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Spawning of Twelve Groundfish Species in the Alaska and Pacific Coast Regions, 1975-81

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One of the important reasons for attempting to define the timing and locations of fish spawning more precisely is the significance of reproduction in the seasonal cycle of population activities and migration. Although few details of the seasonal movements and activities of continental shelf fishes are well-known, a useful model that is often employed to describe the relationships of processes within the general seasonal cycle is the migratory circuit model of Harden Jones (1968), further elaborated by Northcote (1978) and described in the report.

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SPAWNING OF TWELVE GROUNDFISH SPECIES IN THE ALASKA AND PACIFIC COAST REGIONS, 1975-81

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ABSTRACT

This report presents data and analysis regarding the spawning of 12 groundfish species in the eastern Bering Sea, Gulf of Alaska, and off Washington, Oregon, and California, based upon gonad maturity stage data collected during fisheries research surveys. Included are maps showing the geographic locations where fish in spawning condition have been observed, and the distribution of these observations with respect to time, depth, and bottom water temperature.

The observations of reproductive condition had been recorded over 7 yrs of fisheries surveys conducted by the Northwest and Alaska Fisheries Center, 1975-81, and were available for all cruises and species in a computer-based information system. These data were retrieved from the data base, linked with the corresponding station data, then mapped and summarized. The total volume of maturity data included in the system for the 12 species of groundfish studied was 63,004 data records, including 9,717 observations of spawning fish.

Species included in the study were walleye pollock, *Theragra chalcogramma*; yellowfin sole, *Limanda aspera*; flathead sole, *Hippoglossoides elassodon*; sablefish, *Anoplopoma fimbria*; Pacific cod, *Gadus macrocephalus*; rex sole, *Glyptocephalus zachirus*; Atka mackerel, *Pleurogrammus monopterygius*; arrowtooth flounder, *Atheresthes stomias*; rock sole, *Lepidopsetta bilineata*; Dover sole, *Microstomus pacificus*; butter sole, *Isopsetta isolepis*; and Pacific whiting, *Merluccius productus*. However, the amount of information available for each species varied considerably.

Also included are a comparison of results between regions and species, a discussion of some of the limitations of the data and methods, and a list of suggestions for future work.

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INTRODUCTION

One of the important reasons for attempting to define the timing and locations of fish spawning more precisely is the significance of reproduction in the seasonal cycle of population activities and migration. Although few details of the seasonal movements and activities of continental shelf fishes are well-known, a useful model that is often employed to describe the relationships of processes within the general seasonal cycle is the migratory circuit model of Harden Jones (1968), further elaborated by Northcote (1978) as shown in Figure1.

Although Northcote's model was developed in the context of discussing migratory strategies in freshwater fishes, it also seems appropriate for many marine, continental shelf fish species in temperate and arctic regions. In the model, major events in the seasonal cycle are spawning, feeding, and overwintering. To conduct these activities, fish appear regularly at certain locations by migrating to and from the different activity areas.

Driven by endogenous rhythms and environmental cues such as photoperiod and temperature (Liley 1980), fish move to relatively fixed spawning areas.' Factors influencing the timing and location of spawning presumably include some, or all, of the following: the favorable dispersal and colonization of spawners, increased spawning success, decreased predation of spawners and their offspring, and increased survival of eggs, larvae, and adults (Emlen 1973).

Following spawning, feeding becomes important and there is a movement to habitats where food is readily available. These dispersal movements are likely to result in decreased competition for food (and perhaps decreased predation due to reduced densities); increased growth and size; improved body condition (i.e., condition factor) and survival; and increased fecundity.

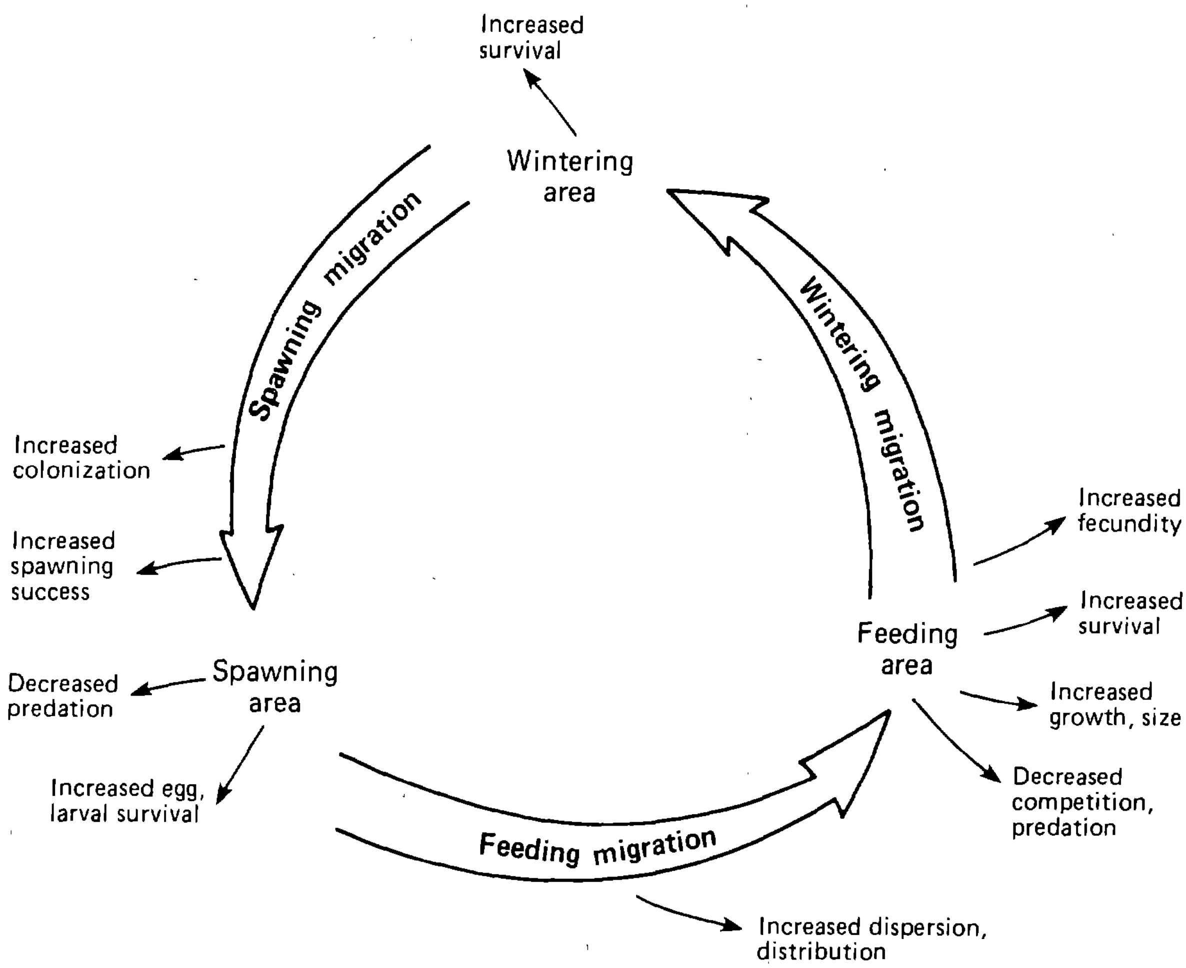

Figure 1.--The seasonal cycle of population activities and migration, including probable selective factors (adapted from Northcote 1978).

During winter months there is a movement away from unfavorable habitats to more desirable winter refuge areas. In northern waters, unfavorable conditions might be caused by ice cover, cold lethal temperatures, extreme turbulence, suspended sediments, and low food availability.

Because of their biological significance, the timing and location of spawning aggregations are also of fundamental interest to commercial fishing and fisheries management and research, in the following situations:

1. In commercial fishing, for planning fishing tactics, since fish are usually easiest to catch when they are aggregated for spawning and roe products are often highly valued;
2. In fisheries management, for conserving depleted stocks by protecting their time and place of spawning from overfishing;
3. In habitat protection aspects of fisheries management, since spawning and nursery areas are generally considered to be sensitive and important areas to protect from pollution, degradation, and human alteration;
4. In fisheries research, for planning surveys (e.g., egg and larval surveys, hydroacoustic surveys), to estimate stock abundance, and to improve the efficiency of the sampling effort through focusing; and
5. To improve our understanding of stock recruitment processes, production and receiving areas, reproductive cycles, and annual migration patterns.

At the present time, however, much of our understanding of the reproductive ecology of commercially-important North Pacific and Bering Sea groundfish is limited to generalities or, in the case of a few species, detailed studies made at single (often foreign) locations. Although we have descriptions of the general modes of reproduction of the major species (Breder and Rosen 1966) and their general breeding sites (e.g., offshore, sometimes in deep water), egg characteristics, and parental care, there is still need for many more specific studies in the particular geographic regions of interest.

Traditional sources of information used for defining the timing and location of spawning activities are in situ observations, the commercial fisheries, plankton surveys, and fisheries research surveys. Observations made in situ, such as those obtained during the diving studies described by Rosenthal (1980), can provide valuable information and insights into the reproductive behavior of many nearshore fishes; but the method is usually limited to relatively shallow depths. Other basic sources of information are observations from the commercial fisheries, obtained through interviews with fishermen and analyses of seasonal variations in the target areas, catch per unit of effort (CPUE), and catch composition; yet few of these results are recorded in the published literature.

Ichthyoplankton surveys have long been one of the principal sampling approaches used to determine spawning areas and times (Smith and Richardson 1977). Typical objectives of applications of this method are to locate spawning concentrations of important stocks, determine the geographic and vertical boundaries of spawning, and to determine the distribution of the spawning production over time. Limitations of the approach, however, often include formidable sampling problems, biasing due to transport of eggs and larvae away from the actual spawning grounds by ocean currents, and the difficult identification of newly-spawned pelagic fish eggs. An additional restriction, with surveys in the northeastern Pacific Ocean and eastern Bering Sea, is that a disproportionate number of fish species have demersal eggs (Kendall 1981).

Despite difficulties, ichthyoplankton surveys have provided some of the best, and most specific, information on the spawning times and locations of the major fish resources in many regions. Recent studies in the Alaska area include those of Dunn and Naplin (1974); Waldron and Vinter (1978); Dunn et al. (1979); Kendall, Dunn, Rogers, Matarese, and Garrison (1980); Kendall, Dunn, Wolotira, Bowerman, Dey, Matarese, and Munk (1980); Nishiyama and Haryu (1981); and others summarized-by Waldron (1981). Studies off the Pacific Coast have included the numerous research projects conducted as part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program (e.g., Ahlstrom 1969; Ahlstrom and Moser 1975; Ahlstrom et al. 1978) and by others off Oregon and Washington (e.g., Pearcy et al. 1977; Kendall and Clark 1982).

Fisheries research surveys conducted by the National Marine Fisheries Service (NMFS) and its predecessor agencies during the past 30 years have also collected information useful for describing some aspects of reproductive ecology. At the Northwest and Alaska Fisheries Center (NWAFC), groundfish trawl survey data are available from more than 200 cruises conducted in the Pacific Northwest and Alaska regions. One type of data collected since 1975 has been thousands of observations of the reproductive condition of fish recorded as gonad maturity stages (Holden and Raitt 1974:127-129). This data has received little analysis, perhaps because of its incidental nature within any single set of cruise results.

This report evaluates maturity stage data in the NWAFC survey data base and presents data on spawning characteristics of 12 groundfish species in the Alaska and Pacific Coast regions. Characteristics that are described include the geographic locations where fish in spawning condition have been observed, and the distribution of these observations with respect to time, bottom depth, and bottom water temperatures.

