AYK Herring Report
No.12

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DISTRIBUTION AND MIGRATION AND STATUS OF PACIFIC HERRING

by

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December 1979

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ABSTRACT

Pacific herring are an important part of the Bering Sea food-web and form the basis of a major commercial fishery. Until recently Japan and the U.S.S.R. have been major exploiters of herring. Catch peaked in the early 1970's at 145,579 mt, and then declined in response to overfishing and poor recruitment. Recently herring abundance has increased, and the United States has become the dominant exploiter of herring.

Most herring are harvested in coastal waters during the spawning period which commences in late April/mid-May along the Alaska Peninsula and Bristol Bay and progressively later to the north. Spawning occurs at temperatures of 5-12 C and the time of spawning is related to winter water temperatures with early spawning in warm years and late spawning in cold years. During spawning eggs are

deposited on vegetation in the intertidal zone of shallow bays and rocky headlands. Eggs hatch in 2-3 weeks as planktonic larvae and metamorphose to juveniles after 6-10 weeks. Little is known of larval and juvenile stages in the eastern Bering Sea.

Sexual maturity begins at age 2, but most herring mature at ages 3 and 4, the ages of recruitment to the fishery. Herring as old as age 15 occur; very few beyond age 10 are present in commercial catches. Age specific mortalities are unknown but the average instantaneous natural mortality rate is estimated to be 0.46-0.47. The rate of growth is generally greater in the Bering Sea than in the Gulf of Alaska, but within the Bering Sea growth decreases to the north. Herring feed on the predominant larger zooplankton--euphausiids, and copepods.

Three major stocks occur in the Bering Sea: northwest of the Pribilof Islands, Gulf of Olyutorski, and Cape Navarin. These have been identified as individual stocks based on differences in growth and maturation rates, and dissimilar age structures. Herring wintering northwest of the Pribilof Islands migrate to the Alaska coast in spring and spawn in Bristol Bay and between the Yukon and Kuskokwim Rivers. Although some may also spawn in the eastern Aleutian Islands, Alaska Peninsula, and Norton Sound, herring in these areas may also winter inshore near spawning grounds. Northward of Norton Sound some herring winter in brackish lagoons and estuaries.

Herring wintering northwest of the Pribilof Islands arrive on the winter grounds in October and concentrate in waters of 2-4 C at depths of 105-137 m through the winter. In March schools migrate to the coast for spawning. After spawning they appear to remain in coastal waters because few are found on the shelf or slope. In late August, they reappear in offshore waters in the areas of Unimak and Nunivak Islands, and the seaward migration to the winter grounds continues through September and October.

Although assessments of eastern Bering Sea herring have ranged from 374 thousand mt to 2.75 million mt, the current estimate of spawning biomass is 432-864 thousand mt. Fisheries data indicate that herring declined rapidly following peak harvests in the early 1970's and that peak catches were supported by a few strong year-classes. Weak year-classes occurred through the early 1970's, and recruitment appears to be normalized in recent years.

Research is required to refine estimates of abundance and biological characteristics of stocks, to improve the capability for predicting changes in resource abundance, composition and availability, and to identify the origin and distribution of herring in offshore areas.

INTRODUCTION

The Pacific herring (Clupea harengus pallasi) is a member of the family Clupeidae which has a global distribution and includes about 50 genera and 190 species found mostly in tropical and temperate waters (Svetovidov 1952). They occur in the North Atlantic and North Pacific areas, are similar in appearance and differ primarily in the number of vertebra (55-57 vs. 52-55). Pacific and Atlantic species also differ biochemically, with significant differences observed in the frequencies of eight genes (S. Grant, Northwest and Alaska Fisheries Center, Seattle, Washington, Personal Communication). Svetovidov (1952) believes that Pacific herring arrived from the Atlantic some time between the Pliocene and the "post-glacial 'transgression'" via the Asian Arctic. Pacific herring also differ from Atlantic herring in spawning and migrational behavior; the former are spring spawners, whereas the latter are divided into spring, winter, summer, and autumn spawners. Pacific herring spawn between the intertidal zone and about 20 m and deposit eggs on vegetation, whereas, Atlantic herring spawn in deep water on a gravel bottom. Pacific herring generally remain near the spawning ground year round and do not make extensive seasonal migrations as many Atlantic stocks do.

In the North Pacific Ocean, herring are distributed along the Asiatic and North American continental shelves (Fig. 1): in Asia they range from Taksi Bay, near the mouth of the Lena River, to the Yellow Sea (Andriyashev 1954); and in North America, from Cape Bathurst in the Beaufort Sea, to San Diego Bay, California (Hart 1973).

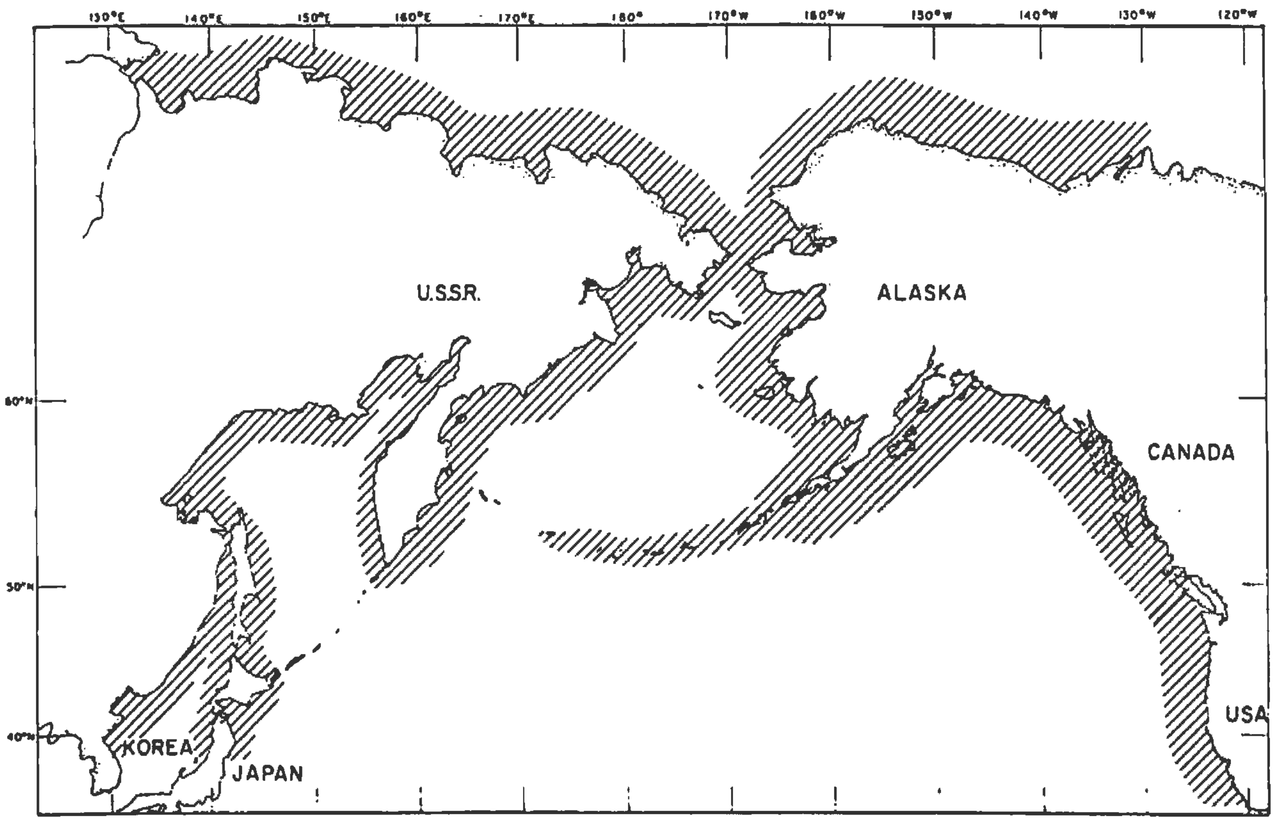

FIG. 1 Geographic range of Pacific herring (Clupea harengus pallasi) in the North Pacific Ocean.

Herring are an important part of the eastern Bering Sea food-web. They are pelagic planktivores which are highly adapted with large mouths and numerous fine gill rakes for efficient utilization of euphausiids, copepods and other zooplankton. In turn, herring are important prey for marine mammals, birds and roundfish. Mathematical simulations of the ecosystem in this area by Laevastu and Favorite (1978) indicate that annual total mortality equals one half of herring biomass production and that 95% of total mortality is by predation. Given this level of mortality, it is understandable that herring stocks exhibit strong fluctuations in abundance with seemingly small changes in fishing or environmental factors.

The abundance of herring declined sharply in the early 1970's and only recently has an increase become apparent. Although several hypotheses could be advanced to explain the cause of the strong population fluctuations observed, data are insufficient to establish conclusively a causal factor. Since rapid, marked changes in abundance are expected to occur in the future, it will be necessary to be able to identify the causes and predict their occurrence and magnitude.

Present knowledge is rudimentary and inferences on many aspects of life history must be drawn from other more thoroughly studied populations. Research is needed on all aspects of herring biology, especially of interspecies interactions and environmental effects on herring.

