fishing efficiency of the two fishing gears.

Geographical distribution of annual CPUE by Korean trawlers in the Bering Sea by statistical block(lat.1/2° *1° long.) from 1983 to 1987 are shown in figure 7. The values of CPUE appears in this figure are adjusted values in the high seas and unadjusted values in the southeastern Aleutian Basin and eastern Bering Sea.

ACKNOWLEDGEMENTS

Our thanks are extended to Mr. Yeong Seung Kim and Soon Song Kim for their help with collecting data and many useful comments on the manuscripts. Many members of Deep Sea Resouces Division put a great deal of works for calculation and typing of this paper.

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Low, L. L., and I. Ikeda. 1980. Average density index for walleye pollock, Theragra chalcogramma, in the Bering Sea. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRT-743, 9p.

Table 1. Annual catch of Alaska pollock by Korean trawlers in the eastern and High seas of the Bering Sea, 1980-1987.

Year	Eastern Bering +		Southeastern Aleutian +		High Seas ++	
	No. of vessels operated	Catch (t)	No. of vessels operated	Catch (t)	No. of vessels operated	Catch (t)
1980	22	110,153.4				12,509
1981	29	113,058.4			0	0
1982	29	147,279.4		30,687.3	5	2,934
1983	28	168,110.8		12,497.7	25	66,558
1984	27	169,578.5		16,375.4	26	80,317
1985	27	164,348.0		6,005.6	26	82,444
1986	27	83,026.7		7,870.6	30	155,718
1987	9	351.9			32	241,870

Eastern Bering : Continental shelf/slope of eastern Bering Sea within US FCZ

Southeastern Aleutian : Southeastern Aleutian Basin within US FCZ

High Seas : High seas in the Aleutian Basin

Data sourse : + National Fisheries Research & Development Agency

++ National Fisheries Administration

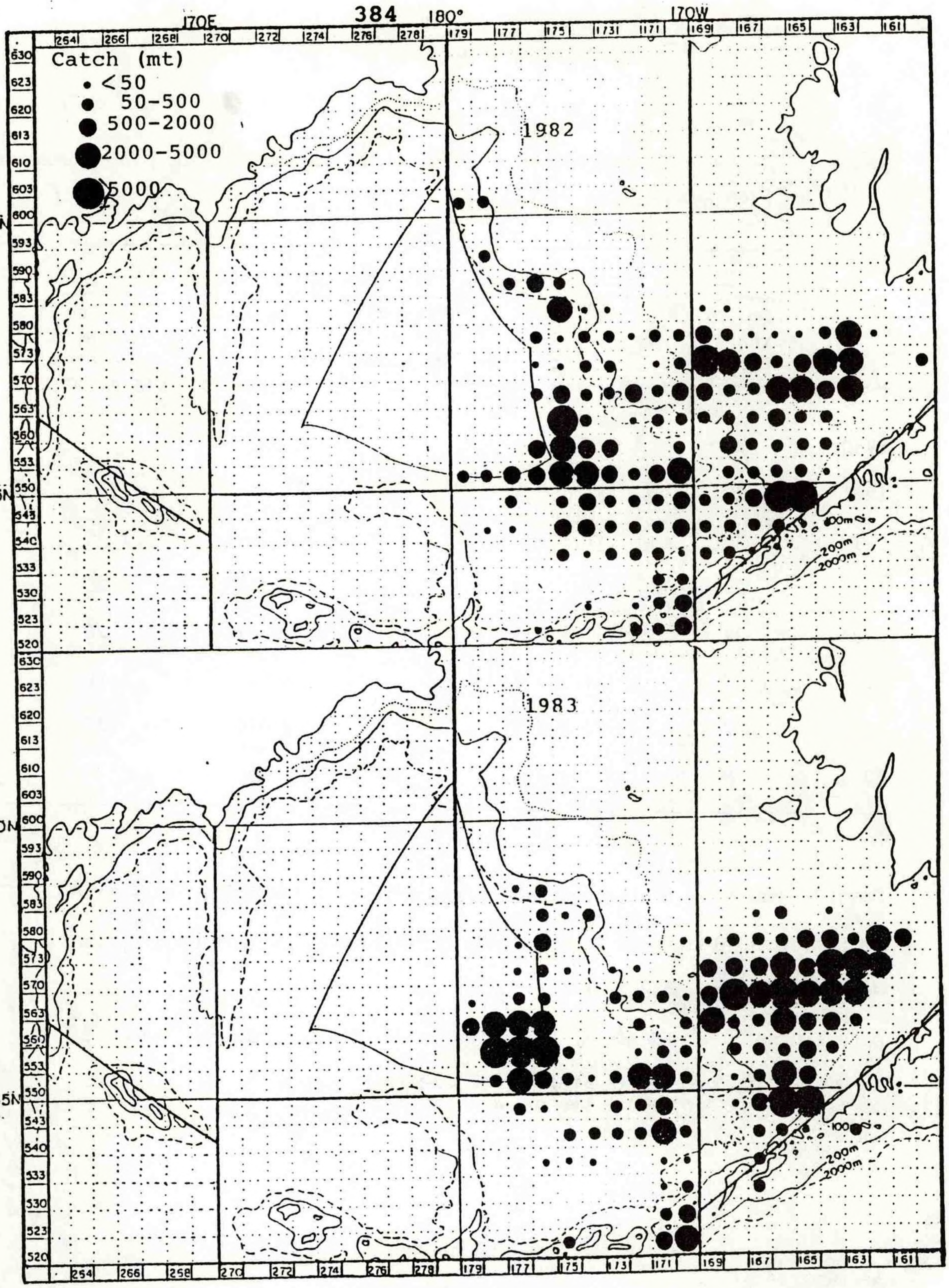

Figure 1. Geographical distribution of catch for Alaska pollock by Korean trawlers in the Bering Sea, 1982-1983.

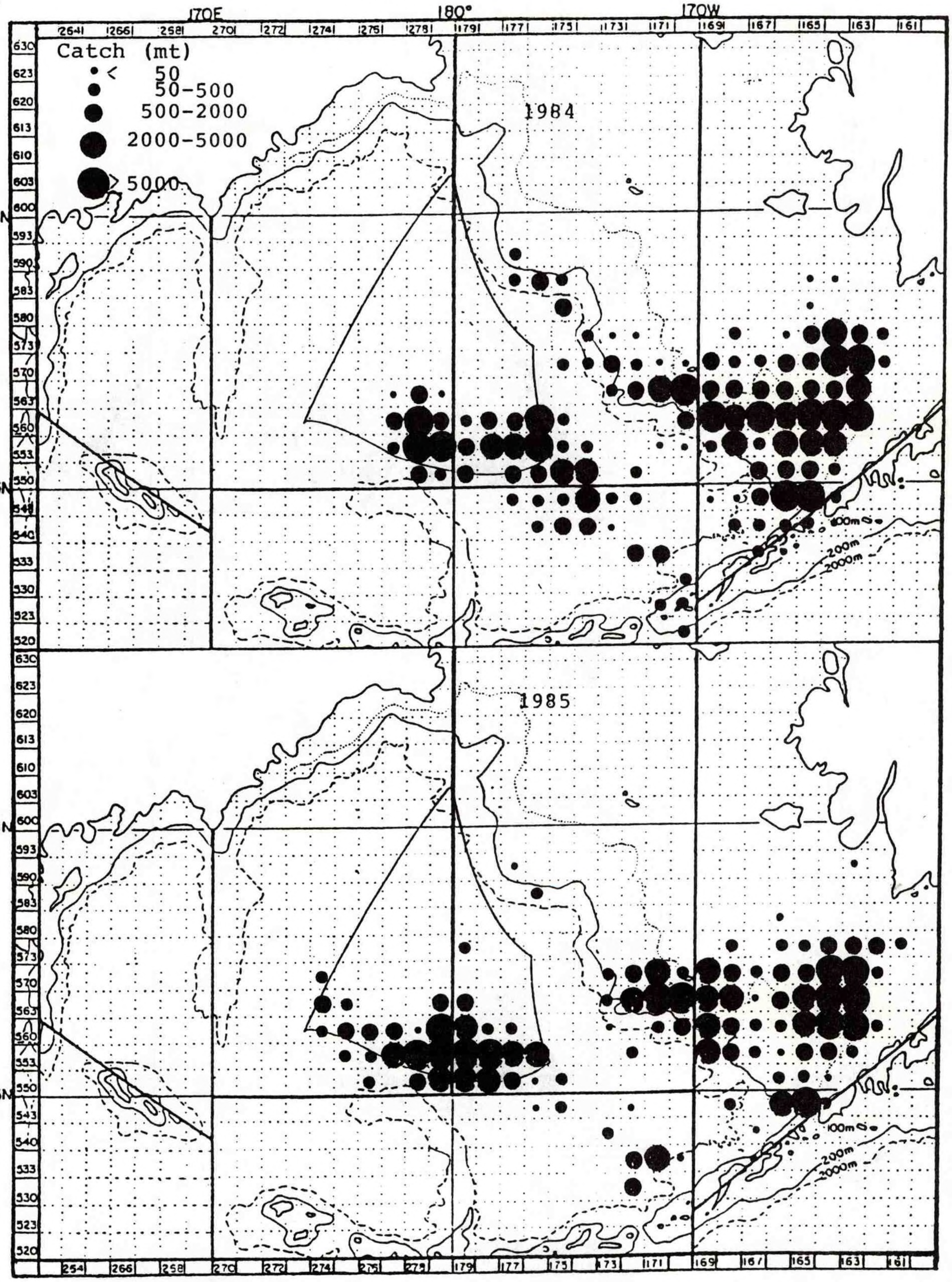

Figure 1. Continued, 1984-1985.