Fourteen Sebastes species from the Gulf of Alaska, and seven from the Pacific Coast, were not included in the analyses because of their generally complex ovoviviparous or viviparous reproductive patterns typically involving a number of important events well-separated in time (Breder and Rosen 1966). In ovoviviparous species such as Pacific ocean perch, Sebastes alutus, mating involves pairing with internal fertilization. The eggs are incubated within the ovary for several months, then at some later date the mature larvae are released at appropriate spawning grounds (Major and Shippen 1970). Because of this complex biology, successful applications of maturity stage methods to the different Sebastes species require extra careful work. In addition, two salmon species were omitted from the study because of their anadromous reproductive habit.

METHODS

Survey Coverage and Data Origination

The data used for this study were obtained from fisheries research surveys conducted in the Pacific Coast and Alaska regions, primarily by personnel of the NWAFC's Resource Assessment and Conservation Engineering (RACE) Division. The majority of this information was collected during bottom trawl surveys of-continental shelf groundfish, although some came from pelagic fish surveys using midwater trawl gear and deepwater surveys using fish traps. The geographic coverage available from all surveys and all years of observations was quite extensive.

The geographic distribution of the sampling effort has ranged from off San Diego, California (lat. 32°36'N), to the northern Bering Sea (lat. 60°00'N). In the Bering Sea the principal coverage, since 1971, has come from annual bottom trawl surveys of the eastern continental shelf, and occasional hydroacoustic surveys of pelagic fish stocks over the eastern continental shelf and central Aleutian Basin. Over the years, most of this fieldwork has been conducted from May to August, but some data were available from all months except December.

Although the total level of sampling effort in the Gulf of Alaska has been much the same as in the Bering Sea, there have been about 50% more cruises because the average size of individual surveys has been smaller. Most of this survey work has been conducted from June to September, but data were available from all months of the year and there was considerable coverage from February to May. Observations of reproductive condition, specifically spawning stage data, were available from locations along the continental shelf from the Semidi Islands (long. 156°47'W) eastward to Dixon Entrance (long. 133°00'W).

Coverage of-the Pacific Coast continental shelf from San Diego, California, to Cape Flattery, Washington (lat. 48°23'N), was available from several large-scale bottom and midwater trawl surveys, and occasional deepwater surveys made using fish traps. Most of the fieldwork was conducted from July through September, although data were available from eight months of the year.

The data collection procedures used in these fish population surveys have been increasingly standardized (see Smith and Bakkala 1982:2-8 for specific examples). At each sampling station a trawl net is towed, or a fish trap is set, for a regular duration. Fish and invertebrates recovered in the sample are sorted by taxa, identified to the lowest reliable taxonomic level, then weighed and counted. Subsamples of the species of interest are sorted by sex, then the lengths within each sex group are recorded as length-frequency data. Other types of biological data are then collected according to interests and opportunities, and recorded as specimen data. These include length-age samples, length-weight measurements, and length-maturity observations.

At the end of each cruise leg, all standard data (including specimen information) are edited and filed with the results from all previous fisheries surveys of the region (Mintel and Smith 1981) in a computer data-base system at the NWAFC.

Coding of Reproductive Condition

Observations of sexual maturity and reproductive condition were collected at available opportunities following the procedures described by- Holden and Raitt (1974), and Hilge (1976). General and species-specific tables were established that defined stages of gonad conditions based on the external appearance and macroscopic examination of the ovaries or testes.

At sea, individual fish were then classified by one of five (or more) maturity code numbers. Characteristics that were used for the classification included gonad size, shape, color, texture, and degree of oogenesis and spermatogenesis. An example of a general five-point maturity table, applied to several different species during many different surveys, is shown in Table 1.

As discussed by Vladykov (1972), Holden and Raitt (1974), Hilge (1976), and Hempel (1979), the methods of coding gonad conditions into discrete stages based upon macroscopic inspection are artificial and arbitrary. However, the approach is useful because of its convenience, low cost, and suitability for application to large numbers of fish at the time of collection. The fundamental limitation is that the procedure attempts to categorize into discrete stages what is essentially continuous gonad development. In addition, there is often a failure to adequately distinguish between sexual maturation, i.e., the attainment of first maturity, and subsequent variations in gonadal development associated with the seasonal breeding cycle. The ambiguous distinctions between these different phases of reproductive development lead to subjectivity in most applications.

Fortunately, for the purposes of this study, observations of' fish that were judged to be in spawning condition were probably the least ambiguous classification of the various reproductive phases and coding schemes. Females were categorized as being in spawning condition (or running ripe) when the ovaries were fully distended and would extrude transparent ripe eggs under light abdominal pressure. Males were considered to be in spawning condition when the testes were white and fully distended, blood vessels associated with the.-testes were not noticeable, and sperm would run freely under light pressure.

Table 1.--General five-point maturity table used for oviparous, isochronal spawners (both sexes).1/

Code	Gonad condition	Description
1	Immature	Gonads small,' situated close to vertebral column; ovaries pink or translucent; testes translucent.
2	Developing	Gonads small to about one-half length of ventral cavity; transparent and/or opaque ova visible to naked eye; testes swelling.
3	Spawning	Ova and sperm run under slight pressure; most eggs translucent, with few opaque eggs left in ovary.
4	Spent	Ovaries and testes flaccid and empty; ovaries may contain remnants of disintegrating ova; testes bloodshot.
5	Inactive	Adults with gonads firm and shaped, but showing no development of ova or sperm.

1/ Source: ADP Codebook (Mintel and Smith 1981:16).

Data-base Retrievals and Analyses

The observations of fish in spawning condition, and all other maturity stage data, are available in the NWAFC's computer data-base system described by Mintel and Smith (1981). The data resources are organized into three geographical area data bases: Bering Sea and Aleutian Islands, Gulf of Alaska, and Pacific Coast. Each area data base has five primary file types that represent the basic survey data. Haul and specimen files were used for this study.

Haul file data describe the characteristics of each sampling site and the sampling gear. At the time of this study, the total volume of haul data available was approximately 21,000 records. Specimen file data contain the biological observations from each haul sample. There is usually one record per observation (i.e., individual fish) and multiple specimen records per haul. The total volume of specimen data available in the data base exceeded 225,000 records.

The basic methods used for analyses in this study were to retrieve observations of spawning individuals from each area data base, to associate these with the corresponding haul data, then to proceed with mapping and statistical summarizations. These basic steps are shown in Figure 2.

Specimen data records containing observations of fish in spawning condition were retrieved from the master specimen file, by species and sex. These files were then summarized yielding one specimen data record per haul. The corresponding haul records were retrieved from the master haul file to provide lists of stations at which fish in spawning condition had been observed. Values in the year, month, sampling depth, and bottom water temperature fields of the station data were inventoried, then a mapping program

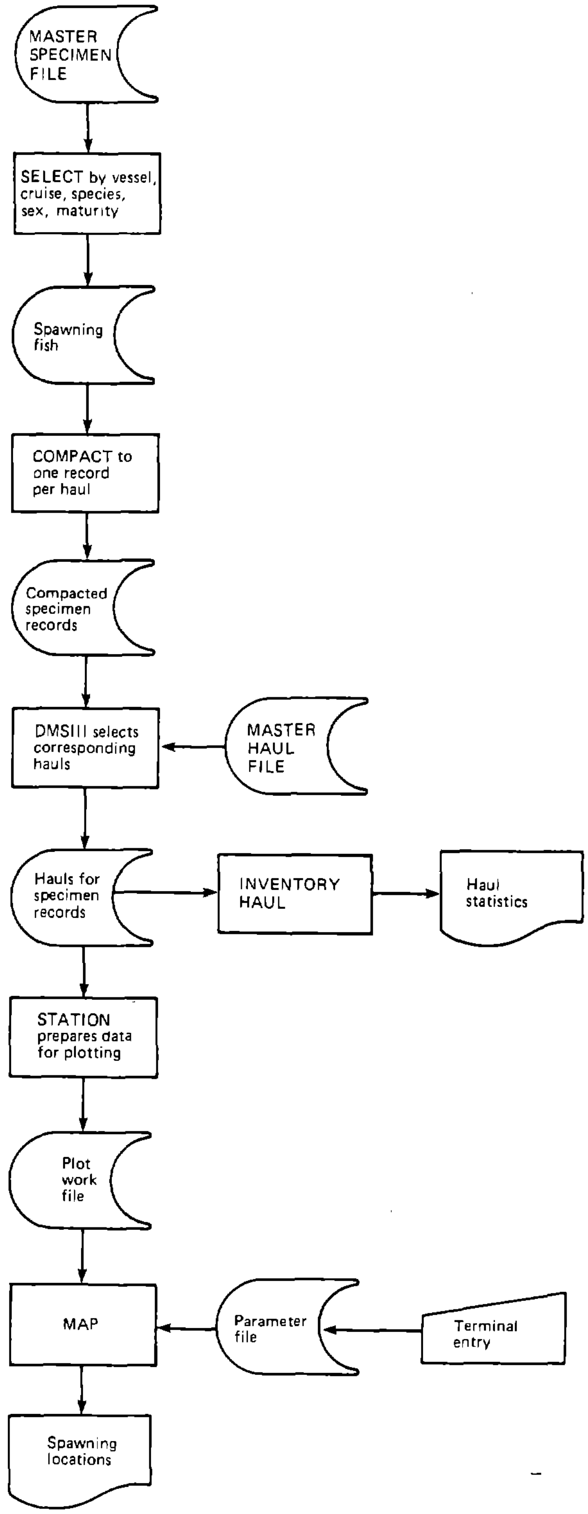

Figure 2. --Summary of the major steps for data-base retrievals and analyses. See Mintel and Smith (1981) for further descriptions of the computer programs and procedures.

was used to plot the geographic locations at which spawning individuals had occurred.

The methods used for information retrieval and interpretation followed the general procedures outlined above, but numerous exceptions required time and attention to resolve. In particular, these included clarifying differences among approximately l0-15 maturity code tables.

RESULTS

Bering Sea and Aleutian Islands

The Bering Sea and Aleutian Islands data base contained maturity stage data for 10 fish species, including 3 species that had been observed in spawning condition (Table 2). These species were walleye pollock, *Theragra chalcogramma*; yellowfin sole, *Limanda aspera*; and flathead sole, *Hippoglossoides elassodon*. The other seven species, for which a total of 1,886 maturity observations had been recorded with no retrievable spawning information, were rock sole, *Lepidopsetta bilineata*; Alaska plaice, *Pleuronectes quadrituberculatus*; Pacific cod, *Gadus macrocephalus*; saffron cod, *Eleginus gracilis*; longhead dab, *Limanda proboscidea*; Pacific herring, *Clupea harengus pallasi*; and eulachon, *Thaleichthys pacificus*. For these species, spawning conditions had either not been observed or recorded, and some species had poor coding documentation.

walleye Pollock

Maturity stages of 11,626 walleye pollock had been recorded over the years, from April to August. These included 1,519 observations of individuals in spawning condition. Spawning males were observed at 73 sampling locations and females at 82. The composite distribution of these 155 locations is shown in Figure 3.

Spawning walleye pollock were observed along the outer region of the eastern Bering Sea continental shelf from Unimak Pass to northwest of Zhemchug Canyon, 350 km northwest of St. Paul Island. Most of the stations (99%) had been occupied in 1976 and 96% were from April to May (Fig. 4). Bottom depths of the spawning locations ranged from 71 to 417 m, although 62% of the stations

Table 2.--Summary of maturity stage data available in the Bering Sea and Aleutian Islands data base that included observations of fish in spawning condition.