FISHERIES

Archeological excavations in the area indicate that net fisheries had been developed as early as 500 BC (Hemming et al. 1978), and subsistence fishing for herring continues in many native villages, especially in villages between the Yukon and Kuskokwim Rivers where alternative food resources (salmon, moose, etc.) are absent or in low abundance (Barton 1978). Commercial herring fisheries developed in the northern Bering Sea around the turn of the century. Marsh and Cobb (1910) reported that a small fishery developed in Grantley Harbor on the Seward Peninsula about 1906 to supply salt herring to Nome. Prior to 1909, another small herring fishery developed in Golovin Bay, Norton Sound (Rounsefell 1930). Although the Grantley Harbor fishery apparently was short-lived, the last reported catch was in 1917 when 300 barrels were packed, the Golovin Bay fishery operated until 1941.

The first large scale herring fishery began in 1928 when a purse-seine fleet fished at Unalaska. Salteries were established at Dutch Harbor in following years, and the catch increased to a peak of 2,277 mt in 1932 (Barton 1978). Catches ranged between 1-2 thousand mt until 1937, and thereafter declined until 1946 when the fishery ended. Lack of demand and accompanying low prices for cured herring was the principal reason for the demise of this fishery (Wespestad 1978a). A herring fishery resumed in 1959 when Soviet exploratory trawlers located wintering concentrations along the continental slope northwest of the Pribilof Islands (Dudnik and Usol'tsev 1964). During the first season, 10,000 mt were harvested

(Fig. 2). Catches increased in following years as effort increased but declined sharply in 1965 and 1966 when herring could not be located and effort was greatly reduced.

Japanese vessels began targeting on herring in the late 1960's. A trawl fishery was established on the winter grounds from November to April and a gillnet fishery, which operated off the western Alaska spawning grounds, from April through June (Wespestad 1978b). In 1977, the area east of 168°W and north of 58°N was closed to foreign herring fishing to protect native subsistence fisheries, and in 1978 the 168°W closure line was extended to the Alaska Peninsula. This greatly limited the gillnet fishery; no foreign gillnetting occurred in 1978 and only a very limited amount in 1979.

Catch and effort peaked in the late 1960's/early 1970's and then declined (Fig. 3). The peak catch occurred in 1970 when 145,579 mt was harvested (see Fig. 2). Catch dropped abruptly the following year, increased slightly in 1972, and then declined until 1976 when an increase occurred. In 1977, an allowable catch of about 21,000 mt was established by the U.S. when the 200-mile Fishery Conservation Zone was established. Herring harvests have been maintained at this level to the present time.

U. S. herring fisheries resumed on a small scale in Norton Sound and northern Bristol Bay in the late 1960's for herring roe and herring roe-on-kelp for the Japanese market. Harvests were small, generally under 100 mt, until 1977, when the catch increased to 2,550 mt. The fishery expanded further in 1978, and the catch

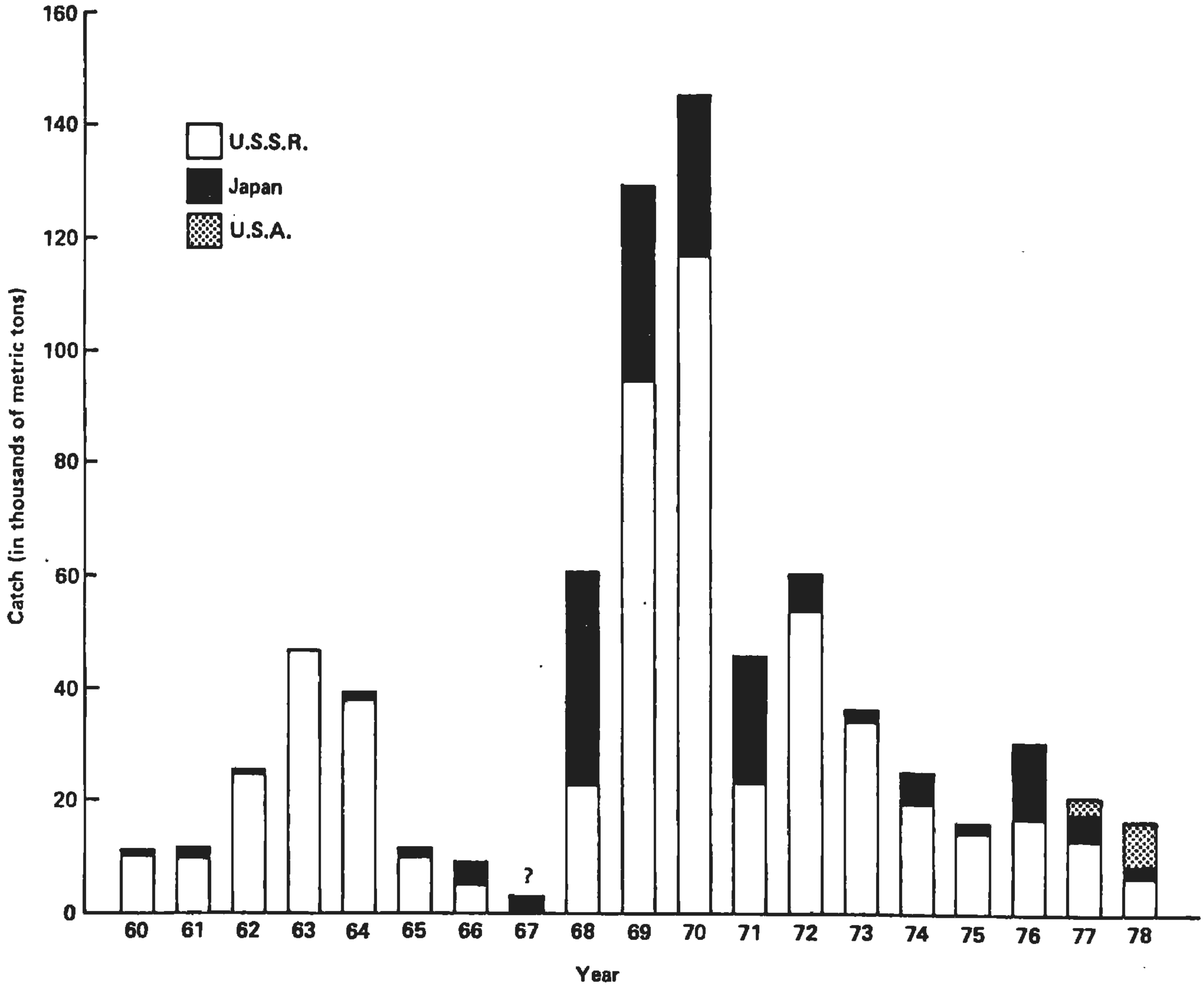

FIG. 2 Eastern Bering Sea herring catch 1960-78.

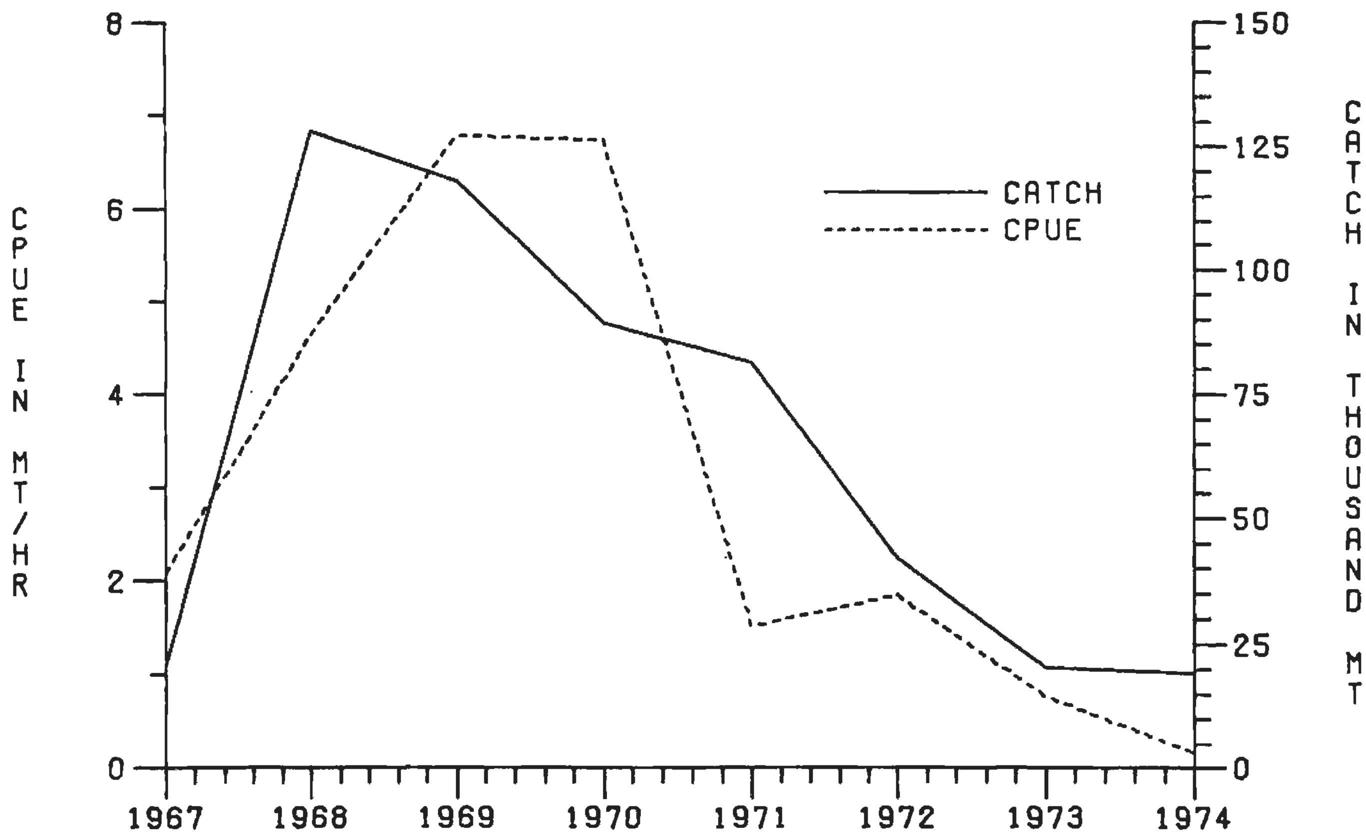

FIG. 3 Catch and catch per unit effort (CPUE) relationship for large Japanese stern trawlers in the eastern Bering Sea, 1967-1974.