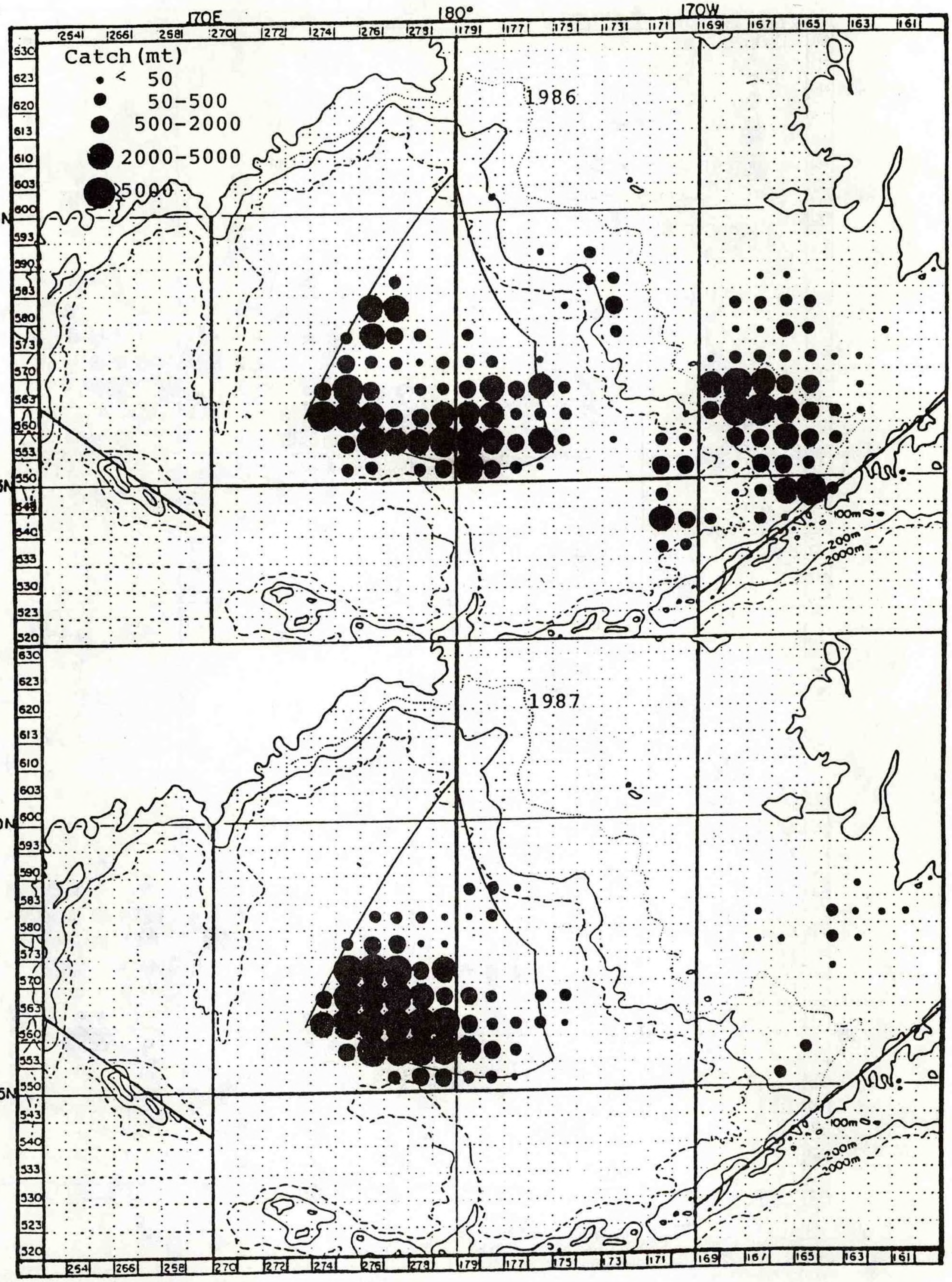

Figure 1. Continued, 1986-1987.

Table 2. Factors employed on effort standardization for Alaska pollock by Korean trawlers in the Bering Sea

Factor	Identification
1. Qualification level	o Pollock majority (over 50%) data for the statistical block (Lat. ½° x 1° Long.) by month
2. Area - Time	o Outer continental shelf/slope, South of lat. 57°N (June-November) o High Seas of Aleutian Basin (each month) o Southeastern Aleutian Basin (February)
3. Fishing gear	o Considered as the same within the same area-time cell, different between the continental Shelf(bottom trawl) and Aleutian Basin (midwater trawl)
4. Vessel size	o Grouped by gross tonnage and horse power of the vessels

Tonnage	Mark	Horse power	Mark
1000 GRT	A(omitted)	2000-2500 HP	1
1000-1500	B	2500-3000	2
1500-2000	C	3000-3500	3
2500-3500	D	3500-4000	4
3500-4500	E	4500-5000	5
5000-6000	F	5000	6
		5500-6000	7

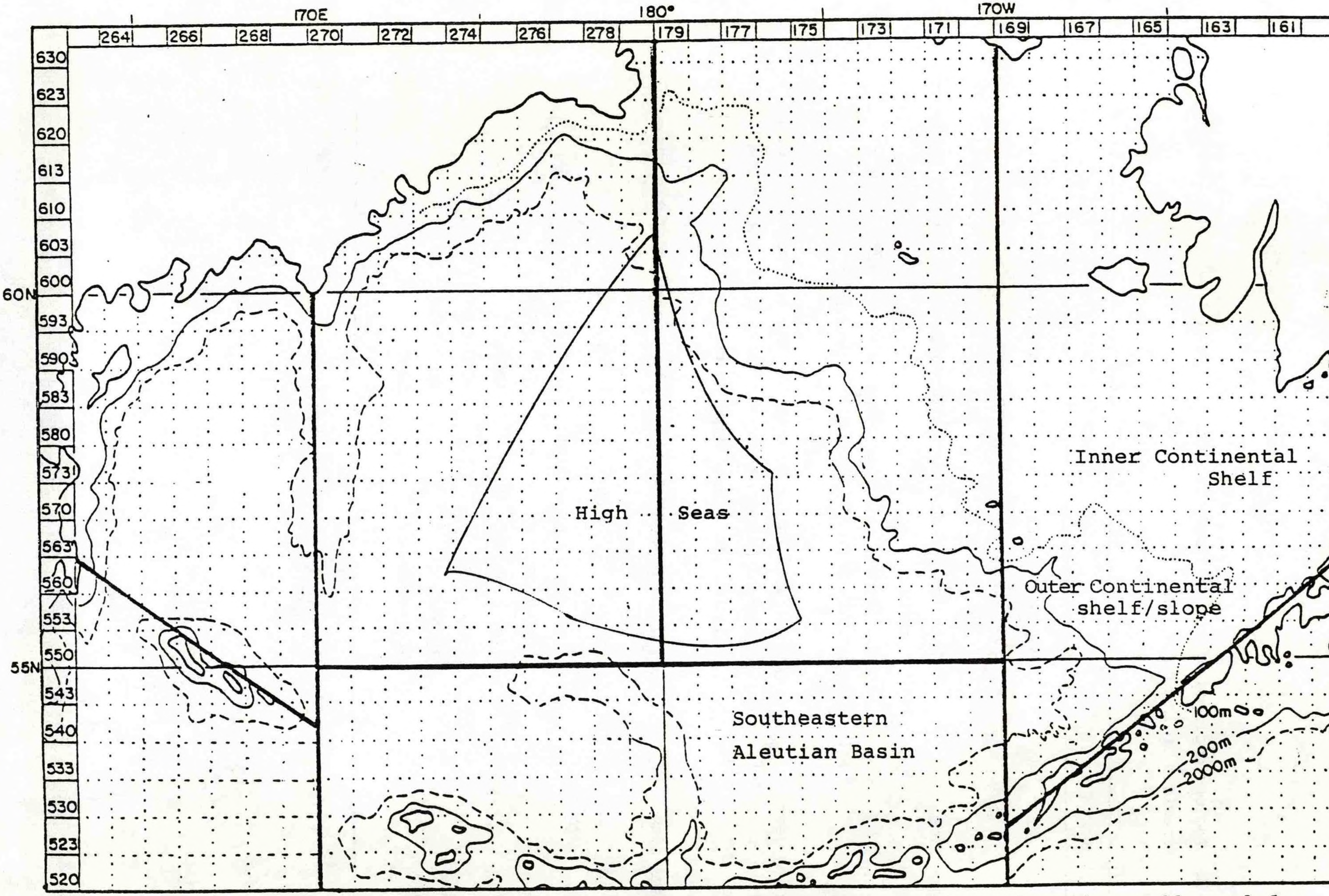

Fig. 2. Map showing the statistical block (lat. ½° x 1° long.) and location-time cell used for calculating the effort standardization.

Table 3. Estimated mean relative fishing power (P_i) and coefficient of variation by vessel size class for Alaska pollock of Korean trawlers in the Bering Sea

Vessel size class	Continental shelf/slope		Southeastern Aluetian Basin		High Seas	
	$\overline{P_i}$	CV	$\overline{P_i}$	CV	$\overline{P_i}$	CV
B1	0.710	0.37	0.650	0.72	0.614	0.26
B2	0.785	0.14	0.683	0.52	0.637	0.35
C2	0.633	0.19	0.880	0.29	0.534	0.22
B3	0.796	0.36	0.728		0.795	0.31
C3	0.752	0.16	1.173	0.47	0.718	0.25
C4	0.855	0.41	1.440	0.63	0.836	0.23
D4	0.906	0.12	0.850	0.28	0.768	0.19
D5	-		-		1.050	0.29
E5	1		1		1	
E6	0.879	0.04	0.929	0.04	1.003	0.10
F6	0.969	0.11	1.602	0.27	1.125	0.32
F7	0.969	0.13	0.866	0.25	1.180	0.23
results of regression of $\overline{P}$ to vessel size class						
b(slope)	0.03		0.04		0.05	
R^2	0.74		0.25		0.87	