Species -	Number of maturity observations	Months	Number of spawning individuals	Stations with spawning males	Stations with spawning females
Walleye pollock	11,626	April-August	1,519	73	82
Yellowfin sole	1,312	June-July	126	0	2
Flathead sole	1,134	August-September	3	2	0
TOTAL	14,072		1,648	75	84

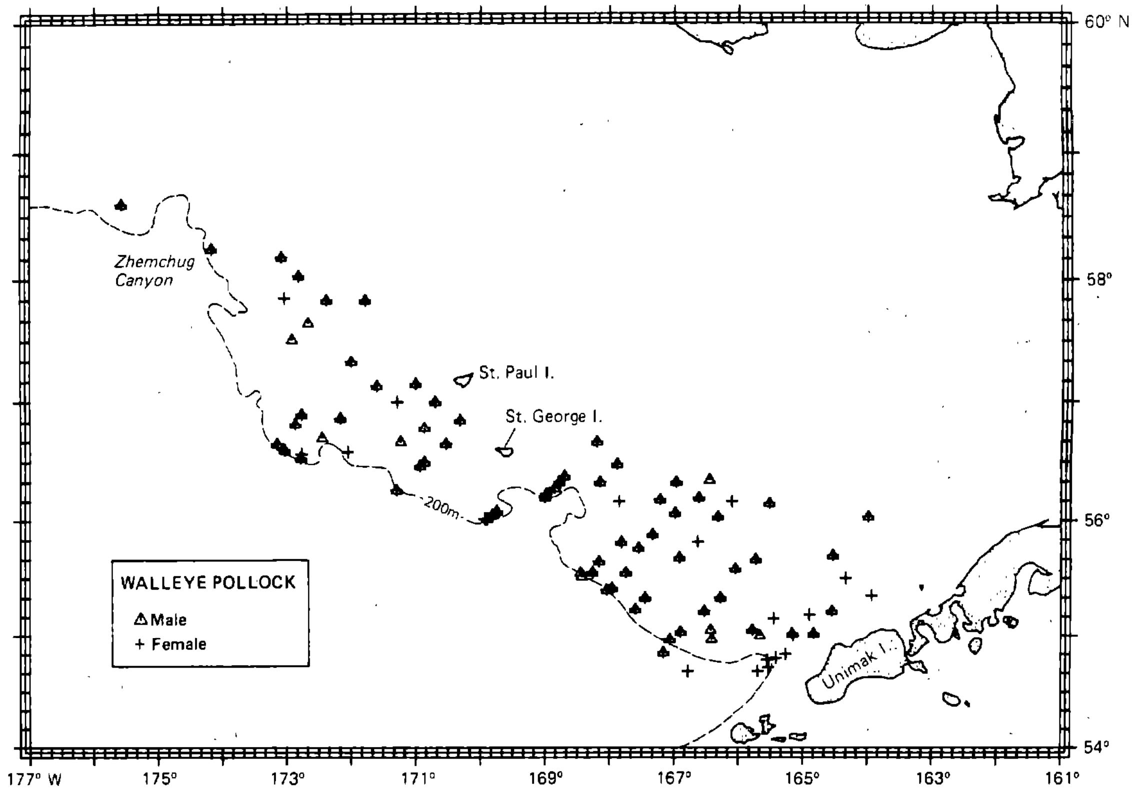

Figure 3. --Locations where walleye pollock in spawning condition have been observed in the eastern Bering Sea.

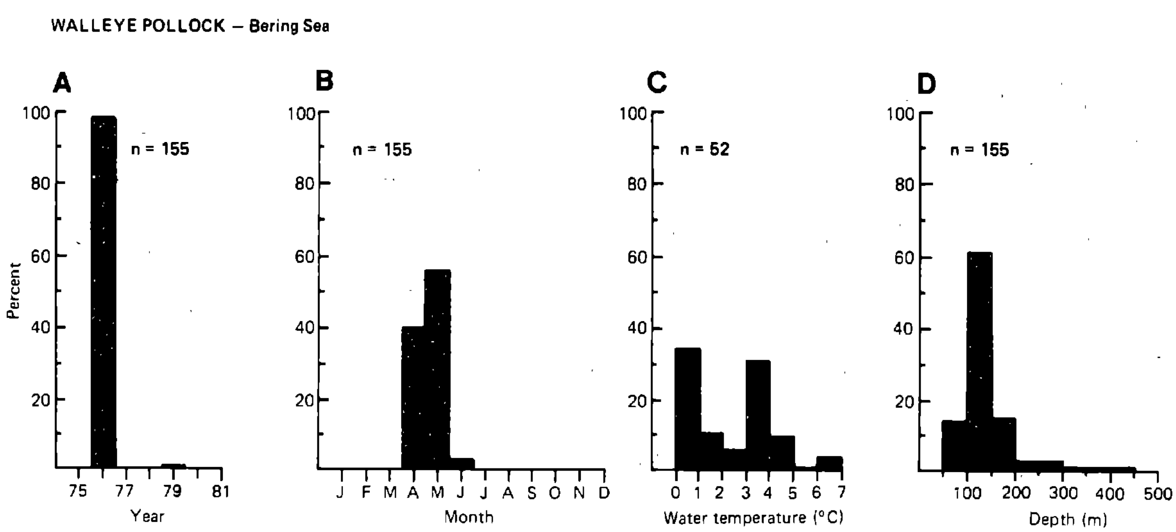

Figure 4. --Characteristics of the stations at which walleye pollock in spawning condition were observed in the eastern Bering Sea: A) distribution among years; B) months; C) bottom water temperature; and D) -sampling depth.

occurred within the interval l00-150 m. Temperatures of the bottom water at 52 stations, where profiles had been made using expendable bathythermograph (XBT) probes, ranged from 0.0° to +6.8°C, with a median of +2.6°C.

Pleuronectid Flatfish

Although maturity observations of 1,312 yellowfin sole were available, there were only 126 records of individuals in spawning condition from two stations sampled in July 1979. These were located at bottom depths of 550 m and 730 m, directly west of the Pribilof Islands (Fig. 5).

Only three flathead sole, from a total of 1,134 maturity observations, were observed in spawning condition at two stations in the outer continental shelf region (Fig. 5). These locations were both sampled in August 1975 at 106 m depth.

Gulf of Alaska

The Gulf of Alaska data base contained maturity data for 11 demersal and pelagic fish species. Excluding euchalon, all had retrievable spawning observations. These were walleye pollock; sablefish, *Anoplopoma fimbria*; Pacific cod; flathead sole; rex sole, *Glyptocephalus zachirus*; Atka mackerel, *Pleurogrammus monopterygius*; arrowtooth flounder, *Atheresthes stomias*; rock sole; Dover sole, *Microstomus pacificus*; and butter sole, *Isopsetta isolepis* (Table 3).

Walleye Pollock

Maturity condition observations of 20,192 walleye pollock had been made from January to August, including 3,805 records of fish in spawning condition. Spawning males were observed at 56 stations and females at 71. Figure 6 shows the composite distribution of these 127 locations.

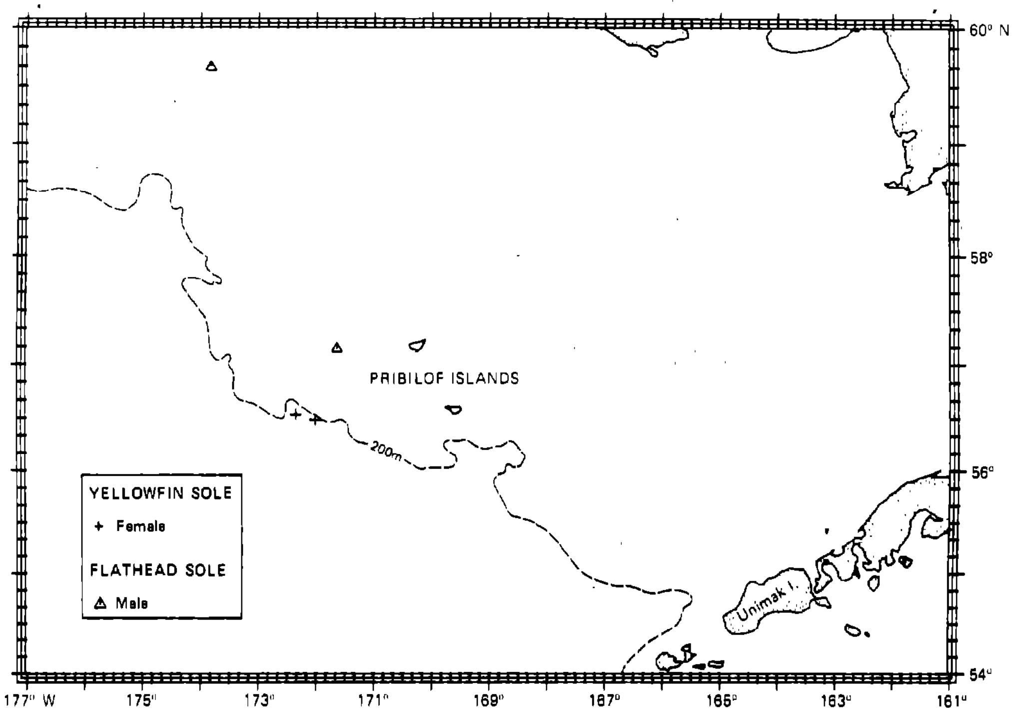

Figure 5.--Locations where yellowfin sole and flathead sole in spawning condition have been observed in the eastern Bering Sea.

Table 3.--Summary of maturity stage data available in the Gulf of Alaska data base that included observations of fish in spawning condition.

Species	Number of maturity observations	Months	Number of spawning individuals	Stations with spawning males	Stations with spawning females
Walleye pollock	20,192	January-August	3,805	56	71
Sablefish	6,556	January-August	204	43	21
Pacific cod	4,853	January-August	958	32	33
Flathead sole	2,588	January-August	879	25	27
Rex sole	1,966	January-August	481	6	18
Atka mackerel	1,631	February-August	49	1	3
Arrowtooth flounder	1,630	January-August	106	8	10
Rock sole	868	January-April	567	7	9
Dover sole	777	January-August	341	12	14
Butter sole	75	March-April	37	1	1
TOTAL	41,136		7,427	191	207

Spawning walleye pollock were observed at numerous locations in the Shelikof Strait and Kodiak Island region, and along the edge of the outer continental shelf from Chirikof Island to the northeastern Gulf of Alaska. In Shelikof Strait, the spawning locations followed the narrow contours of the bottom trough, with sites extending southwest to the edge of the outer continental shelf.

Depths of the 127 locations ranged from 55 to 459 m, although 82% occurred within the interval 150-300 m (Fig. 7). Characteristics of the data with respect to time were that most originated from 1980, and the distribution of the stations among months was February, 11%; March, 30%; April, 37%; May, 18%; and June-August, 4%. Bottom water temperatures at 62 locations with XBT data ranged from +l.l° to +7.2°C, with a median of +4.9°C.

Sablefish

Maturity condition observations of 6,556 sablefish were available, including 204 records of sablefish in gravid condition. Gravid condition, for males, was when the testes appeared milky white, soft, and flaccid. Females were considered to be gravid when translucent eggs were loose in the body cavity or could be extruded from the oviduct under light pressure. Gravid males were observed at 43 locations and gravid females at 21. These 64 locations are shown in Figure 8.

Gravid sablefish were observed southwest of Kodiak Island in the Shumagin Islands area and at clusters of stations off southeast Alaska. These latter positions were near Fairweather Ground, directly west of Cape Ommaney, and west of Prince of Wales Island.