rose to 7,025 mt. In 1979, catch increased again to approximately 12,000 mt. Most of the U. S. harvest is taken with purse seines and gillnets in northern Bristol Bay between Cape Constantine and Cape Newenham. Additionally, smaller fisheries occur in Goodnews Bay, Security Cove, Cape Romanzof and Norton Sound (Fig. 4).

GENERAL BIOLOGY

Spawning

Herring spawn along the western Alaska coast in late spring to midsummer (see Fig. 4). In most years, spawning occurs first along the Alaska Peninsula and in Bristol Bay in late April to mid-May and progressively later to the north. In Kotzebue Sound, it may extend from July through mid-August (Barton 1978). It usually commences soon after the spawning grounds become ice-free and has been noted to commence when water temperatures are approximately 3-5.5 C (Scattergood et al. 1959), although it has been recorded over a range of 6-10 C in northern Bristol Bay (Warner and Shafford 1977) and in a range of 5.6-11.7 C on spawning grounds between Norton Sound and Bristol Bay (Barton 1979).

Prokhorov (1968) found that the approximate time of spawning in the western Bering Sea is related to winter and spring water temperatures with early maturation in warm years and delayed development in cold years. The past two years (1978-1979) have been mild winters, 1979 especially so, and herring have arrived on the spawning ground several days to two weeks earlier then average; while in 1976, a cold year, spawning herring were not evident until mid-June. Svetovidov (1952) believes that the shore spawning be-

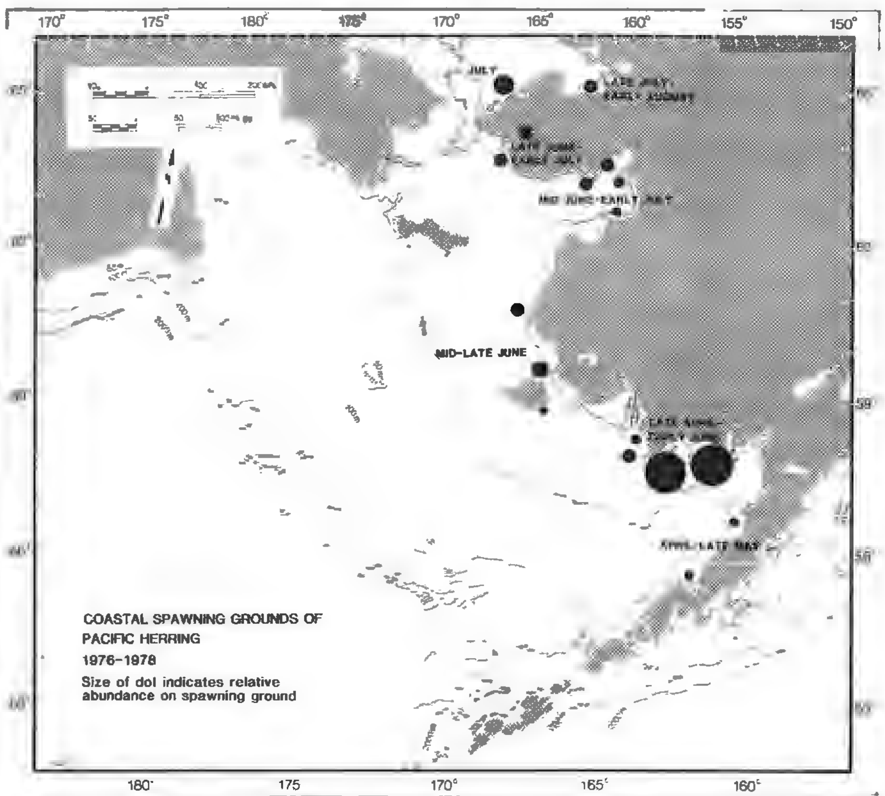

FIG. 4 Distribution, time of spawning and relative abundance of Pacific herring on coastal spawning grounds observed during aerial surveys, 1976-1978.

havior of Pacific herring is due to a lack of high water temperature in deeper water.

The duration of spawning may range from a few days to several weeks. Generally, the older herring are the first to spawn, followed by successively younger fish. Eggs are deposited on vegetation in intertidal and shallow subtidal waters, predominantly on rockweed (*Fucus* spp.) and eelgrass (*Zostera* spp.) (Barton 1979). There are two types of spawning habitats: rocky headlands, and shallow lagoons and bays (Barton 1978). Southward of Norton Sound most spawn is found in the intertidal zone on rockweed, while from Norton Sound northward most spawn is found in the shallow subtidal zone on eelgrass. Barton believes area differences are partially due to smaller tide changes in the northern areas.

Eggs take 10-21 days to hatch depending on water temperature. In northern Bristol Bay, this takes 13-14 days at 8-11 C (Barton 1979). However, Alderdice and Velson (1971) have suggested that optimum temperatures for Pacific herring egg development are 5-9 C and that below 5 C egg mortality occurs.

Little is known of the magnitude or causes of egg mortality on eastern Bering Sea spawning grounds, but studies in British Columbia revealed wave action, exposure to air and bird predation as major factors (Taylor 1964). Wave action may be a major cause in the Bering Sea because it has been observed that a severe storm subsequent to spawning activity destroyed both deposited eggs and rockweed in the upper intertidal zone along the south shore of

Cape Romanzof (Gilmer 1978). Predation of fish may also be an important egg mortality source. Concentrations of flatfishes, particularly yellowfin sole, have been observed on the spawning grounds in northern Bristol Bay (John Clark, ADF&G, personal communication). Stomach examinations of flatfish in spawning areas by both authors have revealed a high rate of egg consumption.

Larval and Juvenile Development

General Background Information from Barkley Sound, B.C. Studies

Herring hatch as larvae averaging 8 mm in size, and this planktonic larval stage lasts for approximately 6-10 weeks, at which time the larvae have grown to approximately 30 mm and begin to metamorphose into juveniles (Taylor 1964). During the larval stage, they are subject to high and variable mortality rates. An important source of mortality may be failure to obtain proper food after yolk sac absorption and from passive transport away from the coast by prevailing currents (Outram and Humphreys 1974). Stevenson (1962) found that when larvae in Barkley Sound were transported to the open sea, few of the transported larvae survived. He did not find temperatures and salinity to be important factors in inshore areas but believed the high mortality of larvae offshore was possibly connected to the increased salinity of the open sea. There are indications that the direction and magnitude of surface stress may affect larval survival, a northward wind stress (along a N/S coast) will result in net onshore flow and a piling up of water against the coast, causing onshore retention of larvae and good year-classes, offshore movement is associated with poor year-classes

(Outram and Humphreys 1974).

Upon completion of metamorphosis, juveniles are free-swimming and begin to form schools that enlarge and move out of the bays as summer progresses (Taylor 1964). Hourston (1959) found that juveniles moved from the spawning grounds on the northwest side of Barkley Sound to rearing grounds on the southeast side. No specific reason could be found for migration to the southeast other than a preference for calmer, sheltered water found there. Juveniles in Barkley Sound actively feed at depths of 0.6-5 m at dawn and dusk. No sampling was done at night, but some inactive schools were observed near surface. Juvenile schools were found in a range of salinities, but most were found at 25 $^{o}/oo$ salinity, which corresponds to Fujita and Kokudo's (1927) point of best fry survival.

Bering Sea

Little is known about the juvenile stage in the Bering-Chukchi Sea region from the time herring leave the coast in their first summer until they are recruited to the adult population. Rumyantsev and Darda (1970) indicate that juveniles feed in coastal waters in summer and move to deeper water in winter (juvenile herring in British Columbian and southern Alaska waters winter offshore and reappear in bays the following summer -- Taylor 1964; Rounsefell 1930). In the western Bering Sea, ages 0 and 1 herring inhabit areas nearer shore and at lower temperatures than adults (Prokhorov 1968).

Juveniles were found in the Port Clarence area in 1977, and more than 50% of the juveniles were captured in Imuruk Basin, the brackish forebay of the Port Clarence/Grantley Harbor complex. Apparently herring in the northern Bering Sea and Chukchi Sea may have a much lower salinity tolerance as eggs and fry were found in Imuruk Basin near Port Clarence in water of $4^{o}/oo$ salinity (Barton 1978). Although juveniles were present in the spring spawning period (late June-early July), significant numbers were not captured until mid-August. Their presence in Hotham Inlet in November was indicated by stomach analyses of sheefish (Stenodus leucichthus). Further substantive numbers of age 1 herring were captured in June in Hagemeister Strait of northern Bristol Bay (Barton 1979).