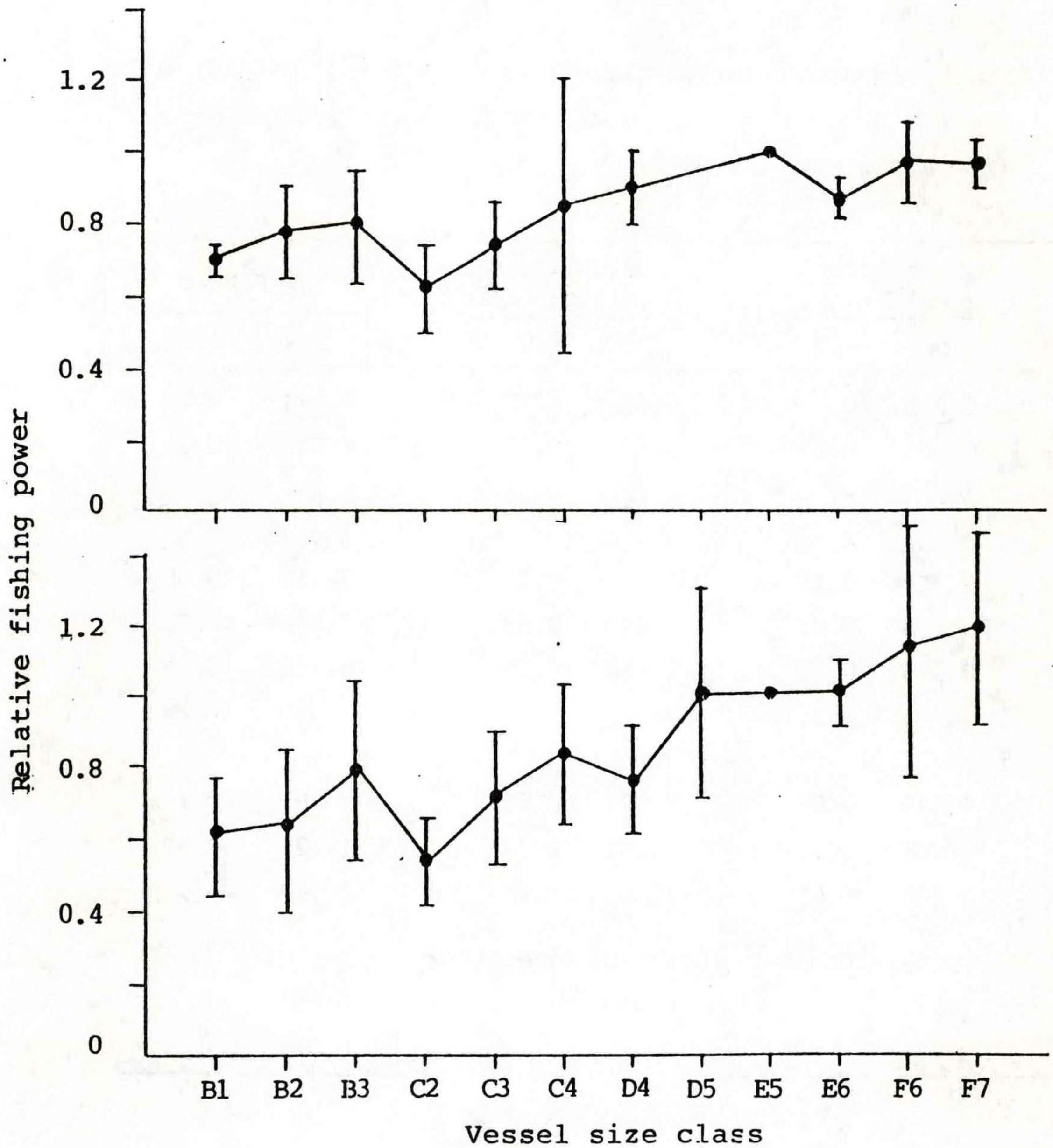

Fig. 3. Estimated relative fishing power and standard deviation by vessel size class for Alaska pollock by Korean trawlers in the Bering Sea. Upper, eastern Bering Sea, lower, high seas of the Bering Sea.

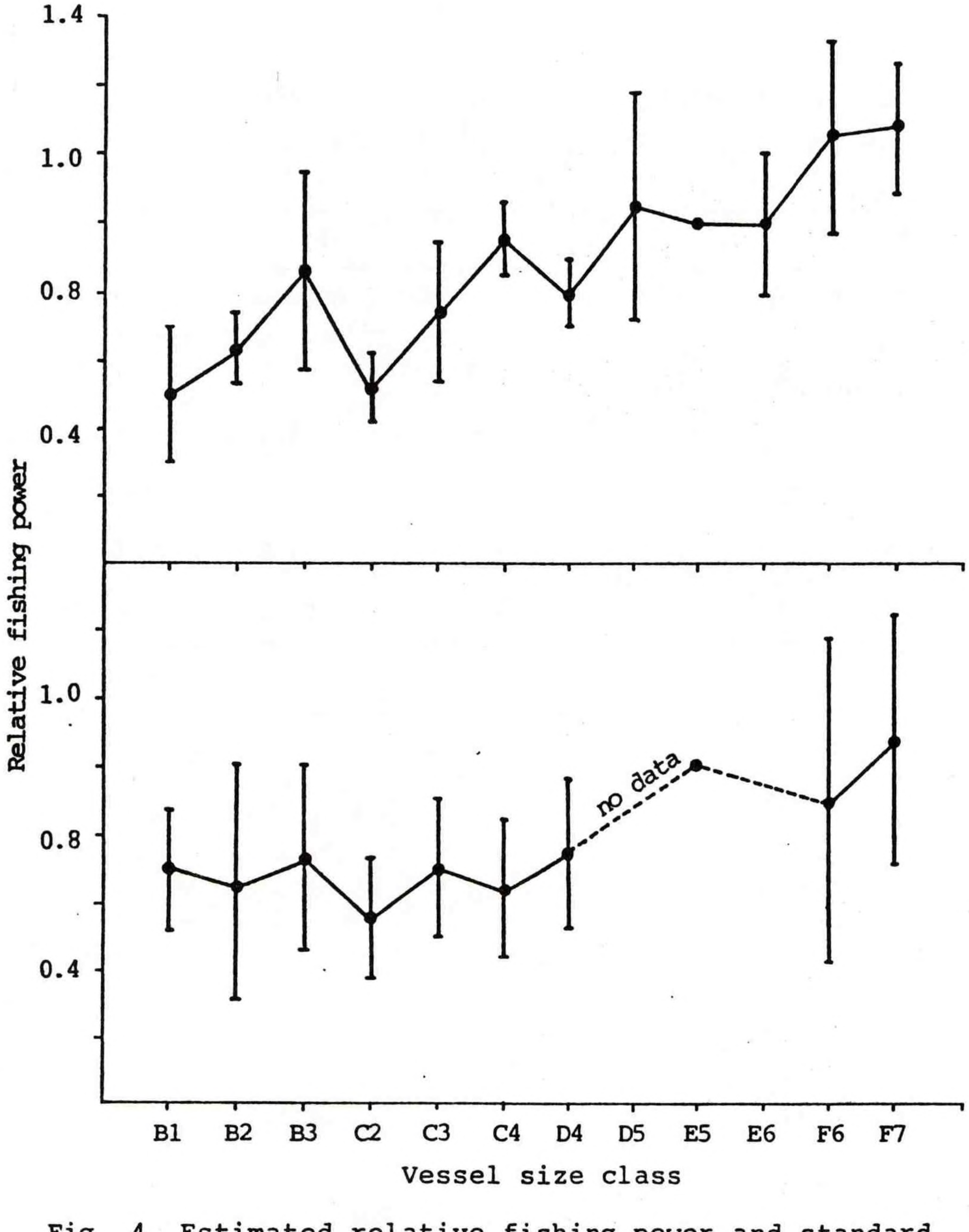

Fig. 4. Estimated relative fishing power and standard deviation by season and by vessel size class for Alaska pollock of Korean trawlers in the high seas of the Bering Sea. Upper, winter season (October-February), lower, summer season (April-September).

Table 4. Annual CPUE for Alaska pollock in the eastern Bering Sea, 1981-1986, using nominal and adjusted effort

Year	Effort (h)			CPUE (mt/h)		
	Nominal(N)	Adjusted(S)	(N/S)	Nominal(N)	Adjusted(S)	(N/S)
1982	8,648.51	7,259.39	1.19	6.9	8.2	0.84
1983	10,047.98	9,292.35	1.08	7.5	8.1	0.92
1984	8,889.60	8,336.71	1.07	8.3	8.9	0.93
1985	8,818.07	7,739.09	0.88	7.9	9.0	0.87
1986	7,558.99	6,461.84	0.85	8.5	10.0	0.85

Table 5. Monthly catch proportion (%), and adjusted and unadjusted CPUE (t/h) for Alaska pollock in high seas of the Bering Sea by Korean trawlers, 1983-1987

Year		Jan.	Feb.	Mar.	Apr.	May	July	Aug.	Sep.	Oct.	Nov.	Dec.	Summary
1983	Catch proportion	50.4	38.4	9.6	11.6								63,398.63t***
	CPUE (N)*	8.4	7.7	8.5	5.7								8.2
	CPUE (S)**	10.2	9.0	12.2	6.7								10.0
	N/S	0.83	0.85	0.70	0.85								0.82
1984	Catch proportion	48.1	37.4	9.7	4.8								74,417.2t
	CPUE (N)	7.9	7.1	8.3	4.8								7.7
	CPUE (S)	9.0	10.1	10.0	6.3								9.3
	N/S	0.88	0.83	0.83	0.76								0.83
1985	Catch proportion	57.1	28.1	0.3	12.8	1.7							74,610.5t
	CPUE (N)	8.1	4.7	8.6	7.5	4.2							6.6
	CPUE (S)	9.6	5.8	8.6	9.2	4.4							7.9
	N/S	0.84	0.81	1.00	0.83	0.95							0.84
1986	Catch proportion	43.0	6.3	2.4	3.9	2.6					6.8	35.0	155,106t
	CPUE (N)	8.1	4.2	5.7	5.6	4.0					9.1	12.9	8.1
	CPUE (S)	9.4	5.4	8.7	6.9	4.5					8.7	15.7	9.7
	N/S	0.86	0.76	0.66	0.81	0.89					0.96	0.82	0.84
1987	Catch proportion	25.0	0.8	-	1.8	4.4	4.2	2.4	4.5	16.2	20.0	20.7	225,933t
	CPUE (N)	9.3	6.2	-	5.2	5.0	3.3	2.1	5.8	9.8	9.5	7.6	7.3
	CPUE (S)	11.2	11.2	-	7.3	5.1	3.3	2.8	9.5	9.9	9.4	9.6	10.8
	N/S	0.83	0.55	-	0.71	0.98	1.00	0.75	0.61	0.99	0.99	0.79	0.68

* unadjusted value, ** adjusted value
*** Catch sample data using for this study.

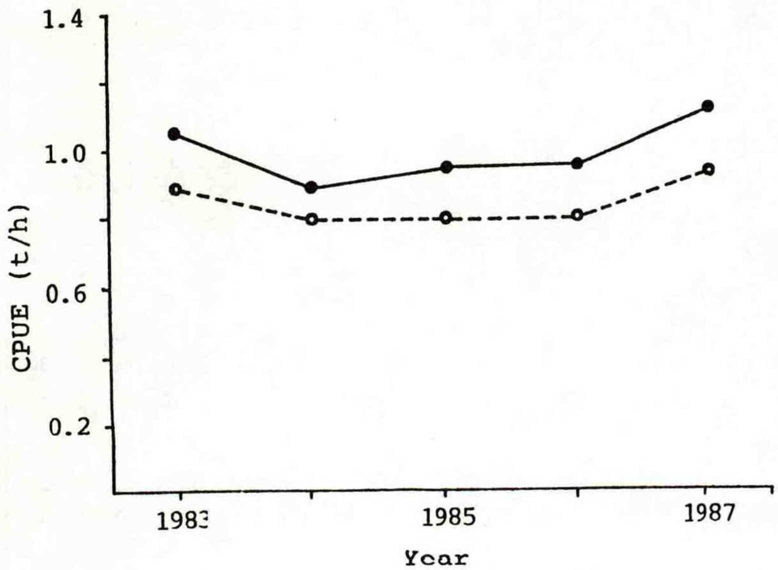

Fig. 5. Relative abundance estimates for Alaska pollock in January of high seas of the Bering Sea, from 1983 to 1987. Solid line, unadjusted CPUE, broken line, adjusted CPUE.