The distribution of these observations among years was 1978, 41%; 1979, 30%; 1980, 20%; and 1981, 9% (Fig. 9). The distribution among months

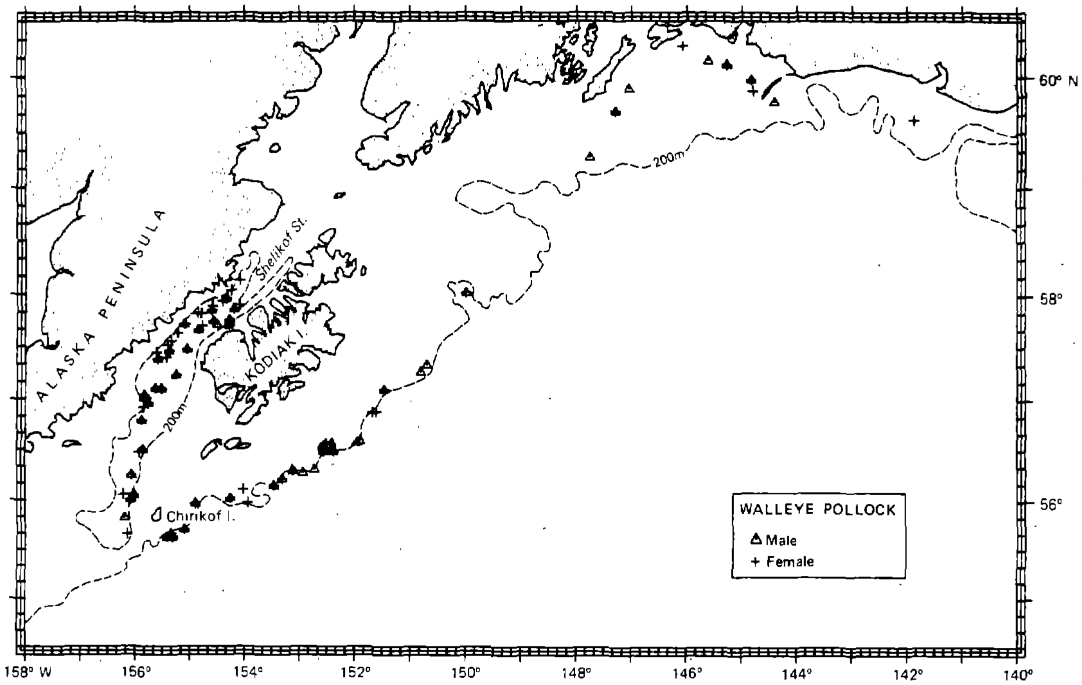

Figure 6. --Locations where walleye pollock in spawning condition have been observed in the Gulf of Alaska.

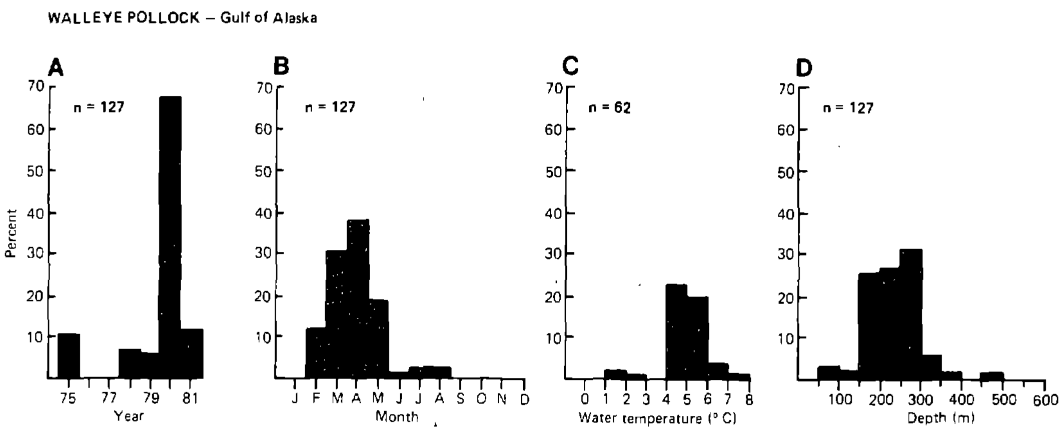

Figure 7. --Characteristics of the stations at which walleye pollock in spawning condition were observed in the Gulf of Alaska: A) distribution among years; B) months; C) bottom water temperature; and D) sampling depth.

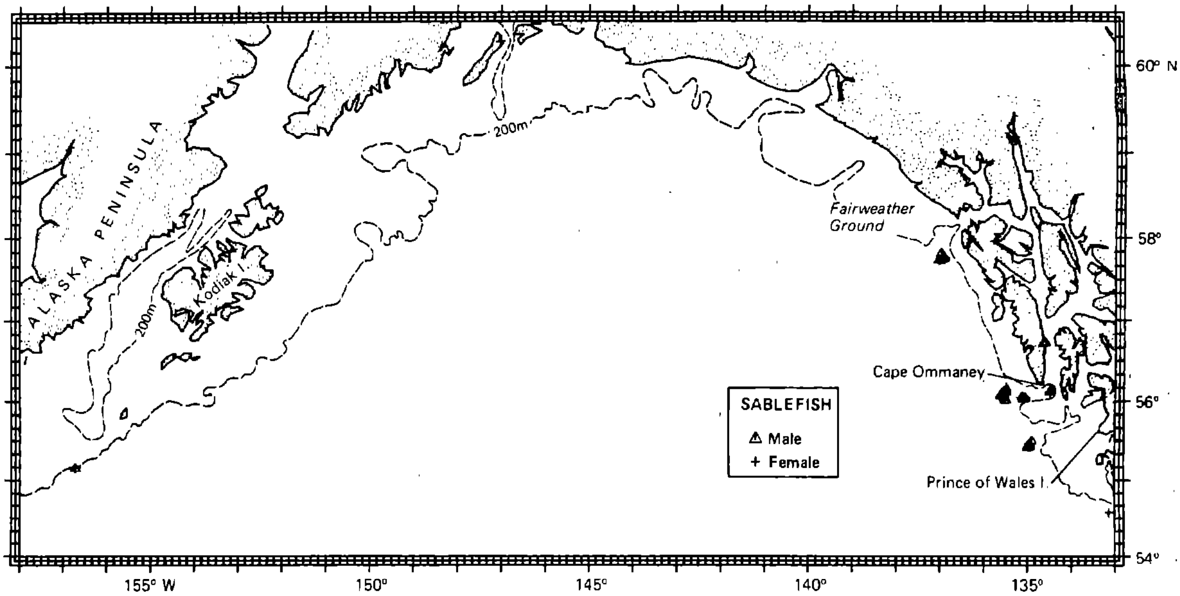

Figure 8. --Locations where sablefish in gravid condition have been observed in the Gulf of Alaska.

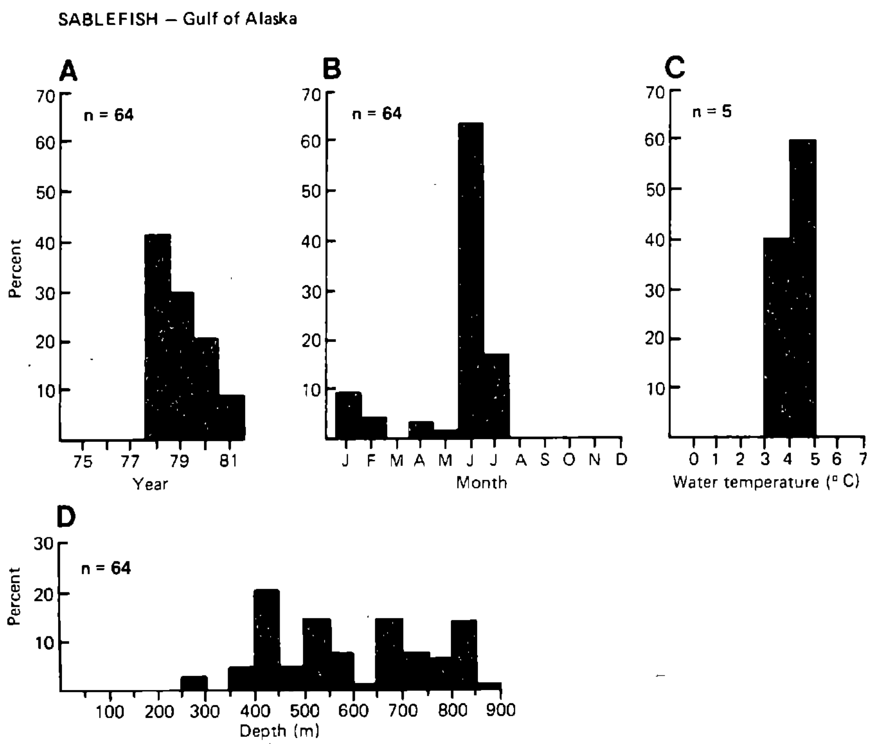

Figure 9. --Characteristics of the stations at which sablefish in gravid condition were observed in the Gulf of Alaska: A) distribution among years ; B) months; C) bottom water temperature.; and D) sampling depth.

was January, 9%; February, 5%; April, 3%; May, 2%; June, 64%; and July, 17%. The depth range from which gravid fish were taken was deep and extremely broad, 272 to 854 m, although most were taken within the interval 400 to 850 m. Bottom water temperatures at five stations with XBT data ranged from +3.7° to +4.2°C, with a median of +4.0°C.

Pacific Cod

Maturity observations had been made for a total of 4,853 Pacific cod, of which 958 were recorded in spawning condition. Spawning males were observed at 32 stations and females at 33. A composite map of these 65 locations is shown in Figure 10.

Spawning Pacific cod were observed at several sites in Shelikof Strait and along the edge of the outer continental shelf from Chirikof Island to Yakutat Bay. However, the greatest number of observations were located south of Kodiak Island in the Chirikof Island and outer Albatross Bank areas.

The distribution of observations among years was 1975, 11%; 1978, 11%; 1979, 14%; 1980, 46%; and 1981, 18% (Fig. 11). The distribution among months was February, 22%; March, 45%; April, 17%; May, 12%; and June-July, 4%. Sampling depths ranged from 73 to 265 m, but 70% of all sites occurred within the interval 150-250 m. Bottom water temperatures at 32 stations with XBT data ranged from +4.5° to +5.9°C, with a median of +5.4°C.

Flathead Sole

Observations of maturity stage had been made of 2,588 flathead sole from January to August, including 879 fish in spawning condition. Spawning males were recorded at 25 locations and females at 27. The composite distribution of these 52 sites is shown in Figure 12.

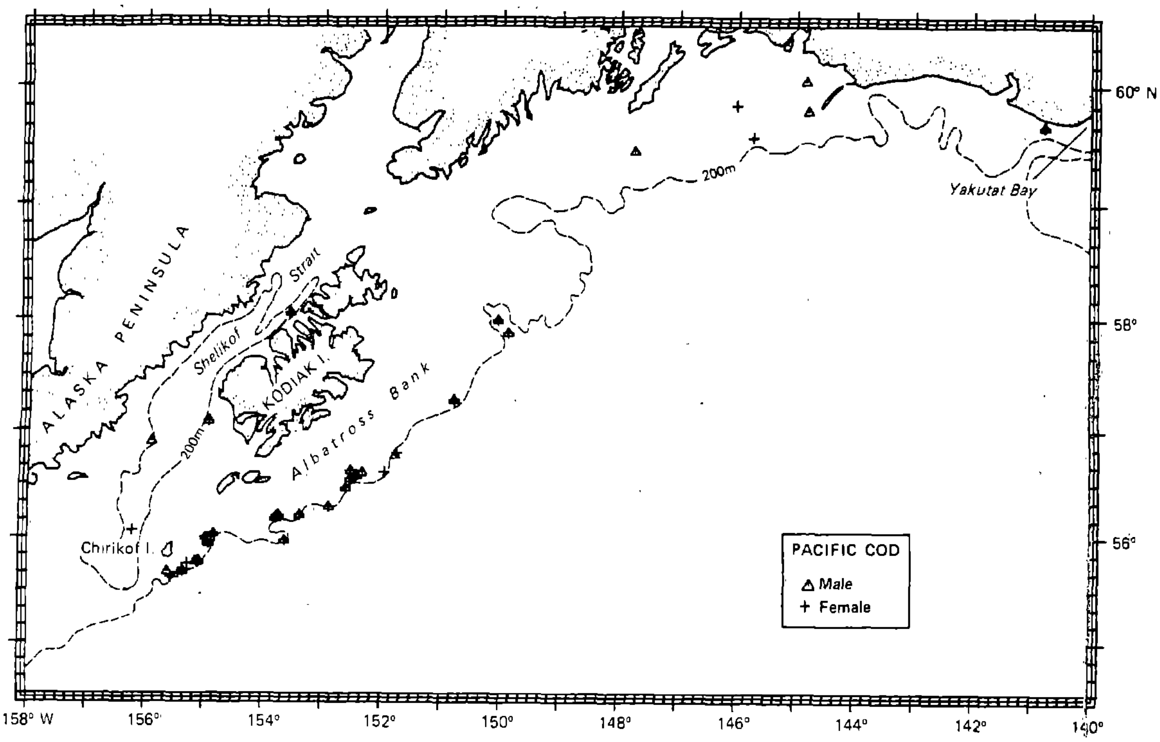

Figure 10.--Locations where Pacific cod in spawning condition have been observed in the Gulf of Alaska.