Wolotira et al. (1977) found both mature pre-spawning and immature herring in autumn (September-October) trawl catches made in the offshore waters of the northern Bering Sea and southern Chukchi Sea; however, age 0 herring were only found in the pelagic area of Norton Sound between Cape Douglas and Golovin Bay.

Maturation and Fecundity

Herring spawn for the first time at ages 2-6 but the majority do not spawn until ages 3 (50% mature) and 4 (78% mature). By age 5, 95% of the population has matured (Rumyantsef and Darda 1970). Sexual maturity of eastern Bering Sea herring coincides with recruitment into the fishery, primarily at ages 3 and 4. The onset of sexual maturity occurs earlier in the herring's southern range (stocks mature between ages 3 and 4 in British Columbia and ages 2 and 3 in California -- Hart 1973, Rabin 1977).

In mature herring fecundity varies as a function of body length and latitude, increasing in size and latitude (Nagasaki

1958); it also appears to be higher in the eastern Bering Sea area than in the Gulf of Alaska or western Bering Sea (Table I).

Age and Growth

Herring have been found to attain an age of up to 15 years (Barton 1978), and generally occur in substantial numbers from ages 3-6, but when strong year-classes occur, ages 7-10 may comprise a substantial portion of the catch.

TABLE I

Fecundity (thousand of eggs) of Pacific Herring in Different Areas of the Northern Pacific Ocean

Area	Age	4	5	6	7	8	Source
E. Bering Sea	1963	26.6	34.4	46.1	59.5	70.8	Shaboneev (1965)
	1964	26.6	32.1	52.4	53.5	77.8	(Rumyantsev & Darda (1970)
Alaska Peninsula	1976	Mean: 26.4	Range:	12.6-84.8	Ages	IV-VI	Warner (1976)
Karaginskii Bay	1963		26.8	30.1	37.4		Kachina[1]
W. Bering Sea	1964			39.2	43.3	50.6	Kachina
Vancouver	1955	19.9	23.8	29.6	38.2	30.4	Nagaski (1958)

[1]Cited in Rumyantsev & Darda (1970).

Stocks grow at about the same rate as those in the Gulf of Alaska and British Columbia until ages 3-4, but growth is greater in the Bering Sea for older fish, and they achieve a greater maximum length and weight than the more southern stocks (Fig. 5). Rounsefell (1930) reported many herring of 380 mm in the catch at Unalaska (compared to a maximum of 330 mm reported for British Columbia -- Hart 1973). In more recent investigations, Rumyantsev and Darda (1970) and Warner (1976) have found Bering Sea herring of 340-345 mm. Barton (1978) found that size-at-age in spawning concentrations along the western Alaska coast from Norton Sound northward are significantly smaller than stocks to the south (Fig. 5).

A general growth curve was derived for eastern Bering Sea herring by applying von Bertalanffy's equation to data reported by Shaboneev (1965) from the winter trawl fishery:

$$L_t = L_{\infty} \; 1\text{-}e^{k(t-t_0)}$$

The parameters of von Bertalanffy's equation are: L_{∞} (maximum length in mm) = 324.5, k (growth rate) = 0.35 and t_0 (age in years, fish was 0 length) = 0.0261.

Warner (1976) computed a von Bertalanffy curve for fish captured in trawl samples in Bristol Bay. His coefficients were L_{∞} = 299, k = 0.18 and t_0 = 2.10. These estimates, although lower, do not differ significantly from Shaboneev's data, given the variances reported by Warner.

<u>Mortality</u>

Beyond the larval stage the rate of natural mortality decreases sharply and continues to decrease slightly until about age 5 when it begins to increase from senility, disease and spawning

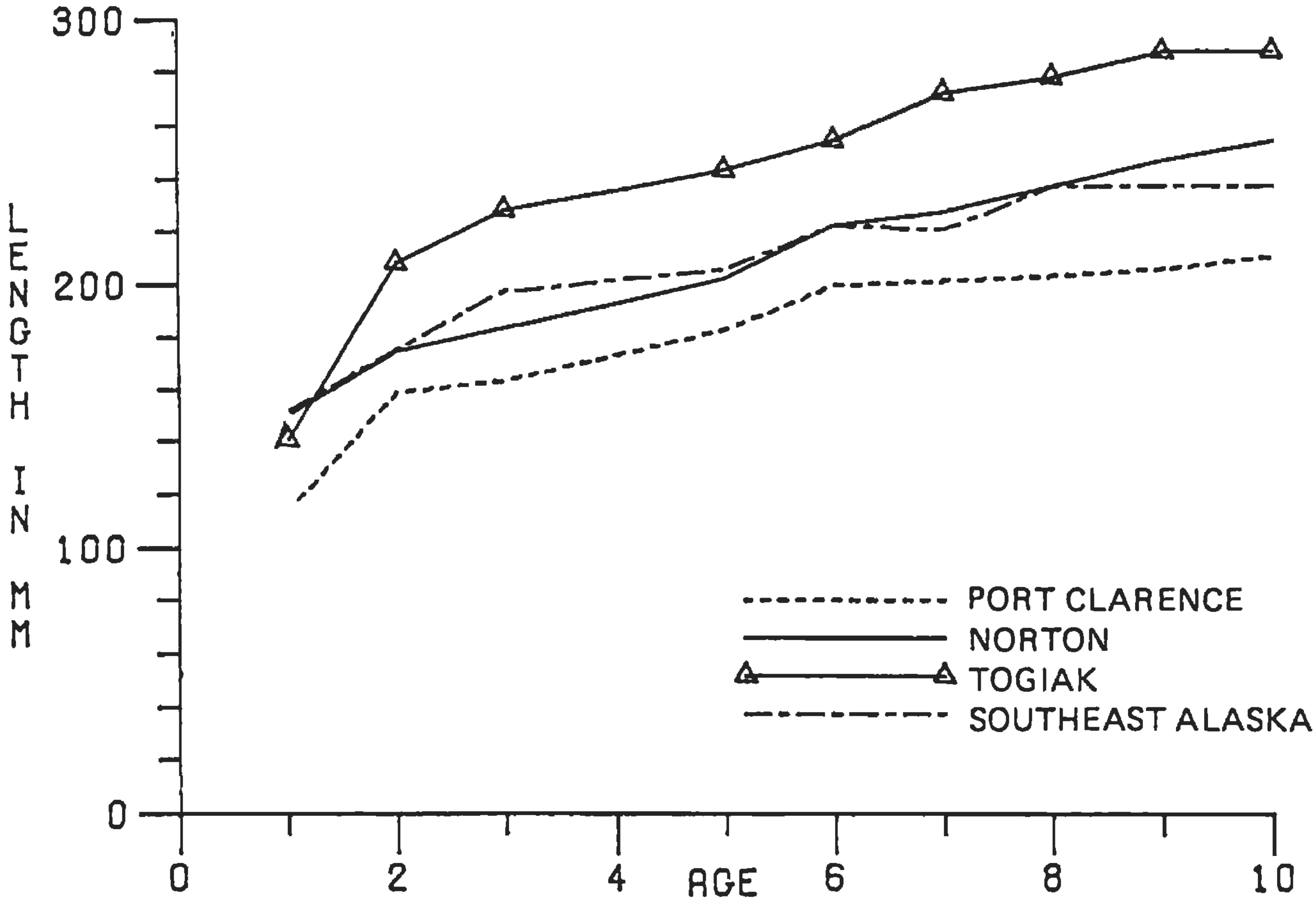

FIG. 5 Size-at-age comparisons of Pacific herring from selected areas in the eastern Bering Sea and the northeastern Pacific Ocean.

mortality (Fig. 6). In the juvenile stage the magnitude of mortality is actually unknown but inferences from other fish populations suggest that it is maximum in years of high egg and larval survival through intense intraspecies food competition (Ricker 1975).

A general estimate of the natural mortality rate for eastern Bering Sea herring was derived by Wespestad (1978a), using the procedure of Alverson and Carney (1975). This method estimates the natural mortality rate for eastern Bering Sea herring to be 0.47. Natural mortality can also be determined by an analysis of catch curves using regression techniques (Ricker 1975). Applying this method to data presented by Laevastu and Favorite (1977), the instantaneous mortality rate for fully recruited ages of eastern Bering Sea herring is determined to be 0.46. Age-specific natural mortality estimates are unavailable for the eastern Bering Sea stocks; however, they are probably similar to natural mortality rates estimated for herring stocks in southeastern Alaska and British Columbia (Table II).