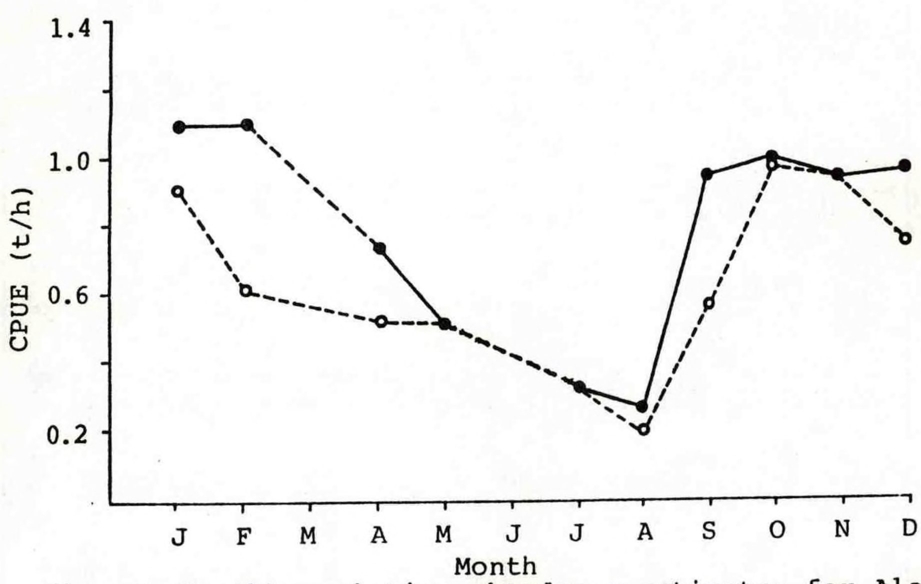

Fig. 6. Monthly relative abundance estimates for Alaska pollock of high seas of the Bering Sea in 1987. Solid line, unadjusted CPUE, broken line, adjusted CPUE.

Table 6. Comparison of adjusted CPUE between eastern Bering Sea and high seas of Aleutian Basin

Year	eastern Bering Sea	High Seas*
1982	8.2	--
1983	8.1	10.6
1984	8.9	9.0
1985	9.0	9.6
1986	10.0	9.4
1987	--	11.2

* ; adjusted CPUE in January

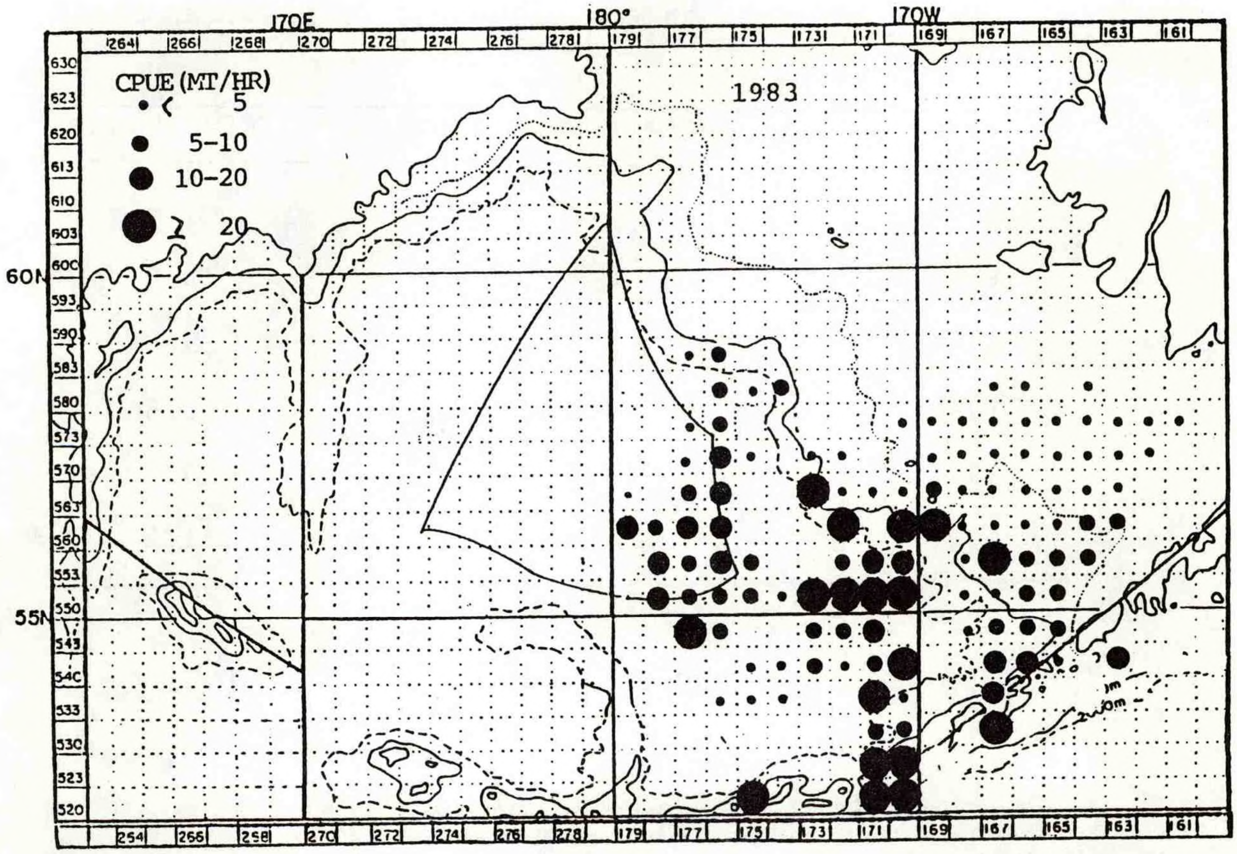

Figure 7. Geographical distribution of annual CPUE of Alaska pollock by Korean trawlers in the Bering Sea, 1983.
The line denotes the boundary of the high seas.
CPUEs in the high seas are adjusted values by vessel size class and the other regions unadjusted values.

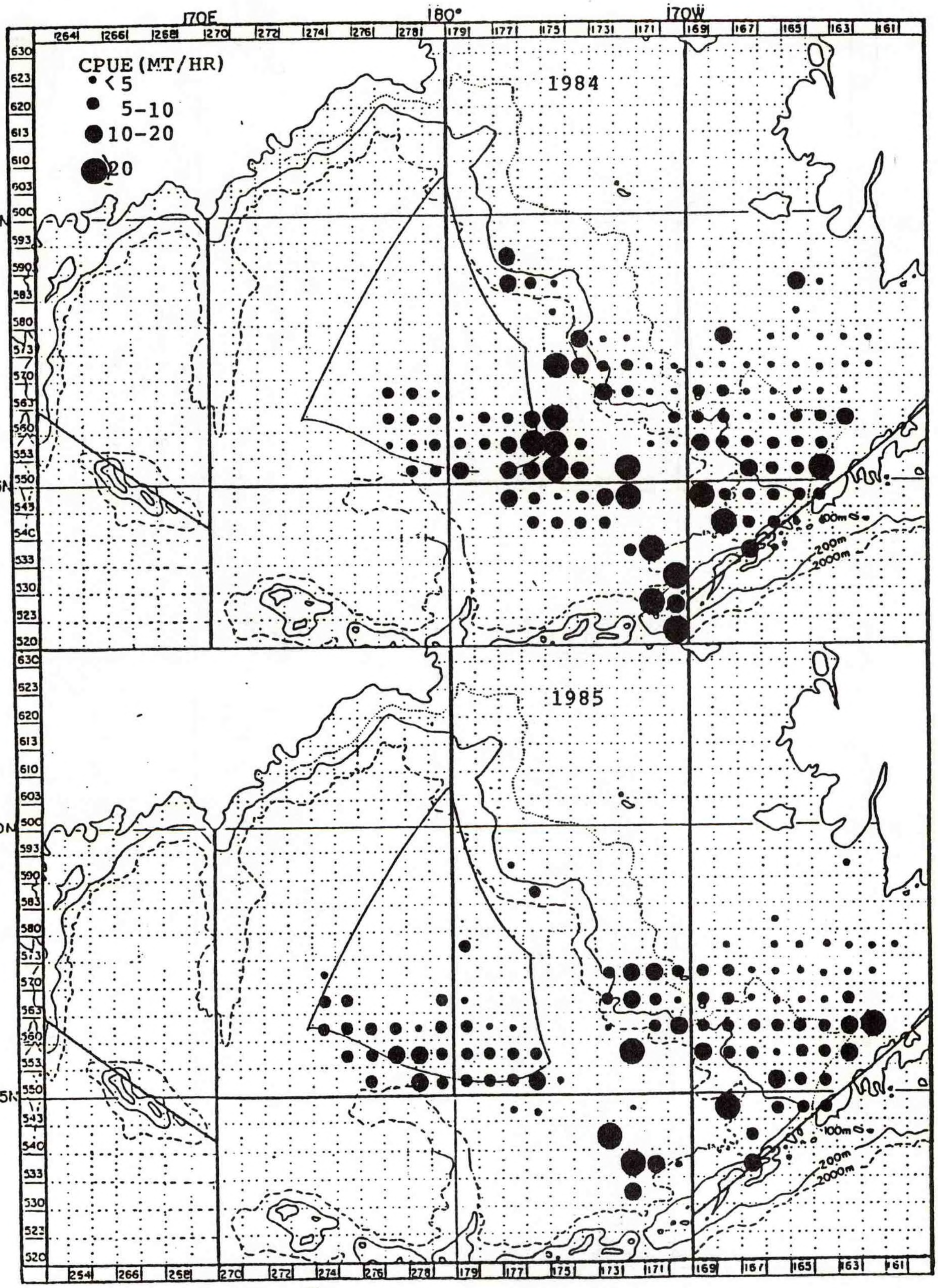

Figure 7. Continued, 1984-1985.