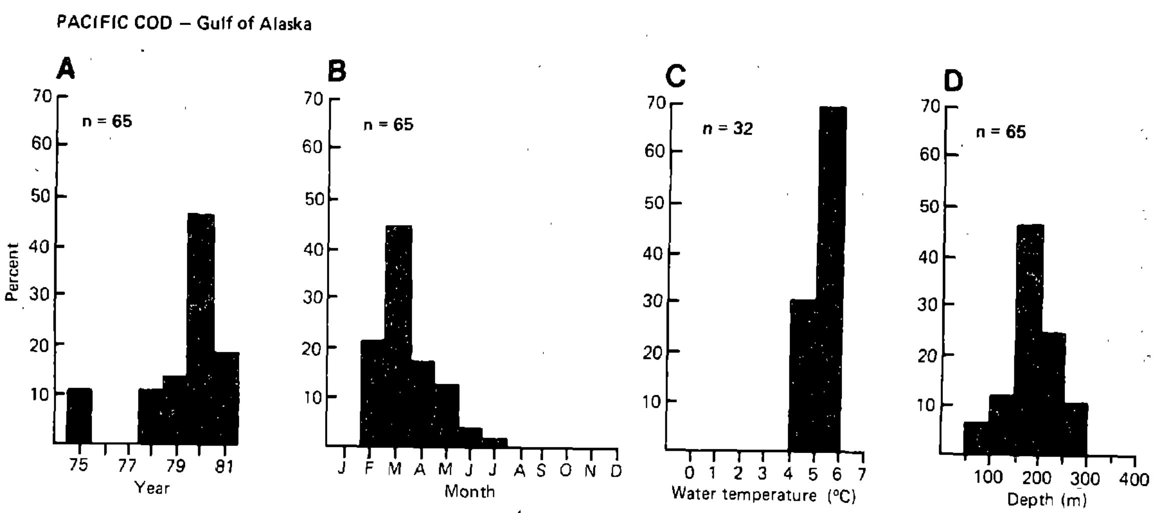

Figure 11.--Characteristics of the stations at which Pacific cod in spawning condition were observed in the Gulf of Alaska: A) distribution among years; B) months; C) bottom water temperature; and D) sampling depth.

Spawning flathead sole were observed in Shelikof Strait, the Chirikof Island area, and at scattered locations along the edge of the outer continental shelf from Albatross Bank to Yakutat Valley. The depth range of the 52 locations was 108-304 m, although a majority (60%) occurred within the interval 108-200 m (Fig. 13).

The distribution of observations among years was 1975, 35%; 1978, 17%; 1979, 10%; 1980, 23%; and 1981, 15%. The distribution among months was February, 8%; March, 19%; April, 31%; May, 25%; June, 4%; July, 9%; and August, 4%. Bottom water temperatures at 18 stations with XBT data ranged from +3.6° to +5.7°C, with a median of +5.0°C.

Rex Sole

Maturity data were available from 1,966 rex sole for the period January to August, including 481 individuals in spawning condition. Spawning males occurred at 6 locations and females at 18, shown in Figure 14.

Spawning rex sole occurred in deep water along the edge of the outer continental shelf from Chirikof Island to Yakutat Bay. The 24 locations at which fish in spawning condition-were observed ranged in depth from 108 to 307 m, but a majority (62%) were within the interval 200-300 m (Fig. 15).

The distribution of observations among years was 1975, 46%; 1978, 8%; 1979, 13%; 1980, 8%; and 1981, 25%. The distribution of observations among months was February, 8%; March, 13%; April, 21%; May, 46%; June, 4%; and July, 8%. Temperatures of the bottom water at five stations with XBT data ranged from +5.0° to +5.9°C, with a median of +5.6°C.

Arrowtooth Flounder

Maturity observations of 1,630 arrowtooth flounder were collected, including 106 records of fish in spawning condition. Spawning males were encountered at 8 locations and females at 10, shown in Figure 16.

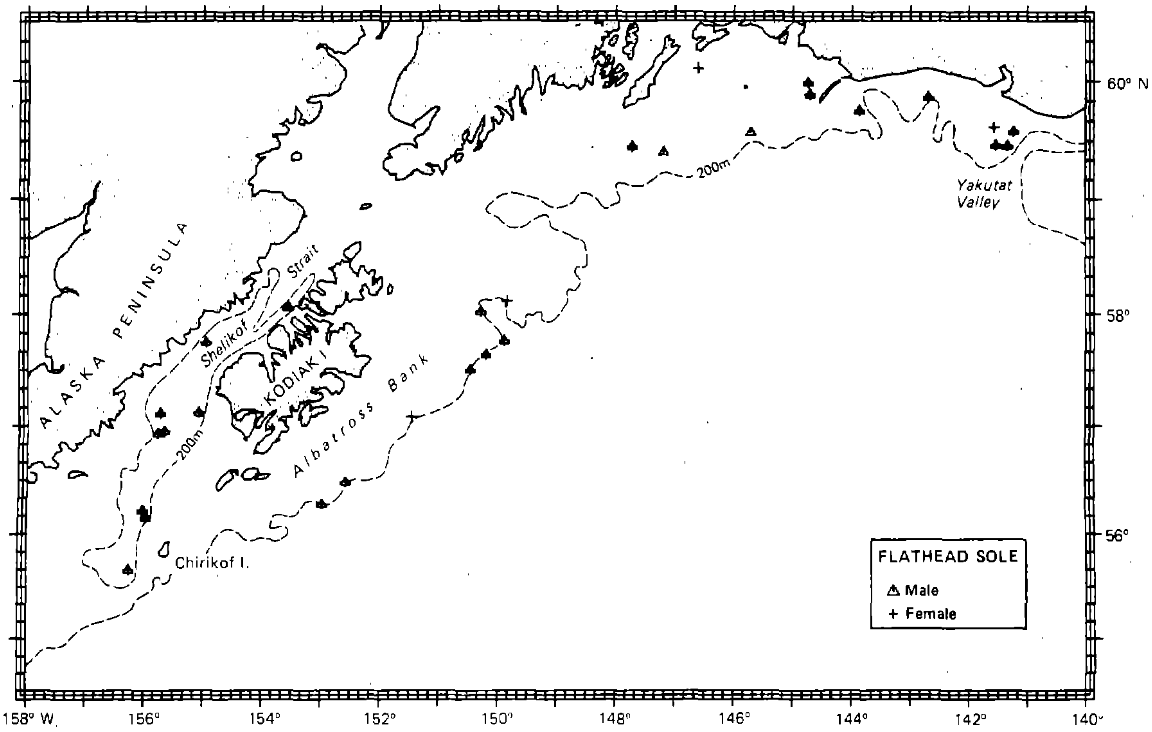

Figure 12.-.-Locations where flathead sole in spawning condition have been observed in the Gulf of Alaska.

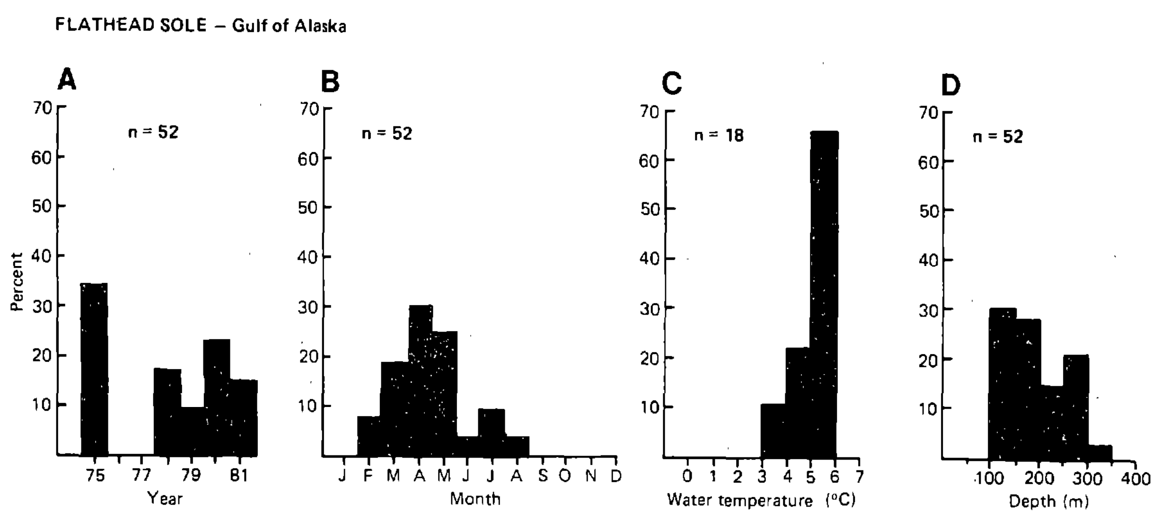

Figure 13. --Characteristics of the stations at which flathead sole in spawning condition were observed in the Gulf of Alaska: A) distribution among years; B) months; C) bottom water temperature; and D) sampling depth.

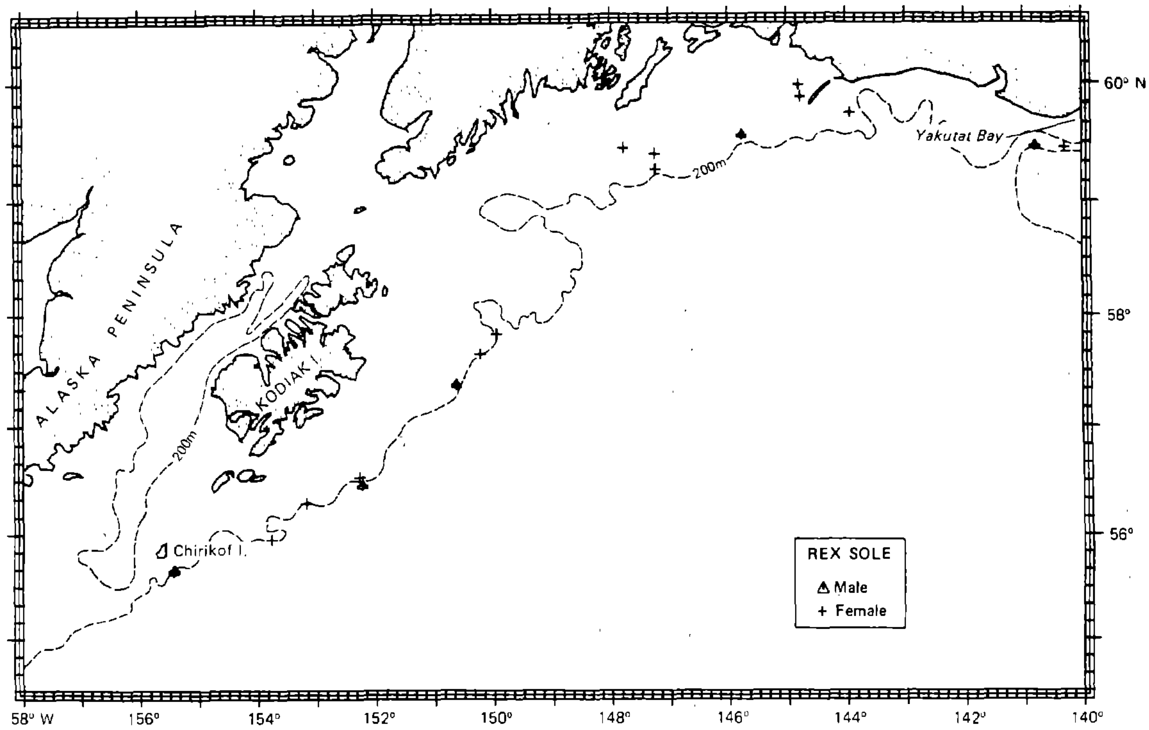

Figure 14. --Locations where rex sole in spawning condition have been observed in the Gulf of Alaska.