TABLE II

Instanteous Rate of Natural Mortality (M) for Herring in the Northeastern Pacific

Area/Age	3	4	5	6	7	8	Source
S.E. Alaska	.20	.33	.46	.59	.72	.85	Skud (1963)
E. Vancouver Is.		.40	.64	.77	.85		Tester(1955)
W. Vancouver Is.		.46	.61	.72	.79		Tester(1955)

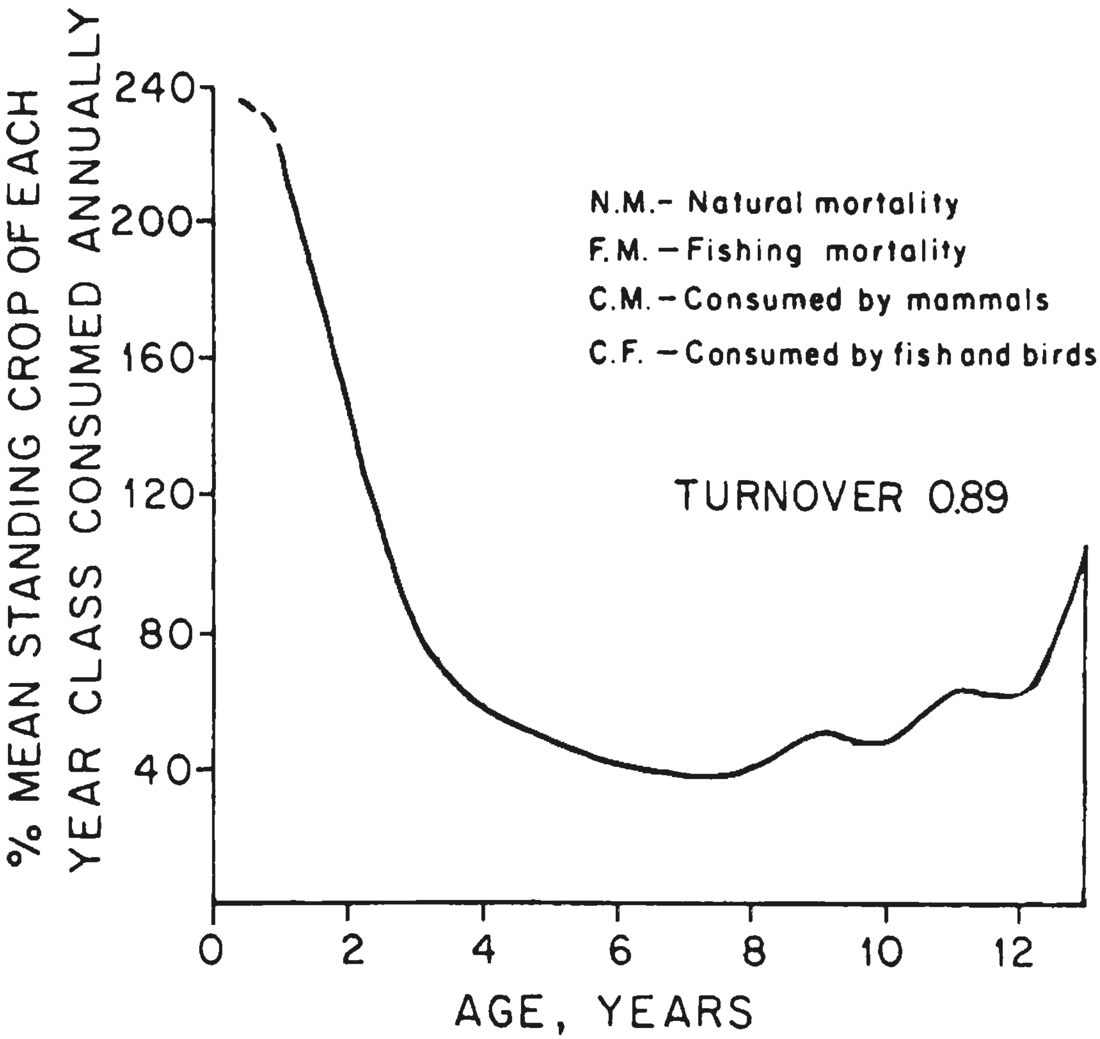

FIG. 6 Total mortality of Pacific herring expressed as percent annual cohort biomass loss.

Food and Feeding

The first food of larvae is usually limited to small and relatively immobile plankton organisms that the larvae must literally nearly run into to notice and capture. Earliest food is sometimes more than 50% microscopic eggs, other items include diatoms and nauplii of small copepods.

Herring do not have a strong preference for certain food species but feed on the comparatively large organisms that predominate in the plankton of a given area (Kaganovskii 1955). Feeding generally occurs prior to spawning and intensifies following spawning (Svetovidov 1952). During the winter, feeding declines and ceases in late winter (Dudnik and Usol'tsev 1964). During November-December, in Kamchatka waters of the western Bering Sea, Kachina and Akimova (1972) found that juvenile herring consumed small and medium forms of zooplankton (chaetognaths, copepods, tunicates) and benthoplankton (mysids). Euphausiids, amphipods, mollusks and other organisms were found rarely and usually in small quantities. In the demersal zone, herring stomachs contained quantities of tubes of polychaete worms, bivalve mollusks, amphipods, copepods, juvenile fish and detritus.

In the eastern Bering Sea, stomachs in August were 84% filled with euphausiids, 8% with fish fry, 6% with calanoids, and 2% with gammarids (Rumyantsev and Darda 1970). Fish fry, in order of importance, were walleye pollock, smelt, capelin and sandlance. In spring, food was mainly Themisto (Amphipoda) and Sagitta (Chaetognatha). After spawning, the main diet was euphausiids, Calanus spp. and Sagitta spp. (Dudnik and Usol'tsev 1964).

Nearly 75% of herring stomachs examined in the spring from Bristol Bay to Norton Sound were either empty or contained only traces of food (Barton 1978). Only 25% of the stomachs examined were at least 25% or more full, and only 3.4% were 100% full. Major food items were cladocerans, flatworms (Platyhelminthes), copepods and cirripeds.

DISTRIBUTION

Stock Distribution

Three major herring wintering rounds have been identified within the Bering Sea: northwest of the Pribilof Islands and in the Gulf of Olyutorski (Prokhorov 1968), and near Cape Navarin (N. Fadeev, TINRO, Vladavostok, U.S.S.R., Personal Communication) (Fig. 7). Differences in the pattern of migration between the coast and the outer continental shelf has effectively isolated Asian and North American herring in the Bering Sea. Different growth and maturation rates, and dissimilar age structures reported by Prokhorov (1968) occur between those wintering near Cape Navarin and northwest of the Pribilof Islands, suggesting that although these groups winter in close proximity there is little or no mixing between them. Most herring which winter near the Pribilof Islands are believed to spawn in Bristol Bay and in areas between the Yukon and Kuskokwim Rivers. This conclusion is based on Soviet research, similarities in age composition, and the distribution of Japanese trawl catches during the spawning migration (Wespestad 1978b, Barton 1979). ADF&G aerial surveys indicate that the greatest abundance of spawning herring occurs in the Bristol Bay area and

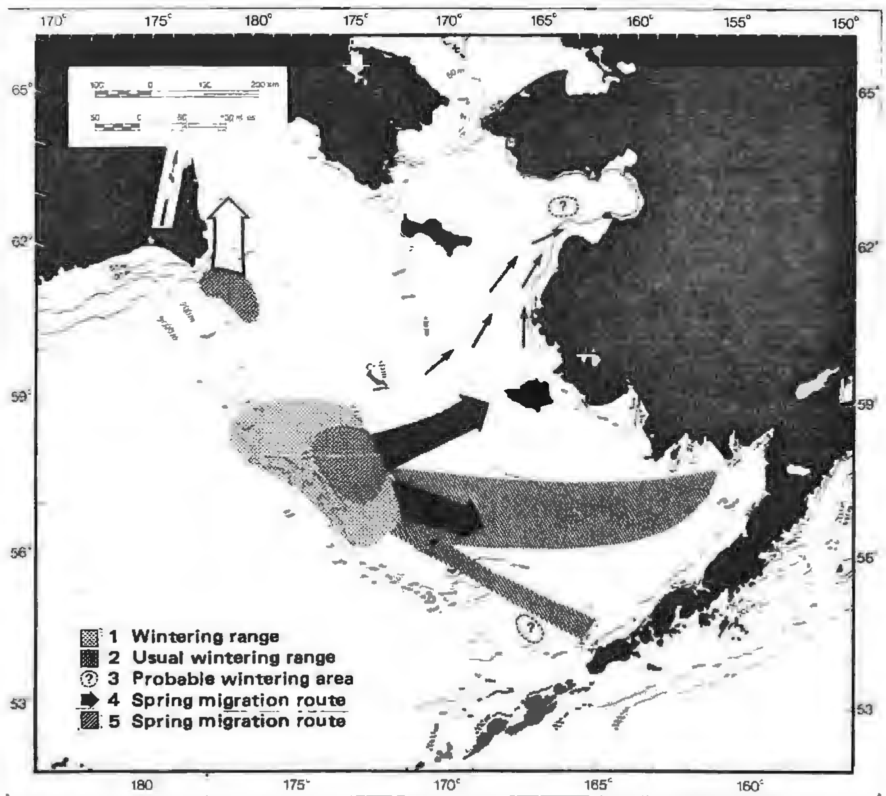

FIG. 7 Range of Pacific herring wintering area northwest of Pribilof Islands and average winter location of Pribilof and Gulf of Anadyr wintering area (1 and 2); possible wintering areas in Norton Sound and north of Unalaska Island (3); migration routes from Pribilof grounds to spawning areas: routes reported by Soviet researchers (4); routes shown by Japanese trawl catches during April and May (5); small arrows--possible routes to Norton Sound and Cape Romanzof.

smaller spawning concentrations occur to the north and south (see Fig. 4).