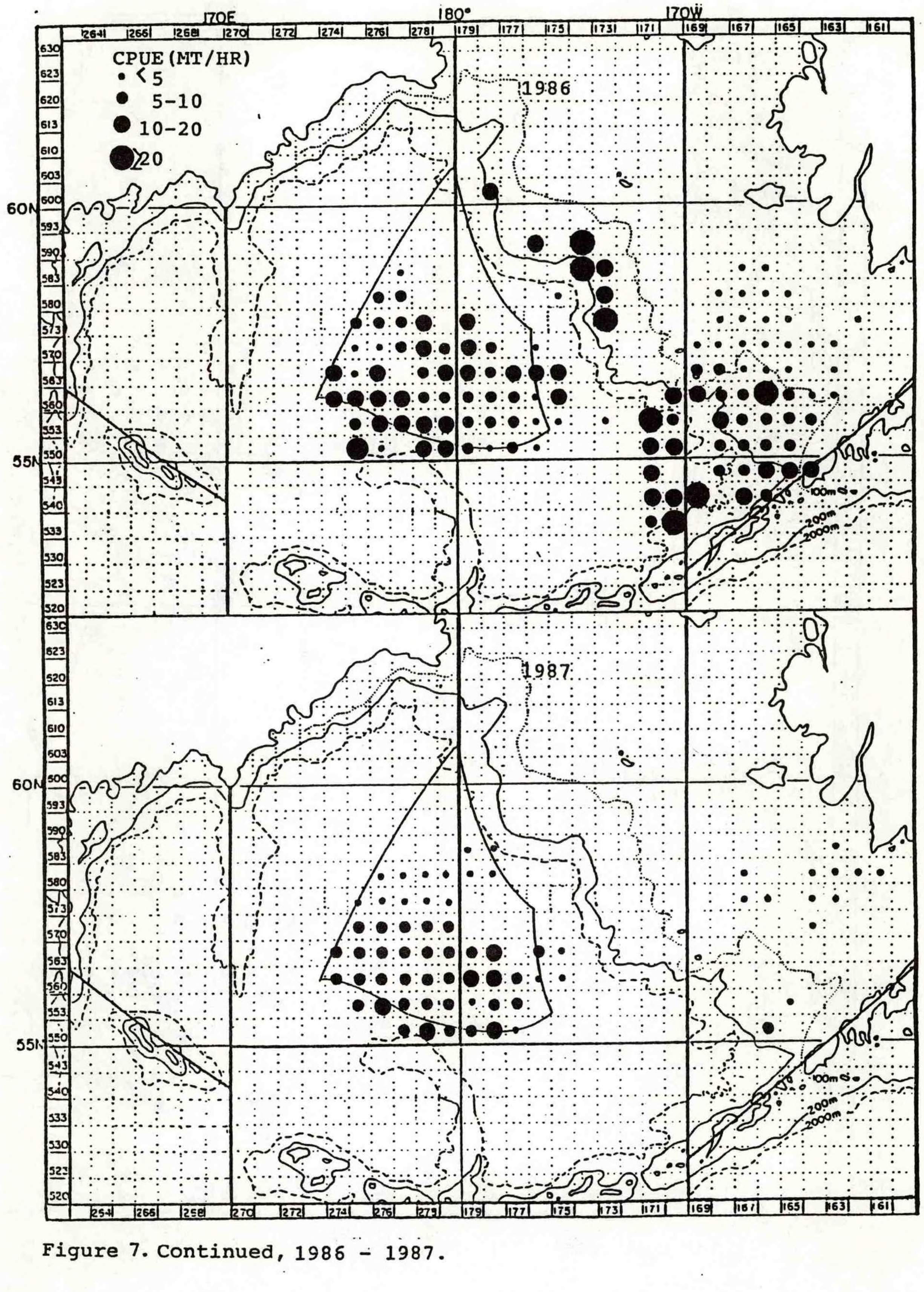

Figure 7. Continued, 1986 - 1987.

APPENDIX 4

Papers from Panel D

INTERNATIONAL SCIENTIFIC SYMPOSIUM ON BERING SEA FISHERIES

PANEL A. OCEANOGRAPHY

A. How Does the Variable Physical Environment Control Productivity?

The Bering Sea, in common with several other northern high latitude seas, is generally considered very productive. The boundaries are the Aleutian-Komandorskiy Island arc on the south, a barrier which separates the region from the North Pacific Ocean, and the land masses of Siberia and Alaska to the west and east. It is characterized by a very broad and shallow continental shelf, which lies to the north of a deep basin. Although some of its characteristics are arctic, such as the seasonal sea ice cover, other properties reflect its geographical position as an extension of the north Pacific Ocean. The Bering Sea is the most extensive of the subarctic waters contiguous to the Arctic Ocean. It supports large populations of marine mammals, birds, fishes and shellfishes, and yet high primary production is not uniform throughout. The area consists of a number of sub-regions of varying productivity and with differing ecological regimes. These regimes have boundaries which are determined by topographic or physical oceanographic factors, which produce variations in water column stability, advection, diffusion, and turbulence. These, then, affect the biological regimes, producing different rates of biological processes and varying allocation of energy. Only the major regimes which involve commercial fish stocks or major populations of marine mammals will be considered here.

Most of the commercially-harvested fish stocks are found in the southern portion of the Bering Sea, extending into Bristol Bay. The central shelf is among the more productive areas within the Bering Sea. During the summer months, this 200 km-wide shelf area is bounded by oceanographic fronts at the 50 m and 100 m depth contours. Exchange of water and material across these hydrographic structures is very slow. Much of this middle shelf region is subject to seasonal sea ice, with its extent highly variable from year to year. One of the more dramatic annual events is the spring bloom, which may be associated with a retreating ice edge or which may take place in open water to the south of the maximum extent of sea ice. In the case of the ice edge, the bloom can be extremely dramatic, with primary production rates and chlorophyll concentrations the equal of any recorded anywhere. This is due to the extreme effectiveness of ice melting as a mechanism for producing water column stability, and perhaps also to the presence of ice algae in the sea ice as a source of cells for seeding the bloom. Alternatively, with increasing solar radiation in spring, surface heating can produce stability and cause a more traditional phytoplankton bloom. The majority of the primary production in this region sinks to the bottom, especially in the case of ice edge blooms, since they occur rapidly and greatly exceed the grazing capacity of the zooplankton population at the time. Such ice edge blooms have been observed in virtually all seasonal sea ice-impacted areas. In the Bering Sea, the role of wind mixing and insolation are as follows: insolation causes stability, either through ice melt or through surface heating, and this stability is sufficiently strong to allow nutrient depletion, especially for nitrogen and perhaps silicon. Wind events play a major role in nutrient replenishment through diffusion across the nutricline (Sambrotto *et al.*, 1985) and, in the case of ice edge blooms, wind can generate ice-edge upwelling (Niebauer, 1982). Mixing across the fronts can be important; there is evidence for nutrient injection into stable surface layers through wind action at fronts (Niebauer and Alexander, 1985). Enhanced vertical fluxes appear to exist at the middle and inner fronts over the eastern Bering Sea shelf (Coachman *et al.*, 1980), and the distribution of birds correlates with the location of the inner front around the Pribilof Islands (Kinder *et al.*, 1983). Although we suspect that the presence of sea ice is important in funnelling the products of primary production to the benthos, in that the ice edge bloom develops extremely rapidly and is very intense, more work is required to demonstrate this in a definitive way. All current evidence suggests that the timing of the bloom, which is related to the presence of ice, may be important. The position of the ice on the shelf is determined more by wind than by temperature, since most of the ice is generated to the north and is moved southward by wind action. In this way, polynyas are generated to the south of the coastlines and islands in the Bering Sea. The primary production in this entire region is quite high, but the biogenic sedimentation also is very high. From an energetic perspective, we can view this as an enhancement of efficiency, since the annual production can be stored more effectively in the benthos than in an ephemeral planktonic community. Indeed, Petersen and Curtis (1980) have suggested that this "benthic shunt" is characteristic of high latitude shelf marine ecosystems.

The outer shelf of the eastern Bering Sea extends from the front at 100 m depth to the continental shelf break. In this region, advection and tidal action drive an on-shelf flow of deeper nutrient-rich waters across the outer shelf. The Bering Slope Current flows northwest over the continental slope. The regime here is more pelagic, and much of the carbon is not sedimented, but is passed up through a food web in the water column or is exported onto the continental slope. Regenerated nutrients are found in the Bering Slope Current at 100 to 200 m depths. This region is probably less affected by interannual variability in wind and insolation than the middle shelf region described above. The primary production may be quite high, probably higher than inshore, but the biogenic sedimentation is much lower.

The most productive area of the Bering Sea is influenced by the Bering Slope Current as it moves around the south of Cape Navarin, bringing high nutrients into the Gulf of Anadyr. This water moves through Chirikov Basin and the Bering Strait, and across the Chukchi Sea. Extremely high primary production occurs here almost continuously over the growing season, fueled by the high nutrients of the Bering Slope Current. Vertical mixing in the Gulf of Anadyr and Bering Straits play a role in enhancing the production, and clearly such mixing is enhanced by wind action. However, the extremely high primary production is not dependent on wind action. This area supports very large populations of mammals such as walrus.

All other regions of the Bering Sea apparently have very low annual primary production.

The discussion has hitherto focused on the relationship between physical oceanographic parameters and lower trophic level production. The link between primary production and fish recruitment has not yet been made, although the capability now exists to study this problem effectively. Examples of U.S. subarctic programs which have made significant progress include the Gulf of Alaska/Shelikov Strait FOCI program, conducted by the National Oceanic and Atmospheric Administration, which is examining the relationship between oceanographic processes, meteorological processes and pollock recruitment. The APPRISE program, also supported by NOAA, is more specifically relating the timing of the spring bloom to larval recruitment success in southeast Alaska. The latter study includes several species, but emphasizes pollock and king crab. Effective fisheries oceanographic studies for the Bering Sea can be designed based on the results of these studies, and this will be essential in order to understand the relationship between the variability in physical processes and fish populations in the Bering Sea.

Without question, the physical environment is the key factor in controlling recruitment, and in order to understand fluctuations in year class strength we must develop the better understanding which can only come from interdisciplinary research, applying the considerable technological capabilities which now exist.

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OCEANOLOGICAL CONDITIONS OF THE BERING SEA BIOLOGICAL PRODUCTIVITY

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The present knowledge of the Bering sea hydrology is, to a great extent, based on the material of the following authors: V.V.Natarov (1963), V.S.Arsenjev (1967), Coachmen et al.(1979), Ohtani (1973), Takenouti & Ohtani (1974). Although these works have laid the foundation for the investigations of the Bering sea hydrology one should note that many of their conclusions require further development, clarification and revision.

The intensive development of hydrological investigations for the last 30 years has allowed both to realise more detailed studies on water structure and dynamics and to begin studing a little-known aspect of their variability in time, that is necessary from the point of view of practical exploitation and protection of the Bering sea resources.

The data on oceanological observations practically of all the cruise investigations of the USSR have been used in the present paper. The total number of oceanological stations is 23327. They are kept on magnetic disks and there is a packet of programs for their primary processing on computers too.