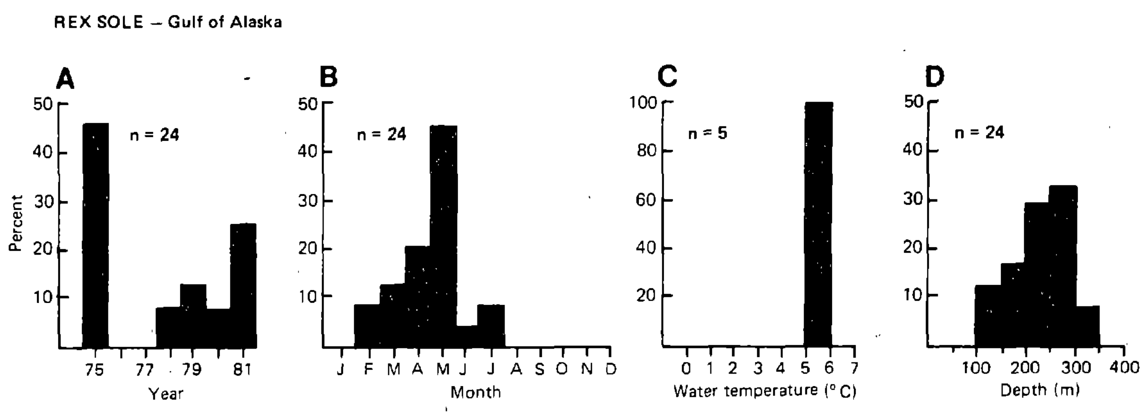

Figure 15. --Characteristics of the stations at which rex sole in spawning condition were observed in the Gulf of Alaska: A) distribution among years; B) months; C) bottom water temperature; D) sampling depth.

Spawning arrowtooth flounder were observed at scattered points along the outer continental shelf east of Kodiak Island to Yakutat Bay. The greatest number of sightings were located in the northeastern Gulf of Alaska off Prince William Sound, off Cape St. Elias, and particularly off Icy Bay.

The distribution of the 18 observations among years was 1975, 16; 1979, 1; and 1981, 1 (Fig. 17). The distribution among months was March, 1; May, 4; June, 7; July, 5; and August, 1. Bottom depths ranged from 108 to 360 m, although 12 of the 18 stations occurred within the interval 108-200 m. Bottom water temperatures at four locations with XBT data ranged from +3.7° to +6.8°C, with a median of +5.4°C.

Dover Sole

Maturity observations had been made on 777 Dover sole, including 341 fish in spawning condition. Spawning males were recorded at 12 stations and females at 14, shown in Figure 18.

Spawning Dover sole were observed at scattered locations along the outer continental shelf off the Shumagin Islands, off Chirikof Island, along Albatross Bank, and off Cape St. Elias and Icy Bay. The depths of the locations varied widely, ranging from 80-541 m (Fig. 19).

The distribution of the 26 observations among years was 1975, 11; 1979, 1; and 1981, 14. The distribution among months was January, 1; April, 2; May, 15; June, 4; July, 1; and August, 3. Bottom water temperatures at eight stations with XBT data ranged from +4.2° to +6.8°C, with a median of +5.8°C.

Other Species

Maturity observations were recorded for 1,631 Atka mackerel from February to August, with 49 individuals found in spawning condition at 4 locations. Two of these sites were located in the Aleutian Islands and two were along outer Albatross Bank (Fig. 20). Bottom depths ranged from 177 to 260 m.

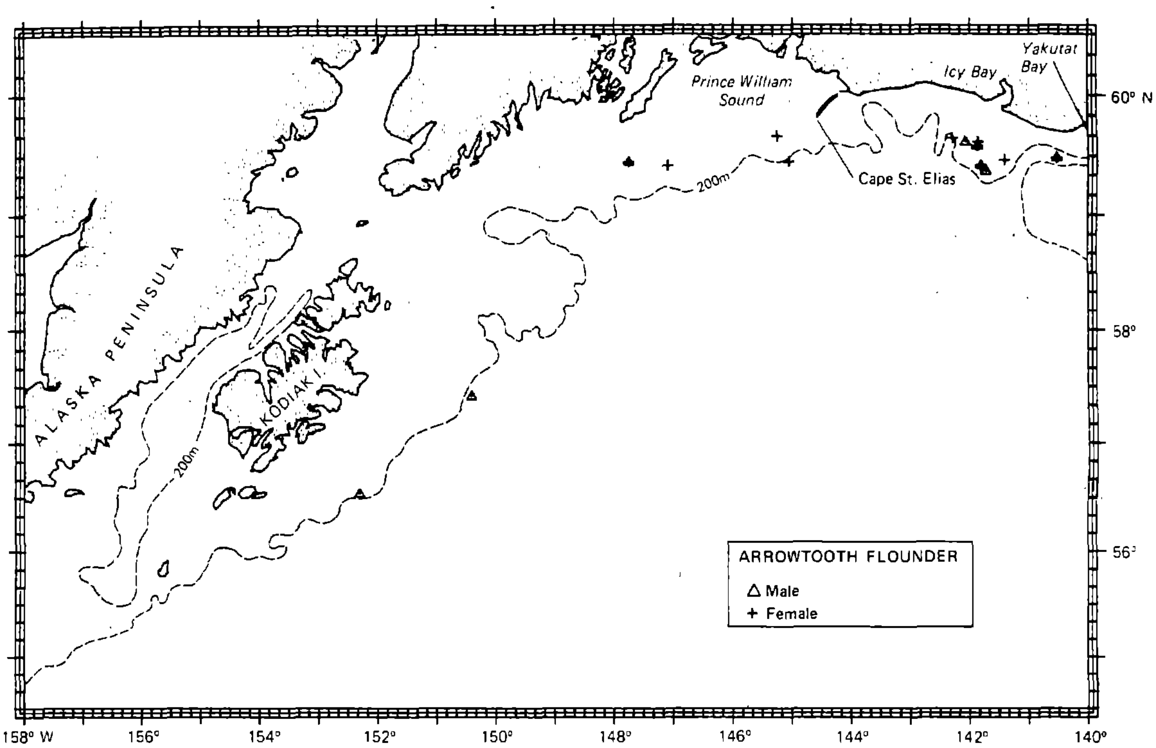

Figure 16. --Locations where arrowtooth flounder in spawning condition have been observed in the Gulf of Alaska.

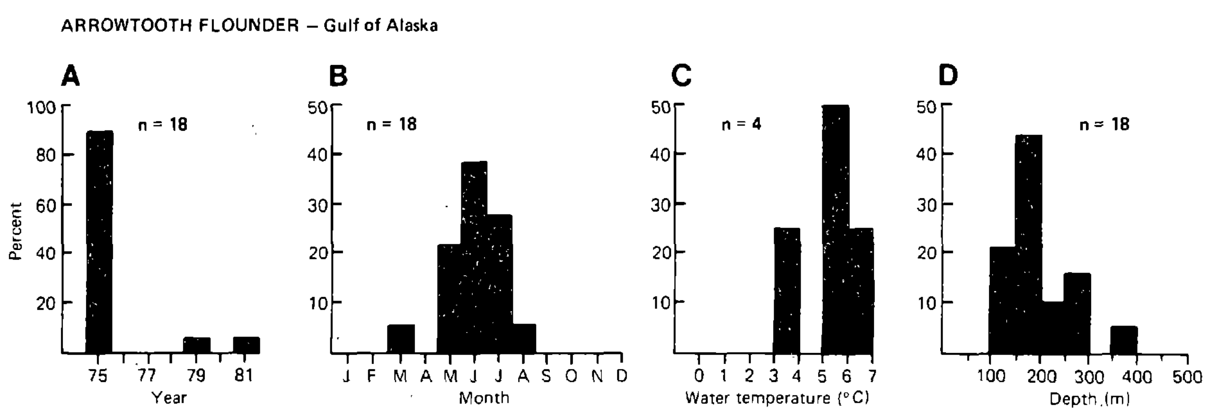

Figure 17.--Characteristics of the stations at which arrowtooth flounder in spawning condition were observed in the Gulf of Alaska: A) distribution among years; B) months; C) bottom water temperature; and D) sampling depth.

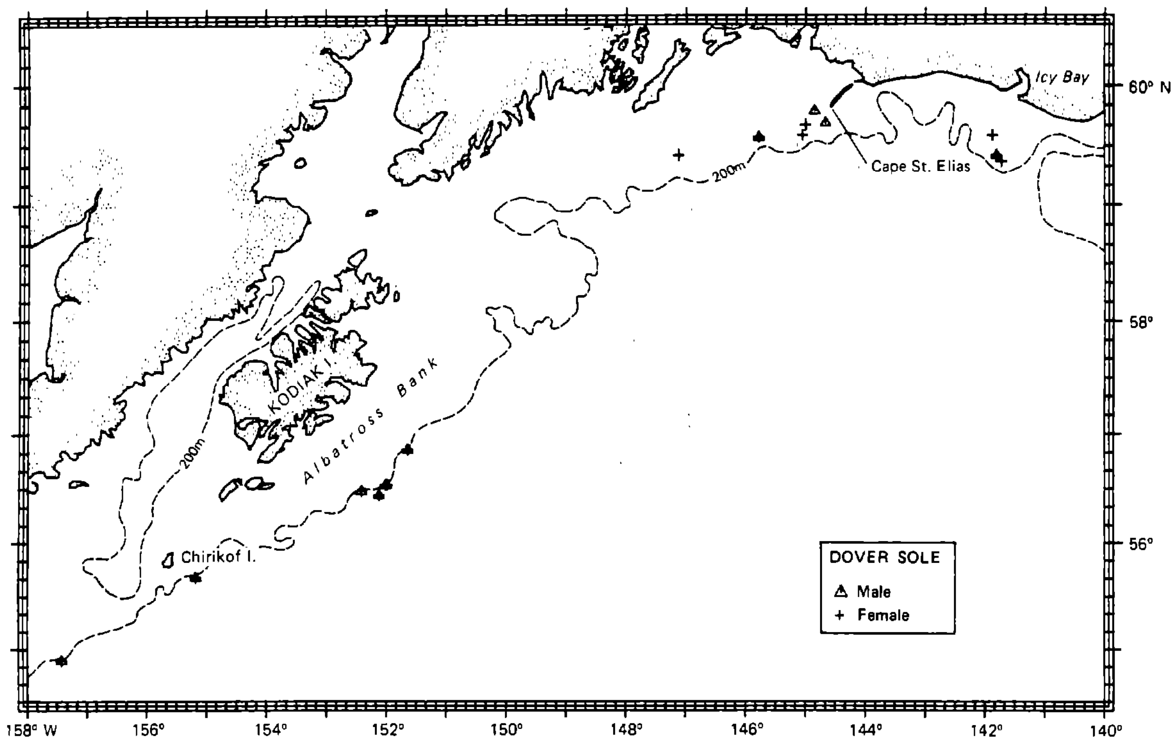

Figure 18. --Locations where Dover sole in spawning condition have been observed in the Gulf of Alaska.