The relation of herring spawning in Norton Sound to spawning stocks to the south is unclear. Those in Norton Sound are genetically similar to spawning stocks to the south (Grant 1979) and appear in inshore waters in late May-early June (Barton 1978) which suggests they may winter offshore. However, it is possible that some or all herring remain in Norton Sound year-round. Barton (1978) reported that an autumn, non-spawning run occurs in Golovin Bay in northern Norton Sound, and herring have been caught through the ice by local residents jigging for cod in this area and near Nome. Further, herring have been found in ringed seal (P. hispida) stomachs collected near Nome in November. To the north of Norton Sound herring occur in Port Clarence, in inlets from the Bering strait to areas within Kotzebue Sound. Many, if not all, stocks found northward of Nome remain in the immediate area year-round and winter in coastal lagoons and brackish bays, even though in several locations (e.g., Port Clarence, Shismaref Inlet, and inner Kotzebue Sound) ice cover may occur (Barton 1978).

Herring may also occur along the Alaska Peninsula and throughout the Aleutian Islands. Marsh and Cobb (1911) reported that a large spawning occurred at Atka Island in 1910, and that spring and autumn runs (the latter presumably non-spawning) occurred at Unalaska and Port Heiden. The fishery which operated at Unalaska in the 1930's and 1940's harvested herring in summer and early autumn, averaging 1,337 mt between 1929-37. The current status of these stocks or their relationship to other eastern Bering Sea stocks is unknown. Recent aerial surveys by ADF&G have found small spawning concentrations on the north shore of Unimak Island, in Heredeen Bay, and in Port Heiden (Warner and Shafford 1977). Catches by Japanese trawlers just north of Unimak Pass in winter indicate that this may be the wintering area of herring spawning on the Alaska Peninsula (Wespestad 1978b).

Seasonal Distribution- Pribilof Stock

Temperature may be the major factor influencing seasonal distributions. Soviet scientists found the herring moving through subzero water temperatures in the spring on the way to spawning grounds, but during summer months they were found on the shelf in the warmer, upper layers of the water column (see Fig. 7). As stated previously, Svetovidov (1952) believes that migrations to the coast for spawning developed because of the lack of sufficiently warm water in spring and summer in the North Pacific Ocean. Also, earlier warming of coastal waters provides an earlier development of phytoplankton and zooplankton and better feeding conditions.

Winter

The major wintering grounds of eastern Bering Sea herring is located northwest of the Pribilof Islands, approximately between 57-59° N lat. representing an area of 1600-3000 km^2 (Shaboneev 1965) that shifts in relation to the severity of winter. In mild winters herring concentrate farther north and west, and in severe winters they move south and east (Fig. 8).

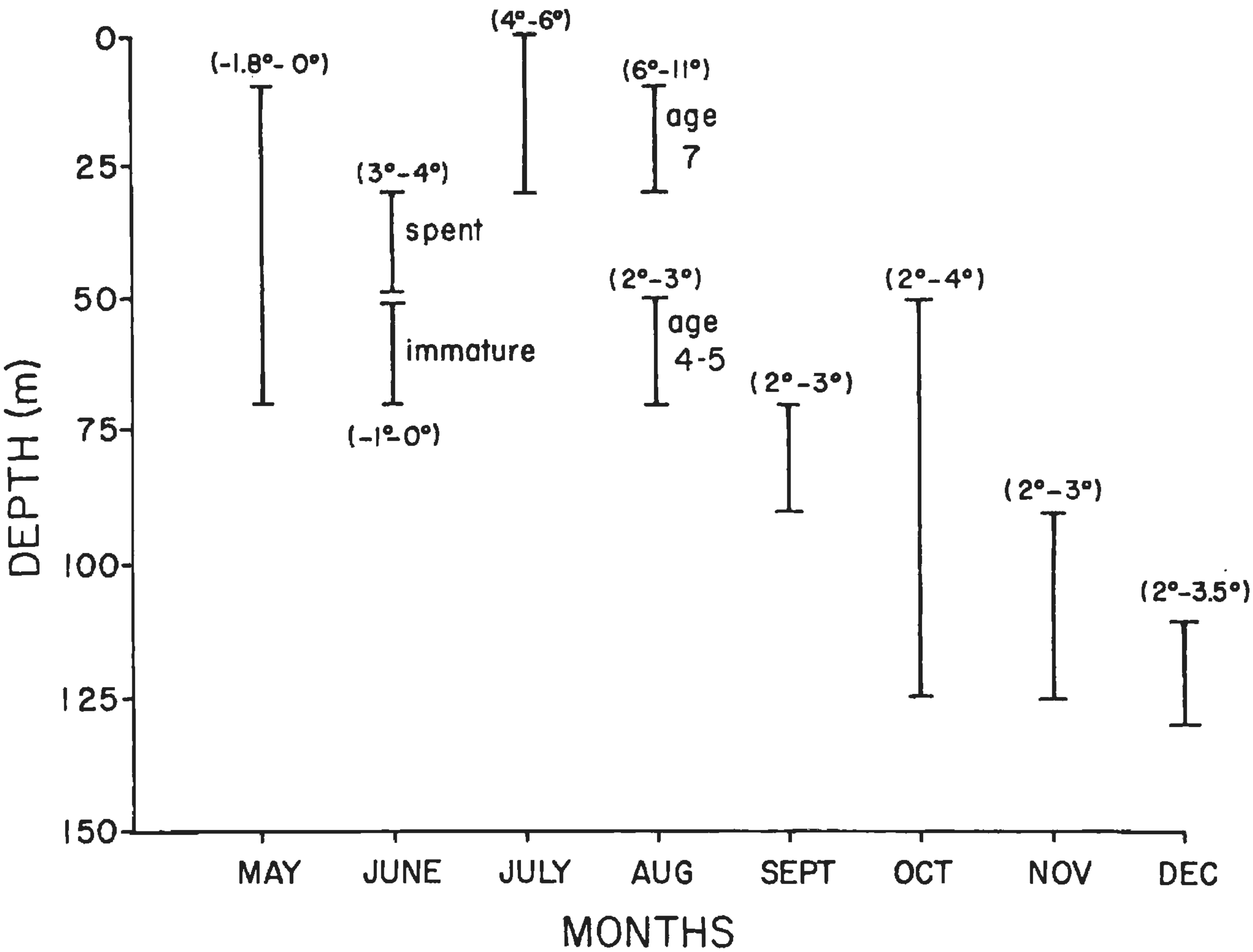

FIG. 8 Monthly distribution of Pacific herring by temperature and depth in the eastern Bering Sea. May-November data from Rumyant'sev and Darda (1970), December data from Shaboneev (1965).

Dense schools are found during the day a few meters off the bottom at depths of 105-137 m and at water temperatures of 2-3.5 C (Dudnik and Usol'tsev 1964). Very few were found shallower on the continental shelf where cooler temperatures prevailed. Distinct diurnal vertical migrations occur in early winters; however, as the season progresses diurnal movements diminish and herring remain on bottom during the day and slightly off bottom at night (Shaboneev 1965).

Spring

Soviet scientists investigating herring distribution in the mid-1960's found that herring left the wintering grounds in late March and believed that herring followed two routes to the coast, and Japanese trawl catches in April and May indicate one major and one minor path (see Fig. 8). The past two years (1978-79) have been mild winters and 1979 especially so. In these years, herring arrived on spawning grounds along the coast several days to two weeks earlier than average; while in 1976, a cold year, herring were not found until mid-June.

Summer

The failure of Soviet surveys in the mid-1960's using gillnets and trawls to locate herring concentrations on the Bering Sea slope or shelf in the summer suggested that most herring apparently remain temporarily in coastal waters after spawning. Annual NWAFC summer trawl surveys covering much of the continental shelf of the eastern Bering Sea support this conclusion, as very few herring have been taken in summer surveys (Pereyra et al. 1976; Bakkala and

Smith 1978). A hydroacoustic survey conducted along the outer shelf between Unimak Pass and the U.S.-U.S.S.R. convention line in June-July 1979 found only one herring in 2,558 nm and 35 midwater trawl hauls. These results indicate that only a small amount of herring may remain or return offshore in summer and the bulk remains in coastal waters. Summer distribution may be influenced by the availability of food and heavy phytoplankton blooms (1-3 g/m^3) (Rumyantsev and Darda 1979). They concluded that herring remained in coastal waters during the summer because heavy phytoplankton blooms occur there, and poor feeding conditions exist on the outer shelf. Those captured on the outer shelf during the summer were in poor condition and had been feeding on items of low nutritional value --items other than their preferred zooplankton diet. Herring are believed to avoid the areas of heavy bloom because of low nutritional value of phytoplankton and the gill clogging properties of certain phytoplankton species which interfere with respiration (Henderson et al. 1936).

Concentrations began reappearing in offshore waters in the areas of Nunivak and Unimak Islands in August (Rumyantsev and Darda 1970). The movement to offshore in the area of Unimak Island in August appears to be an annual occurrence, as U.S. fishery observers on foreign vessels first encounter herring in trawl catches in greater than trace amounts at that time and area.