1. Water Circulation

The linear diagnostic model of A.S.Sarkisjan (1977) as the most acceptable for the Bering sea has been used for the calculation of currents. The general scheme of currents observed in the warm period of a year is shown on Fig.1.

The main peculiarity of the Bering sea water circulation is in the presence of large eddy formations of different signs. Cyclonic water movements predominate in the western deep-water part of the sea and both anticyclonic (in the northern half) and cyclonic ones prevail in the vast eastern Bering sea shelf.

The present investigations revealed the quasi-stationary anticyclonic gyrals, one of which is situated to the south of C.Navarin and the other one in the shelf area between St.Matthew and St.Laurence islands.

Attu, Central-Bering and Kamchatka currents are the constituent parts of water ciculation along the entire border of the deep water area of the sea. Their approximate velocities are 5 to 15 cm/sec and only that of Kamchatka strait could increase to 20 cm/sec.

At 59°N The Central-Bering sea current departs from the continental slope, crosses the northern part of the Aleutian trough and is directed to the Korjak coast. Close to the Korjak coast at 174°E the Central Bering sea current is branched in two currents of Kamchatka and Navarin. On the previous schemes of water circulation (Natarov, 1963)(Arsenjev, 1967) The Central-Bering sea current is directed to C. Navarin wherefrom it turns to the south-west and along the Korjak coast moves to the western part of the sea.

Over the greater part of the eastern Bering sea shelf the current velocities do not exceed 2 - 4 cm/sec and in the middle area (between 50 to 100 m isobaths) almost standing water is observed where there are practically no currents except the tidal ones.

Among the great variety of abiotic factors it is currents that play one of the most important roles in formation of the Bering sea productivity.

The favourable conditions for the formation of the higher phytoplankton productivity zones are formed in the course of mixing the Central-Bering sea current warm waters with the shelf cold waters. Therefore the maximum concentrations (over 2,000 mg/cu.m) of phytoplankton are formed on the periphery of warm currents (N.P. Markina, unpublished manuscript). Over the deep-water trough and the middle part of the shelf its concentrations do not exceed 500 mg/cu.m.

Within the USSR economic zone of the Bering sea the most stable concentrations of many commercial fish species are formed in the area of dividing the Central-Bering sea current into those of Navarin and Kamchatka. The high biomass concentration of fish here is, probably, attributed to the discharge of intermediate waters resulting in creation of conditions for the formation of consistently high carrying capacity.

2. Seasonal Variations of Water Temperature

The climatic differences in water temperatures between the North and the South are most evident in winter (January-March).

In May and June the meridianal contrasts are consistent in water temperatures (Fig.2).

In July the complete restructure of the water temperature fields takes place in relation to the more rapid heating of the inshore waters of the sea. The temperature of the inshore waters gets hmgher than that of the open part of the sea, the coastal frontal zones are formed having the temperature gradient of 0.10 - 0.12 grad/km.

August is the warmest month of a year. The open sea waters become evidently warmer, so the great temperature contrasts in the inshore areas characteristic for July tend to noticeably weaken in August.

In September the fall processes start. First, the coastal waters of the northern bays are getting cooled, later on the wave of cold extends over the southern areas of the sea. In October the inshore water temperature is getting lower than that of the open sea. In November the temperature field entirely corresponds to the winter pattern.

The intra-annual variations of water temperatures in the nucleus of the cold intermediate layer (CIL) are observed in the smaller range due to its isolation from the direct atmospheric impact. The monthly temperature fields over the whole period (May-October) of CIL existence hardly differ from each other and have a number of common characteristics:

a) the relatively warm waters adjoin the Aleutian Islands and are attributed to the advection of the Pacific waters,

b) the highest temperature values have been observed in the south-eastern Bering sea,

c) The Central-Bering sea current divides the Bering sea into two cold regions. The nucleus of the eastern region is located between St.Mattheus and St.Laurence Islands while that of the western region over the shelf of Karaginskiy Bay (Fig.3).

Over the Eastern Bering sea shelf beyond the coastal areas the thermic conditions and the patterns of their intra-annual variations in the above bottom layer and at the depth of the subsurface temperature minimum (STM) are practically the same. The greatest changes occur here in September when in the area between 58° and 59°N is formed the warm Nunivak transverse which divide the eastern region of "cold" into two parts: the northern and southern ones.

In October the water temperature at the bottom keeps to rise but the nucleus of "cold" retain. In November the southern nucleus completely transforms and the northern one is observed in the shape of a small spot with water temperature about 0°C.

3. Thermic Condition Fluctuations Observed For Many Years

The size of the region of "cold" observed in summer at the bottom over the Eastern Bering sea shelf changes in dependence on the intensity of the winter chilling. The outer limit of this region is assumed to be the isotherm 2°C (Takenouti, Ohtani, 1974) the spatial fluctuation of which is used for revealing the multi-years variations of thermic conditions in the Eastern Bering sea.

The greatest fluctuation of 2°C isotherm has been observed in the area between St.Matthews Island and Alaska Peninsula. In cold years it is found in maximum proximity to Alaska Peninsula and in warm years it would move to the North upto St.Matthews Island.

Of the observations available at our disposal (1955 -1987) we have referred to abnormally cold years 1959, 1960, 1972-1976, 1984, 1986, to moderately cold years 1961,1962, 1964, 1966, 1968, 1971, 1985, to average years 1956, 1963, 1965, 1970, 1977, to moderately warm 1980, 1982, to abnormally warm years 1955, 1958, 1967, 1969, 1978, 1979, 1981, 1983, 1987.

The general picture of the multi-years fluctuations exposes the predominance of 11 years cyclicity (Fig.4). The phases of warming have always coincided with epochs of the maximum solar activity. This occurred in 50s (1955-1958), the end of 60s (1967-1970) and at the joint of 70s and 80s (1978-1983). The regular warming having started in 1987 coincides with the ascending branch of Wolf's numbers.

The phases of cooling observed in 1959-1966, 1971-1976 and 1984 1986 coincided with the solar activity decrease.

There is no yet any satisfactory explanation of the mechanism of the solar activity impact upon the hydrosphere (Gribbin, 1980), but there is no doubt that the solar activity reflects in the atmospheric processes the large-scaled changes of which cause the respond in the hydrosphere.

The correlation analysis of different parameters of the Bering sea thermic conditions has shown that the sea icing reliably enough reflect s the thermic conditions of not only the winter but also of the spring and summer seasons. The coefficient of correlation between icing and location of the bottom 2°C isotherm over the shelf of the Eastern Bering sea is 0.76 in summer and that of icing and water temperature of the standard Pribilof hydrological transect is 0.68 (offshore part of the transect) and 0.76 (shelf part of the transect).

Our investigations have shown that abundance of the pollock year-classes is weakly related to the thermic indices. The strong year-classes could appear both in warm years (1967, 1970) and in cold years (1972). Nevetheless in the process of cooling or warming the general tendency for decrease or increase of the pollock abundance has been observed. It is not occasional that the year-classes of abnormally warm 1967 and 1979 were among the most abundant.

For the purpose of revealing the role of thermic conditions in formation of abundance of separate pollock generations we have made the model of recruitment related to the sea icing.

The deviation of the recruitment abundance from the level of that of the parental stock (5 year old fish) has been compared with the difference in icing of the years in question. The curvilinear correlation has been found inbetween them. At the low abundance of the parental generation the relation is expressed with one curve and at the high abundance with the other one (Fig.5).

In dependence on the value of the icing changing the progeny abundance could be higher or lower than that of the parental stock by 5 to 25%. Despite the essential simplification the model is fair enough in reflecting the level of significance of the thermic conditions for the pollock abundance fluctuations in the Bering sea.

The obtained model enabled to estimate abundance of the pollock generations appeared after 1981. The strongest year-class was in 1982 the abundance of which according to our calculations exceeds the abundance of the parental stock (1977 year-class) by 20%. The 1983 and 1984 year-classes appeared to be of medium abundance and 1985 year-class of high abundance. The results of the trawl surveys conducted in the last year proved the calculated data. Therefore the obtained model could be used, at least, for the qualitative forcast of the fish resources abundance.

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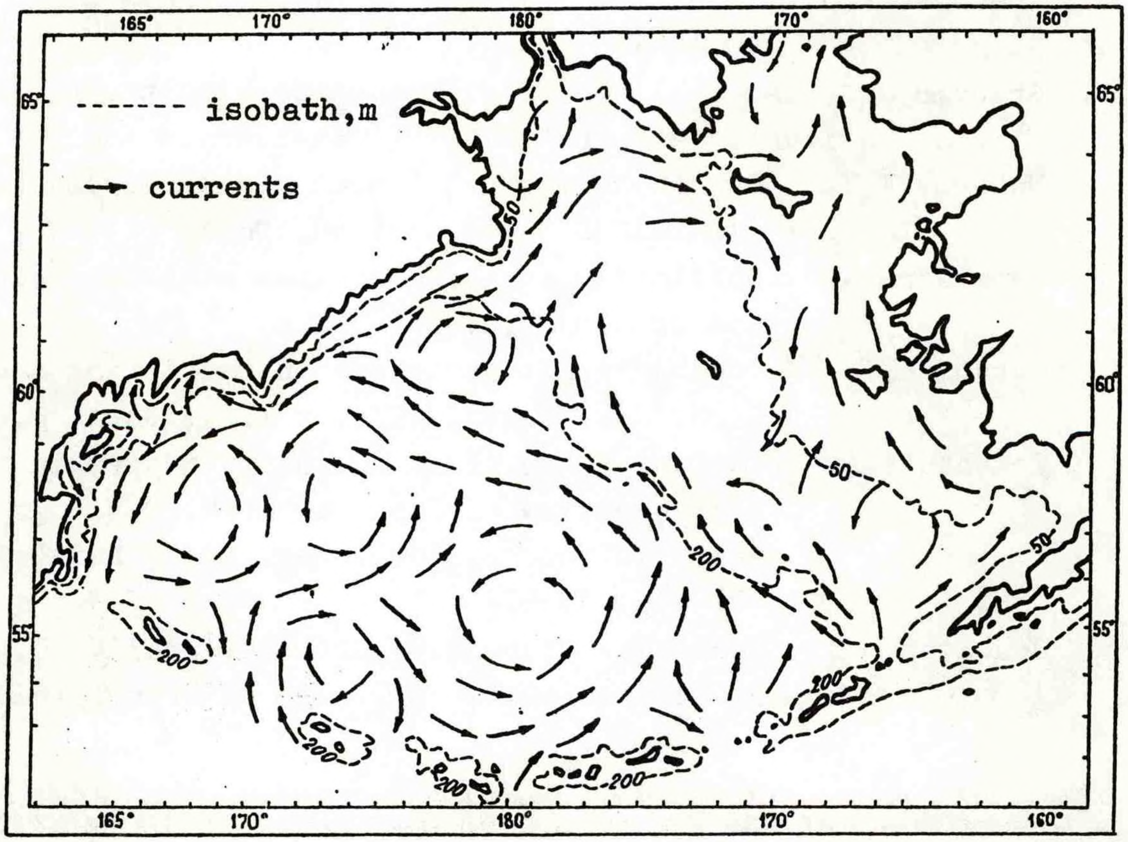