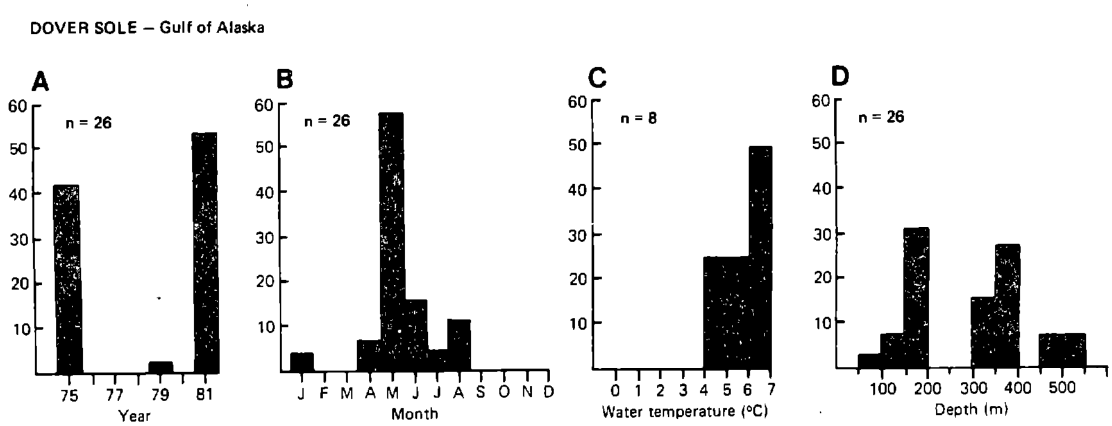

Figure 19. --Characteristics of the stations at which Dover sole in spawning condition were observed in the Gulf of Alaska: A) distribution among years: B) months; C) bottom water temperature; and D) sampling depth.

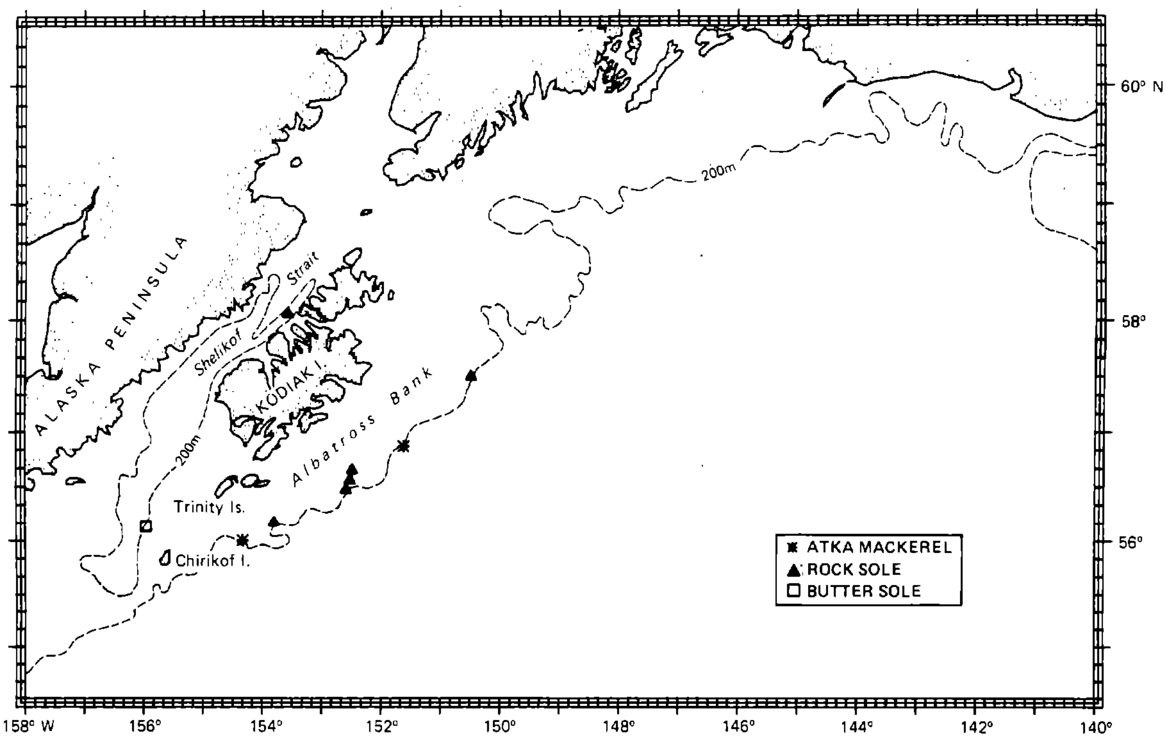

Figure 20. --Locations where Atka mackerel, rock sole, and butter sole in spawning condition have been observed in the Gulf of Alaska.

Rock sole data contained 868 maturity observations from January to April, finding 567 spawning individuals at 16 locations (Fig. 20). Spawning rock sole were observed in Shelikof Strait on the northwest side of Kodiak Island, and along outer Albatross Bank from the Trinity Islands to off Cape Chiniak (northeastern Kodiak Island). Bottom depths of the 16 sites ranged from 146 to 210 m, although 12 (75%) were within the interval 150-200 m. The distribution of observations among years was 1978, 4; 1979, 2; and 1980, 10. The distribution among months was February, 6, and March, 10. Bottom water temperatures at seven stations with XBT data ranged from +4.7° to +5.4°C, with a median of +5.3°C.

A total of 75 maturity condition observations of butter sole were available from March to April 1978; 37 males and females were found in spawning condition. These were recorded at one location (152 m depth) just northwest of Chirikof Island (Fig. 20).

Pacific Coast

The Pacific Coast data base contained maturity stage data for three fish species which were analyzed: sablefish; Pacific whiting, <u>Merluccius productus</u>; and Pacific herring (Table 4). However, the data for Pacific herring did not include any spawning information.

Sablefish

A total of 7,550 observations of the maturity stage condition of sablefish were available from the Pacific Coast, including 456 records of fish in gravid condition. Gravid males were observed at 46 survey stations and females at 40, shown in Figure 21.

Table 4.--Summary of maturity stage data available in the Pacific Coast data base that included observations of fish in spawning condition.

Species	Number of maturity observations	Months	Number of spawning individuals	Stations with spawning males	Stations with spawning females
Sablefish	7,550	July-August	456	46	40
Pacific whiting	246	August-November	186	3	3
TOTAL	7,796		642	49	43

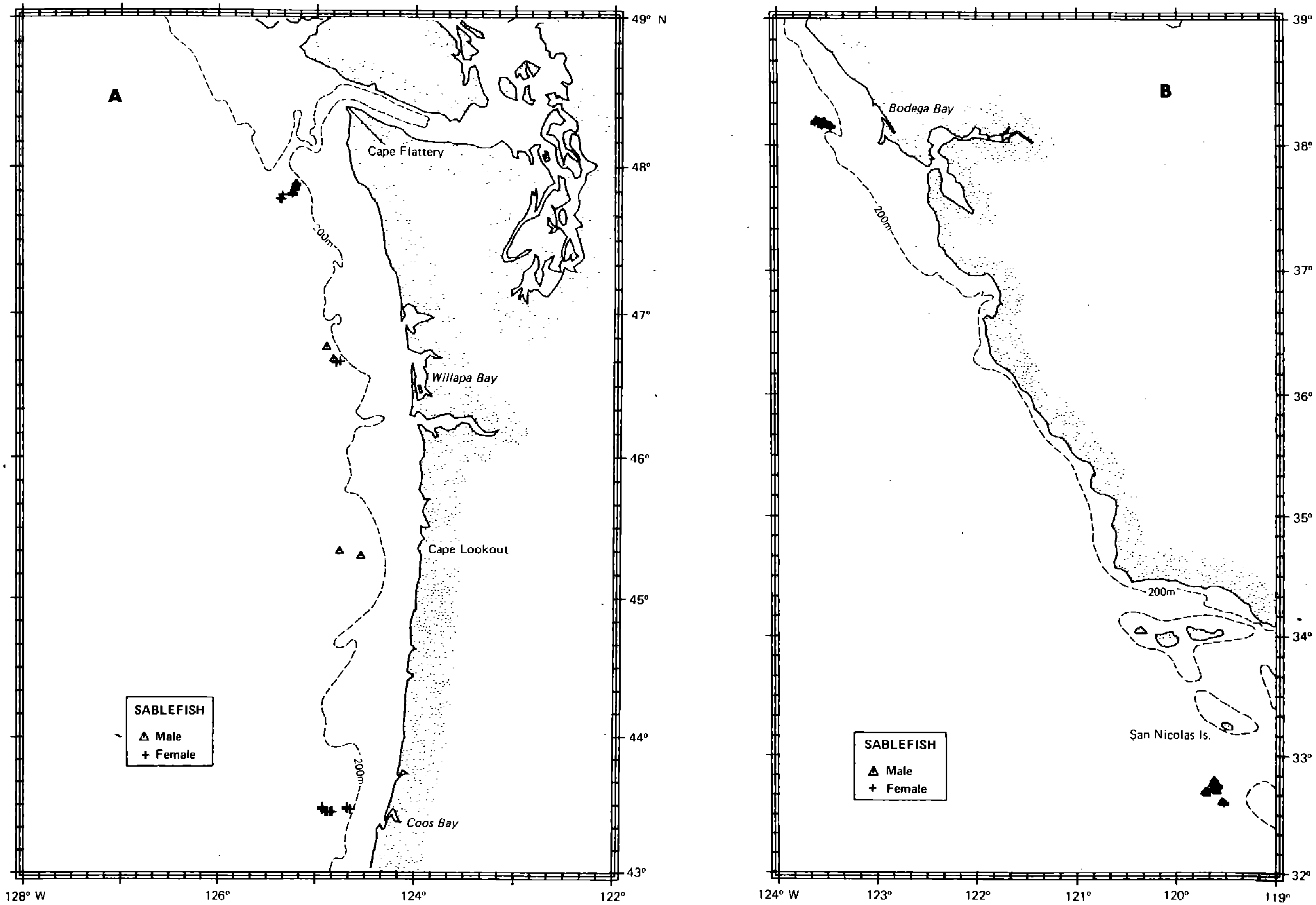

Figure 21.--Locations where sablefish in gravid condition have been observed in the Pacific Coast region: A) Cape Flattery to Coos Bay; B) Pt. Arena to San Diego.

Gravid sablefish were recorded at clusters of stations in deep water along the outer continental shelf from Cape Flattery to San Diego. These included locations off Cape Flattery and Willapa Bay, Washington; off Cape Lookout and Coos Bay, Oregon; and off Bodega Bay and San Nicolas Island, California. The clustered distribution of sightings, primarily from fish trap surveys, is an artifact of a restriction of the sampling effort to a few localized monitoring areas.

The distribution of the 86 observations among years was 1979, 16%; 1980, 70%; and 1981, 14% (Fig. 22). The distribution among months was August, 13%; September, 17%; October, 22%; and November, 48%. The range of bottom depths was extremely broad, 267-1,309 m. Bottom water temperatures at 10 locations with XBT data ranged from +3.7° to +7.5°C, with a median of +4.2°C.

Pacific Whiting

A total of 246 maturity stage observations were available for Pacific whiting that included records of 186 individuals in spawning condition in August 1980. These were from three scattered points along the Oregon coast: off Cape Kiwanda, Cape Foulweather, and Reedsport (Fig. 23). Depths at which these fish were taken were 73, 119, and 247 m; seawater temperatures were +7.0°, +7.3°, and +7.6°C.