The distribution of herring between the time they leave the spawning grounds and the time they reappear in offshore waters is unknown. Salmon fishermen report catching large herring frequently in salmon gillnets in coastal areas of Bristol Bay in late June and July. Also, Dudnik and Usol'tsev (1964), using drift nets, found commercial quantities of herring only in littoral areas along the northern portion of the Alaska Peninsula. The reappearance of seaward migrants in late summer in two locations suggests a summer migration along the coast (Fig. 9). Migration to winter grounds continues through September with the herring progressively moving to deeper water and concentrating in the 2-4 C temperature stratum.

Fall

Concentration on the winter grounds begins in October and continues into winter. Mature fish were found to arrive on the wintering grounds prior to the arrival of immature fish (Ramyantsev and Darda 1970). It was also found that immature fish had a preference or tolerance for lower temperature and saline waters of the shelf than did adult fish (Fig. 10).

Seasonal Distribution - North of Norton Sound

The annual cycle of herring occurring to the north of Norton Sound appears to be markedly different from that of herring in the central and southern Bering Sea. In these areas herring appear to move into brackish bays and estuaries for spawning and wintering, presumably finding suitable temperatures from fresh water rivers and streams. Barton (1978) found herring spawning in Imuruk Basin, a brackish forebay of Port Clarence, in 4 ^{o}/oo salinity. The herring dispersed following spawning and then reappeared in Imuruk Basin in mid-autumn.

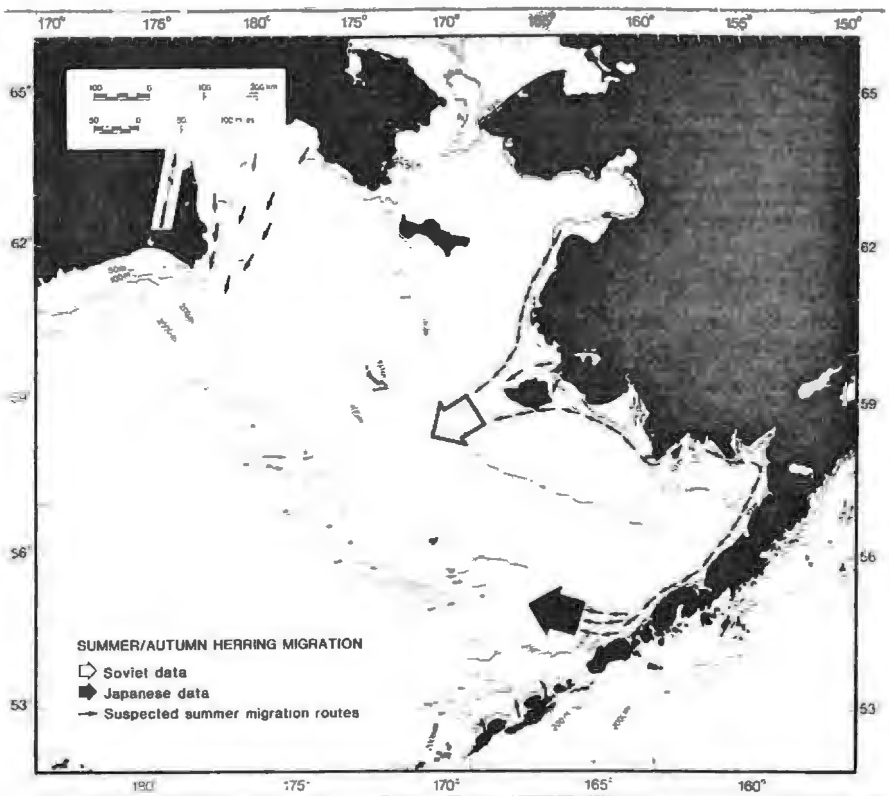

FIG. 9 Summer and autumn migration routes to winter grounds. Large solid arrow: area of reappearance in offshore waters as determined by Soviet research and Japanese catches, large dashed arrow: area of autumn reappearance in offshore waters reported from Soviet research, small arrows: possible summer feeding routes and autumn migration routes.

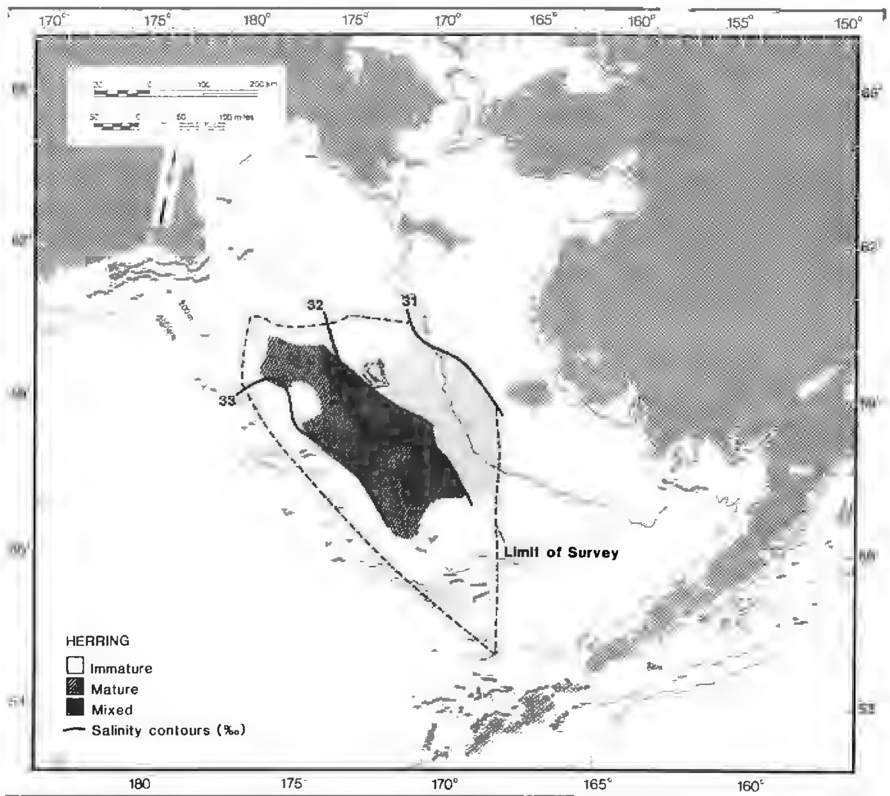

FIG. 10 Distribution of Pacific herring in October and the relationship of adults (mature) and juveniles (immature) to salinity gradients. (Modified from Rumyant'sev and Darda 1970.)

Large numbers of herring were found concentrated just outside Kotzebue Sound in 6-8 C water in September and October (Wolotira et al. 1977). It is possible that these herring move south with the advancing edge of the ice field, however some evidence suggests that they remain in the area through the winter. The phenomenon of herring moving into coastal waters in winter and offshore in summer has also been reported from Asia; Andriyashev (1954) reported that populations occur in Kamchatka, Sakhalin and Honshu which winter and spawn in brackish lakes and lagoons. Barton (1978) cites ADF&G records of herring being found in sheefish (*Stenodus leucichthus*) stomachs which were collected in Hotham Inlet, Kotzebue Sound in late November.

To the south of Kotzebue, on the northwest side of the Seward Peninsula, herring occurred in 11 of 14 stomachs of spotted seals (*P. largha*) collected at Shishmaref in October, and in 13 of 30 ringed seals collected in January and February. Marine mammal biologists who analyzed the stomachs indicated that there was little doubt herring were ingested in the area where seals were captured.

ABUNDANCE TRENDS AND STOCK STATUS

Estimates of absolute abundance are scant, and even relative abundance data are rather limited. Attempts have been made to estimate herring biomass by: 1) a Soviet hydroacoustic trawl survey; 2) ecosystem modeling; and 3) aerial surveys of spawning biomass.

In 1963, three years after the fishery began, the eastern Bering Sea herring biomass was estimated to be 2.16 million mt based on a Soviet hydroacoustic survey of the wintering grounds (Shaboneev 1965). A recent paper by Kachina (1978), using the same data, reduced this earlier estimate to 0.374 million mt by using a lower mean school density of 0.5 fish/m^3 compared to 3.38 fish/m^3 used for the original estimate. According to Shaboneev, schools were surveyed at night and the area and height of schools were mapped acoustically; school composition and age distribution were determined by trawling. The original density (3.38 fish/m^3) was determined by comparing acoustic echograms from the eastern Bering Sea to echograms of schools sampled by purse seines in western Bering Sea coastal water. The revised estimate of 0.5 fish/m^3 is based on densities observed in subsequent surveys of herring concentrations on the winter grounds northwest of the Pribilofs during 1969-71 (N. Fadeev, TINRO, Vladivostok, U.S.S.R., personal communication). The densities derived are questionable but cannot be fully evaluated because few specific details are available regarding Soviet survey methods and accuracy. However, data reported in the literature and from individuals involved with herring hydroacoustic surveys indicate that the range of densities used by the Soviets may be extreme and an intermediate value may be more realistic.

Recently, a numerical ecosystem model was applied to estimate biomass of eastern Bering Sea herring (Laevastu and Favorite 1978). This model simulated herring abundance based on the amount of herring needed to sustain the diet of herring predators at reported rates of consumption. Although the accuracy of input parameters, such as predator population size and consumption rates, has not been sufficiently evaluated, model results show that a minimum stock size of 2.75 million mt of herring is required to maintain components of the ecosystem, including predators, at a level observed in the mid-1960's prior to the start of intensive fishing.

Aerial surveys have been flown in the past several years along the western Alaska coast during the spawning period and the number of schools recorded by surface area (Barton 1979). Estimates of biomass were obtained by converting estimated school surface area, using densities of 0.1 and 0.2 mt/m^2 surface area.