Fig. 1 The general scheme of the Bering sea currents in the warm half ef a year

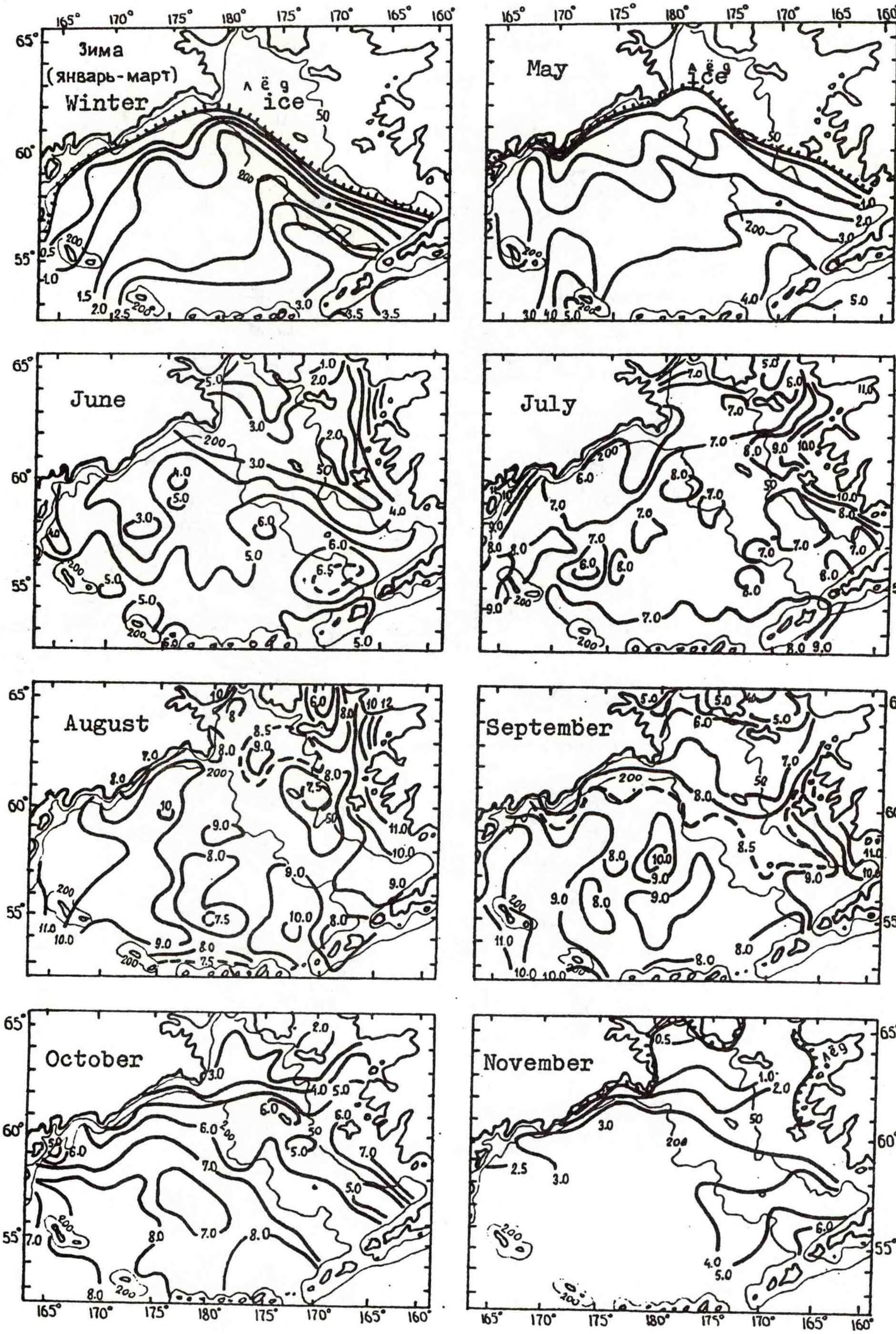

Fig. 2 Average for many years surface temperature fields

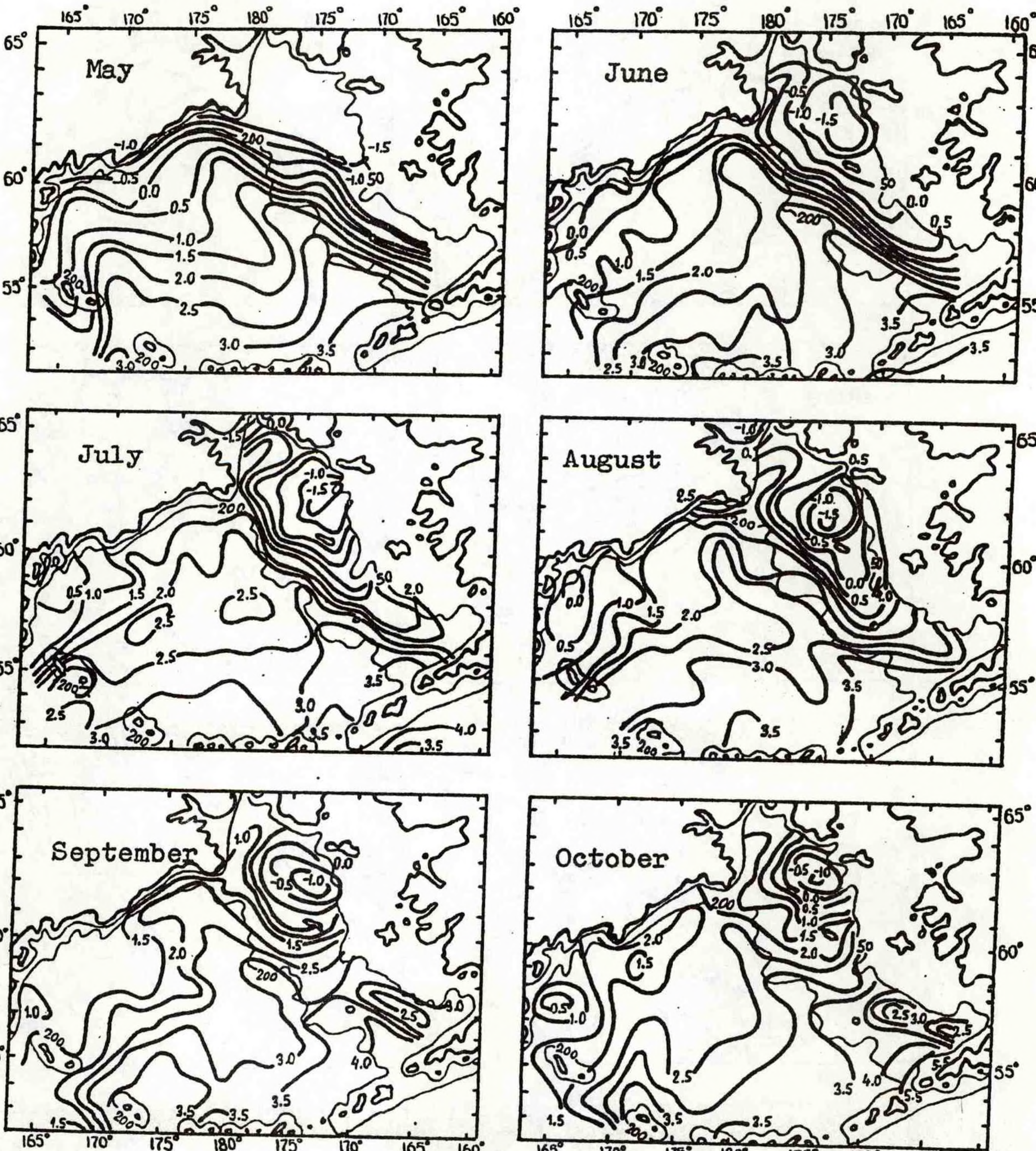

Fig. 3 Average for many years temperature fields in the cold intermediate layer nucleus

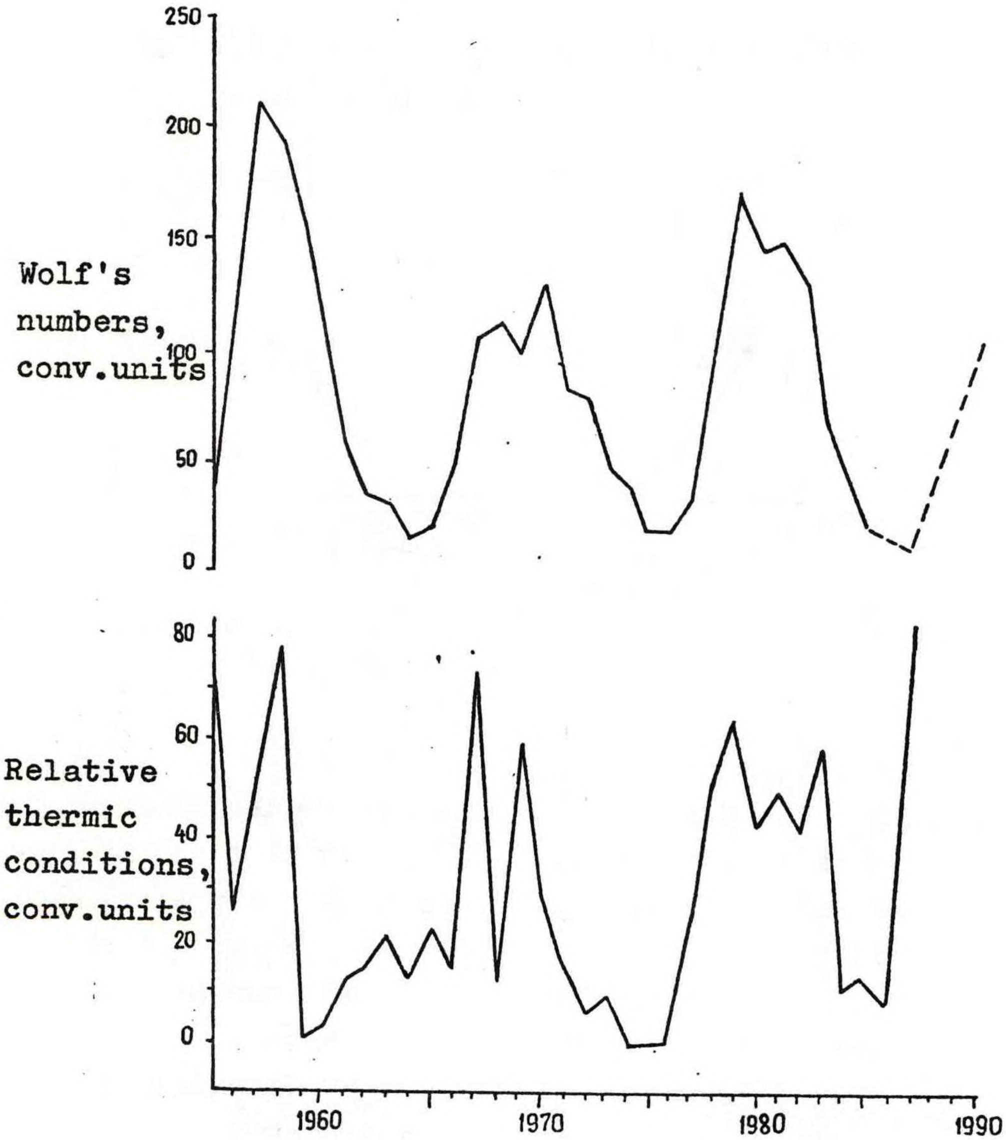

Fig. 4 The multi-years fluctuations of Wolf's numbers (above) and of relative thermic conditions of the Eastern Bering sea waters (below)