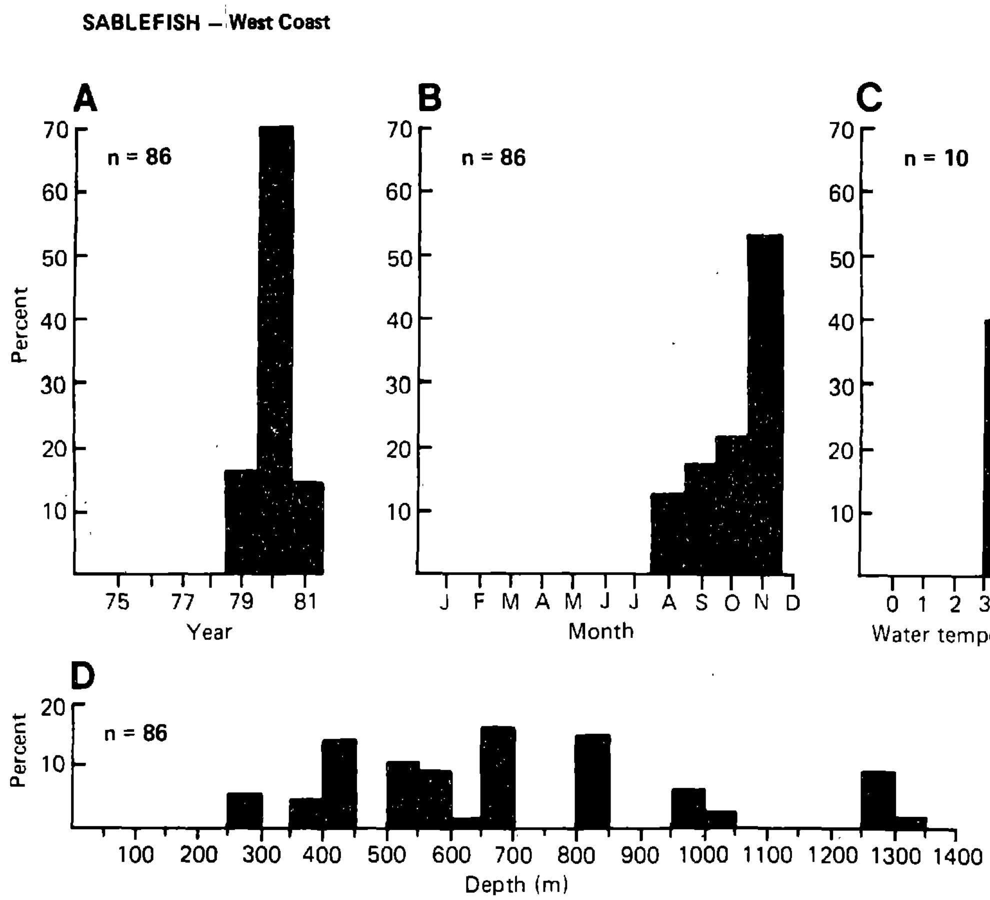

Figure 22. --Characteristics of the stations at which sablefish in gravid condition were observed in the Pacific Coast region: A) distribution among years; B) months; C) bottom water temperature; and D) sampling depth.

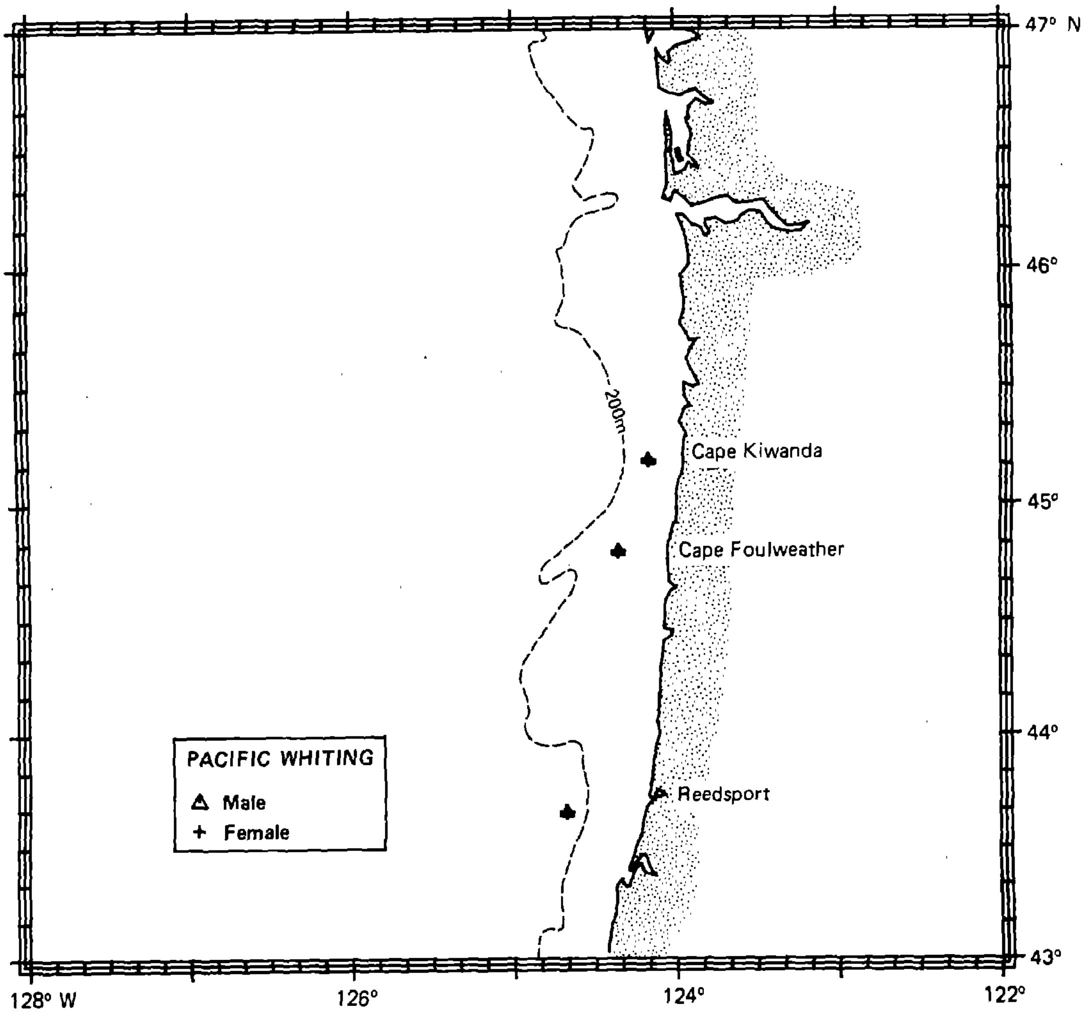

Figure 23.--Locations where Pacific whiting in spawning condition have been observed in the Pacific Coast region.

DISCUSSION

Evaluation of Methodology

The maturity stage data available at the NWAFC is limited because such data were collected incidentally as resources and interest of the field party allowed. As' a result, caution must be used in their interpretation. For example, the distribution of trawl survey effort was highly uneven in time, because the majority of surveys were conducted during summer months. Similarly, individual surveys were limited spatially to particular regions of the continental shelf (generally offshore), and to areas with trawlable bottom conditions.

Because maturity stage data were collected at subsets of the survey stations, the distribution of the maturity data might be expected to be even more irregular in space and time. Two questions that result are:

1) What spawning activities were missed by the surveys due to inadequate coverage, not sampling at the right places or at the right times, or by failing to record the pertinent data, and
2) To what extent are the results, derived from maturity observations, biased by uneven and inconsistent sampling?

The problems raised by these questions are not easy to measure or resolve. In two extreme cases, it appeared that only anomalous observations had been recorded. These were the results for Bering Sea yellowfin sole and Pacific whiting off the West Coast. The only records of yellowfin sole in spawning condition were from extremely deep water, directly west of St. George Island. The general consensus recorded in the literature is that the majority of spawning actually occurs over a broad area of the eastern Bering, Sea shelf from Bristol Bay to Nunivak Island at depths ranging from 15 to 75 m (Musienko

1963; Bakkala 1981). Similarly, the only records of Pacific whiting in spawning condition were from three stations off the Oregon coast in July; however, the adult population is generally thought to spawn in winter off the coasts of southern California and Baja California (Bailey et al. 1982). Although exceptional observations and fragmented data such as these may be useful for elaborating concepts of dominant patterns and their variations, they could also lead to wrong impressions if viewed in isolation.

Another limitation of the approach of using gonad conditions as indicators of spawning areas and times is the presumption of proximity to actual spawning grounds. The assumption made in this study was that the final maturation of the gonads--indicated by running ova and sperm--occurs for only a short time, probably weeks (Liley 1980), so that fish observed at this time and condition should have been at least near their actual spawning sites. Comparisons of the results from this approach and other sources of information should gradually provide clearer understanding.

Interregional Comparisons

Although limitations of the methods must be kept in mind, Table 5 summarizes some of the main spawning characteristics that were identified by the study. All the species were found to have seasonal breeding cycles in which most observations of spawning conditions occurred within a 2-3 month period. Some species had spawning periods synchronized to occur in the early spring (e.g., Pacific cod, walleye pollock, and rock sole); and other species in the late spring and early summer (e.g., flathead sole, rex sole, Dover sole, and' arrowtooth flounder). Walleye pollock appeared in spawning condition earlier in the Gulf of Alaska than in the Bering Sea and generally in deeper water. In the Gulf of Alaska, sablefish appeared in spawning condition predominantly

Table 5.--Comparisons of the spawning characteristics of the principal fish species, summarized from the results of the analyses of gonad conditions.

Region	Species	Principal timing	Principal depth range (m)	Water temperature (°C)[1/]
Bering Sea	Walleye pollock	April-May	100-150	2.6 (0.0, 6.8)
Gulf of Alaska	Walleye pollock	March-April	150-300	4.9 (1.1, 7.2)
	Sablefish	June	400-850	4.0 (3.7, 4.2)
	Pacific cod	February-March	150-250	5.4 (4.5, 5.9)
	Flathead sole	March-May	108-200	5.0 (3.6, 5.7)
	Rex sole	April-May	200-300	5.6 (5.0, 5.9)
	Arrowtooth flounder	May-July	108-200	5.4 (3.7, 6.8)
	Dover sole	May-June	80-541	5.8 (4.2, 6.8)
	Rock sole	February-March	150-200	5.3 (4.7, 5.4)
Pacific Coast	Sablefish	October-November	267-1,309	4.2 (3.7, 7.5)

1/ Median (and range in parentheses).

in early summer, while similar activity was not observed until early winter off the Pacific Coast.

Recommendations for Future Work

On the basis of our review, inventory, and analyses of the gonad maturity stage data in the NWAFC survey data base, we recommend the following desirable changes for future work:

1. Documentation must be available for all maturity data. Basic information includes the maturity code and the meaning of the code numbers used for each particular cruise and species.

2. For general use, we recommend the simplified maturation tables recommended by Hilge (1976). Hilge proposed a four-stage maturity table with the classes "juvenile," "ripening," "running ripe," and "spent," based on the fundamental developmental phases and most significant discontinuities. This approach would reduce uncertainty and subjectivity and should be accomplished with improved training.

3. Standard sampling strategies should be established for collecting maturity data. Maturity data should be collected (by selective sampling, if necessary) from at least 5-10 individuals in spawning condition whenever spawning fish occur in survey catches. Beyond this general recommendation, the protocol for sampling frequency, sample selection, and sample sizes must be based on the requirements for each specific research project.

4. Future research at the NWAFC should emphasize studies of the most important aspects of population reproduction. These include the size and age of sexual maturation (first reproduction), spawning locations and times, and age-specific fecundity.

5. Other types of research that are complementary to the maturity stage approach should be encouraged. These include histological studies to improve our understanding of spsnnatogenesis, oogenesis, and fecundity; studies of the prespawning and spawning behaviors; and studies of egg and larval drift, development, and sources of mortality.

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