Total Recruitment abundance - total parental stock, in conv. units

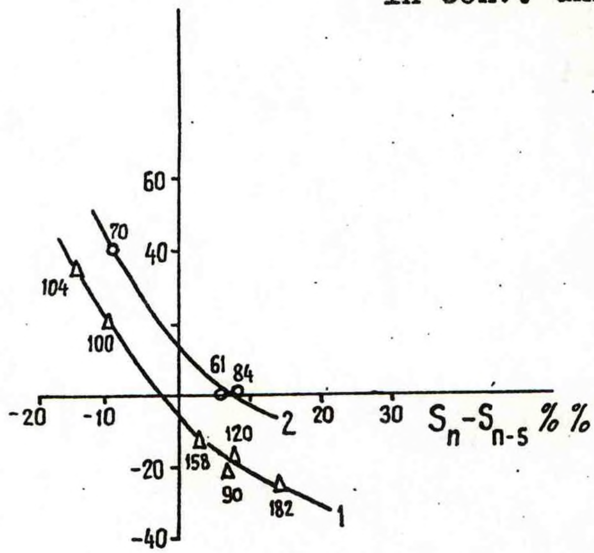

Fig. 5 The deviation of the total pollock recruitment abundance from the total parental stock (5 year old fish) level in dependence on the difference in icing.

1 - the curve of dependence at abundance of the parental stock over 90 conv.units,

2 - the curve of dependence at abundance of the parental stock under 90 conv.units.

APPENDIX 5

Paper from Panel E

A new approach to stock assessment by means of trawl surveys: The method of spline approximation of stock density for the result analysis and design of trawl surveys

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The trawl surveys are very costly and any improvements of their efficiency are urgently needed. At present majority of countries dealing with stock assessment use the method of stratified trawl surveys. The method has been adopted as a standard one in the North East and North West Atlantic in the zones of activity of the International Council for the Exploration of the Sea (I.C.E.S.) and the North Atlantic Fisheries Organization (N.A.F.O.). In the North Pacific the method has not been widely used yet and swept area method with evenly distributed stations is more conventional.

The following fundamental features are specific for the method of stratified trawl surveys:

(1) The method is based on a step-wise model of the distribution of the species studied.

(2) The method relies on a priori delimitated (i.e. made before the current survey) fixed borders of strata while the environment is variable. The delimitation of these strata is rather questionable.

(3) The method relies strictly on randomised locations of trawl stations within each strata. It prevents to adjust the survey design (i.e. positions of trawl stations) to current peculiarities of stock distribution.

The swept area method is similar to the method of stratified surveys. But the swept area method is based on posterior drawing of borders (lines of equal catches). Therefore the method does not take into account information of previous surveys for survey designing.

The method of stratified survey was criticised and new method, method of spline approximation of stock density or, shortly, method of spline approximation, was offered to substitude the first one (Stolyarenko, 1986, 1987; Stolyarenko, Ivanov,1987,1988a). The paper is aimed to attract attention of fishery biologists involved in stock assessments in the Pacific region to the new advanced method. Seemingly, in the Pacific where the fishery biologists do not use the method of stratified surveys widely the spline approximation method will be adopted easier than in the Atlantic.

The most characteristic features of the spline approximation methodology are as follows:

-The stock is computed by means of spline smooth model. In other words, the stock is assessed as a volume (=integral) under "density surface" in which "mountains" and "hills" are images with high and moderate catches while "depressions" are images with low catches. Thus in contrast to method of stratified trawl survey and swept area method which are based on step-wise model the spline approximatiom method exploits a model of smooth stock distribution which is obviously more natural.

-The method uses a depth as a predicting factor in stock assessment and in mapping of stock density. It deals not with catches as itself but with the "catch" function of "latitude-longitude-depth". In each point the relationship between the location (latitude and longitude), depth and stock density (or catch) is computed and the relationship is used for reconstruction of stock density. So the method provides the opportunity for computer mapping of the distribution of stock density. The integral (value of stock) is computed at the same time with mapping.

-The method is optimal for the estimation both stock and stock density (Stolyarenko, 1987).

- The method is based on microcomputer usage, preferable on the ship microcomputer which provides opportunity of adaptive design.

-The method offered includes survey design b e f o r e and d u r i n g survey (frame and adaptive designs).

The frame design means a wise distribution of trawl stations to be made in the survey taking into account the results of preceding surveys. So the frame design can be performed before the current survey. General number of the stations is determined by a real situation and conventional practice (by duration of the survey, area to be investigated etc.). In the North Pacific regular evenly distribution of trawl stations is a widely used practice (e.g. in the Soviet-American surveys of pollock stock in the Bering Sea). The method of stratified trawl survey widely used in the North Atlantic is based on strictly random distribution of trawl stations within each strata. Thus we are led to spend costly ship time both for exploration of promising areas and for not very promising ones with the same research efforts. But it is too expendable. The method of spline approximation leads to concentrate research efforts in the areas which are the most important for stock assessment.

These areas are places with high stock density (catches) and places with highly uncertain catches. The areas are of the most survey importance. The survey importance function (SIF) at the point P can be expressed (Stolyarenko, 1987) as

$$SIF(P) = \sqrt{u^2(P) + w^2(P)}, \qquad (1)$$

where u(P) is annual average stock density (or catches), $w^2(P)$ is a stock density variance. At least two preceding survey data are necessary for the variance estimation.

The SIF can be easily mapped by a microcomputer if the data of all preceding surveys were input into its memory. The method offered distributes trawl stations over the area investigated randomly with probability which is proportional to the SIF distribution. The randomization allows to avoid a systematic error in the station distribution and exploitation of the SIF provides opportunity to use the experience of preceding surveys. It is worthy to note that the method does not require of subdivision of the area investigated into strata (their borders are always are questionable) and, hence, spline stock assessments are not dependant on any schema of the subdivisions.

We recommend to use 70% of trawl stations for the frame design and 30% for the adaptive design (Stolyarenko, Ivanov, 1987).

-The adaptive design is the second important feature of the method offered. The design allows to use the results (data on catches) of the current tows to improve the positions of the next trawl stations and therefore to increase accuracy of stock assessment. The design is based on the distributional maps displayed by the ship microcomputer after each tow when the catch is weighed and the catch data is input in the computer memory. The expert (e.g. a chief of the expedition) has an opportunity to choose points for the next tows if he wishes to check the computer map or if he is not satisfied by randomly distributed station locations. So the method gives opportunity to improve positions of stations taking into account the results of the current survey and to use the experience of fishery biologists.

-The spline approximation method was successfully tested in the shrimp surveys (Pandalus borealis) off Spitsbergen in 1986 and 1987 (Stolyarenko, Ivanov, 1987; Ivanov et al., 1988a,b). The comparison of accuracy of stock assessments received by the spline approximation method and by method of stratified trawl surveys showed that the first method was ca. 30% more accurate. The comparison was made using technique "delete one" (Stolyarenko, Ivanov, 1987). The accuracy increase was achieved without using survey design offered because the results compared were received in the stratified survey. If frame and adaptive designs are used the accuracy increase would be even more remarkable.

-The method offered was developed in the Laboratory of Commercial Invertebrates and Algae of V.N.I.R.O. and was intended to be used for slowly movable or non-motile species (crabs, shrimps, scallops, echinoderms etc.). Besides P. borealis off Spitsbergen, the method has been already used for stock assessment of king crab off West Kamchatka (Stolyarenko, Myasoedov, 1988), scallop off Bear Island (Stolyarenko et al., 1988), red alga Furcellaria in the eastern Baltic Sea (Stolyarenko, Badulin, 1988).

But the spline approximation method was used also for fishes (redfish, cod) if their swimming activity was only moderate and they have no schooling behavior (Stolyarenko et al., 1988). Taking into account that the motility of Alaska pollock is also disregarded during conventional trawl surveys the fish stock seems to be suitable for assessment by the spline approximatiom method.

-The method is applicable not only for trawl surveys. The grab, drag surveys, underwater photography, TV observations, if their results (stock density values) referred to points, can be treated by means of spline approximation method (Stolyarenko, Ivanov, 1987). Moreover, the method was developed for continious observations, e.g. echo sounding records (Stolyarenko, 1988).

-The method offered can be used also for multi-species surveys. The applicability of the method for the multi-species surveys is discussed by Stolyarenko and Ivanov (1988b). The most important modification was made for frame design. The equation (1) in this case will become as

$$SIF(P) = \sqrt{\sum_{i=1}^{n} v_i \,[u_i^2(P) + w_i^2(P)]}, \qquad (2)$$

where v_i is a price (value) of the i-th species (roubles or dollars per kg, ton etc.), n is number of species.

Otherwise, we offer to consider that money are harvested during the survey and the research efforts should be concentrated in areas in which the SIF is determined by total price of all species studied, not their weights in catches.

-The Spline Survey Designer Software System (SSDSS) was developed to realize the method offered (Stolyarenko, 1987, 1988). using personal computer IBM PC/XT/AT and PS/2 (or compatible). The SSDSS is available from V.N.I.R.O., Moscow.

Noteworthy, the method can be used for computation of results received by conventional surveys. Particularly, the surveys with evenly distributed trawl stations can be easily treated by SSDSS. So the survey design (both frame and adaptive) is not necessary part of the method though we consider that the survey design is a fundamental advantage of the spline approximation method.

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