The estimated spawning biomass along the coast from Bristol Bay to Norton Sound in 1978 was 432-864 thousand mt. These estimates include errors in determining surface areas and volumes of schools, recording schools of other fish such as capelin, smelt or sandlance as herring, and recording the same school more than once during the season; and, therefore, may be an overestimate of actual spawning biomass (Barton 1979).

Although biomass estimates are rather rudimentary, CPUE of the Japanese trawl fishery and ADF&G aerial surveys indicate that herring abundance declined sharply in the early 1970's and increased in the late 1970's. The CPUE (mt/hr) for Japanese large stern trawlers decreased from a high of 6.80 in 1969-70 to 0.77 in 1973-74 (Table III). The CPUE of small stern trawlers also declined. The CPUE of the Japanese gillnet fishery exhibited no trend, presumably because vessels were targeting on spawning concentrations which may not reflect population abundance (Wespestad 1978b).

TABLE III

Herring Catch Per Unit Effort Data for the Japanese Trawl and Gillnet Fisheries in the Eastern Bering Sea.

	Stern trawl		Gillnet
Year	Small Trawlers (mt/hour)	Large Trawlers (mt/hour)	(mt/10 tons)
1967	1.25	2.09	-
1968	1.75	4.63	.28
1969	0.81	6.80	.39
1970	1.06	6.74	.24
1971	0.56	1.52	.34
1972	-	1.84	.04
1973	-	0.77	.14
1974	0.29	0.17	.35
1975	-	-	.16
1976	-	-	-

ADF&G aerial surveys have indicated an increase in herring abundance in all major spawning areas during the 1976-78 period (Table IV). Preliminary assessment of observations in 1979 indicate a similar or slightly greater abundance relative to 1978. The longest series of aerial counts is from southern Norton Sound, extending back to 1968 and, similar to the trawl CPUE data, indicate a decrease in abundance during the early 1970's.

The current level of herring abundance cannot be related to former levels due to changes in the fishery. The catch and CPUE of foreign trawlers are no longer useful as indicators of abundance because herring are now largely incidental catches to other fisheries due to increased targeting on pollock, and the allowable catches of herring have been low in recent years (Wespestad 1978b).

Also, the absence of aerial surveys in major spawning areas prior to 1976 precludes the use of this method for determining the relationship of past to present biomass levels.

TABLE IV

Relative Abundance Indices of Spawning Herring Standardized to 1976 In Major Spawning Areas of the Eastern Bering Sea.1/

	1968	1972	1974	1975	1976	1977	1978
Bristol Bay	--	--	--	--	1.0	2.1	20.0
Goodnews Bay/ Security Cove	--	--	--	9.5	1.0	20.9	61.6
Nelson Island	--	--	--	0.5	1.0	1.0	3.2
Norton Sound: St. Michaels to Unalakleet	20.8	8.4	2.9	0.0 2/	1.0	--	4.2

1/ Relative abundance indices are corrected school counts weighted by surface area obtained from aerial surveys.
2/ Minimal survey effort.

Length and age frequency data indicated that catches in the late 1960's and early 1970's were composed of larger and older herring than in the past few years (Table V). These data suggested that recruitment was poor until recently and may have been a major contributing factor to a lower herring abundance. Recruitment appears to have increased beginning with the 1972 year-class (Fig. 11).

TABLE V

Mean Length of Herring Taken in the Fisheries by all Gear in all Months in the Eastern Bering Sea and Alaska Coastal Water.1/

	Foreign Trawl Fishery			Coastal Fishery		
Year	Mean Length (cm)	Sample Size	Probable Average Ages	Mean Length (cm)	Sample Size	Location of Sample
1964	26.60	3,101	7	23.30	339	Norton Sound
1965	29.83	155	8-9			
1966	27.16	48	6-7			
1967	26.20	99	5-6			
1968	29.04	4,771	8-9	28.60	350	Bristol Bay
1969	30.66	3,951	9-10			
1970	30.81	3,813	9-10			
1971	29.21	4,299	8-9			
1974						
1975						
1976			3-4	20.11	791	Bristol Bay
1977	23.40 2/	1,981	4-5	23.00	2,847	Bristol Bay
1978	23.28 3/	3,607	4-5-6	23.27	1,031	Bristol Bay

1/ Standard length for all coastal samples; fork length for foreign samples prior to 1978.
2/ Fork length (Nov. 1976-Feb. 1977) estimated standard length is 22.40 m.
3/ Standard length (Dec. 1977-Jan. 1978).

Sources: Foreign Fishery: Fisheries Agency of Japan, Rumyantsev and Darda (1970). U.S. observers on Japanese and Soviet vessels.

Coastal Fishery: Alaska Dept. Fish & Game, 1964 Annual Report; Bristol Bay Data Report No. 17; Barton et al. (1977). Warner & Shafford (1977).

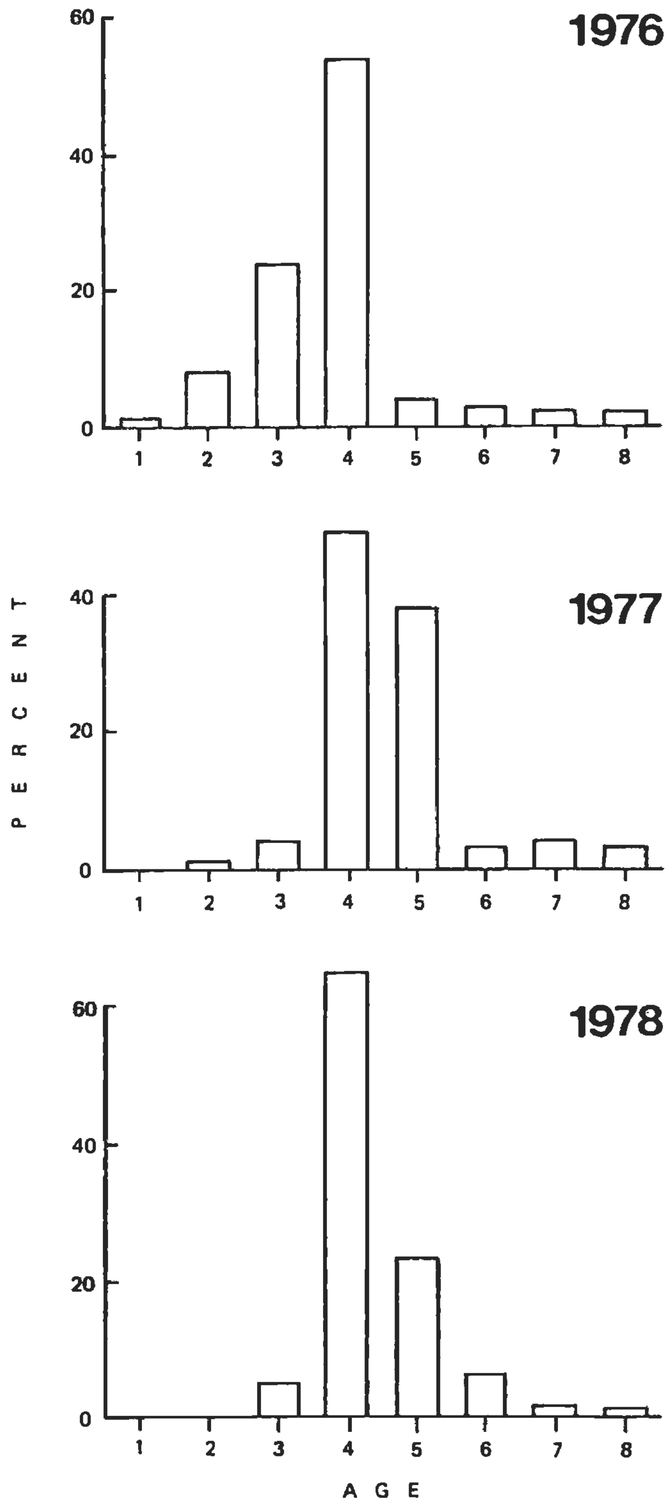

FIG. 11 Age frequency of Pacific herring in the Bristol Bay herring roe fishery, 1976-1978.

Age 4 herring comprised 54% of the catch in 1976, 50% in 1977; and in 1978 comprised 65% of the purse seine catch. In 1979, preliminary results suggest that the recuitment of age 4 herring is decreased from that observed in 1976-78; however, it appears that age 3 fish are present in higher amounts than in the recent past.

Year-class strength data presented recently by Naumenko (1979) show several years of relatively weak year-class strength in the 1960's and early 1970's (Fig. 12). These data suggest that the peak catches of the fishery were sustained by a few strong year-classes and that future yields of this magnitude are likely only in the event of a series of much above average year-classes or change in the ecosystem.

RESEARCH REQUIREMENTS

Research is required to refine estimates of abundance and biological characteristics of stocks; to improve the capability for predicting changes in resource abundance, composition and availability; and to identify the origin and distribution of herring in offshore areas.

Estimates of biomass of specific groundfish resources have been obtained through resource surveys using bottom trawls; however, herring are not generally available to bottom trawls, and other gear and methods must be used for assessing biomass. Hydroacoustic surveys, spawn deposition surveys and aerial surveys of schooled fish are some of the methods under consideration for biomass estimation.

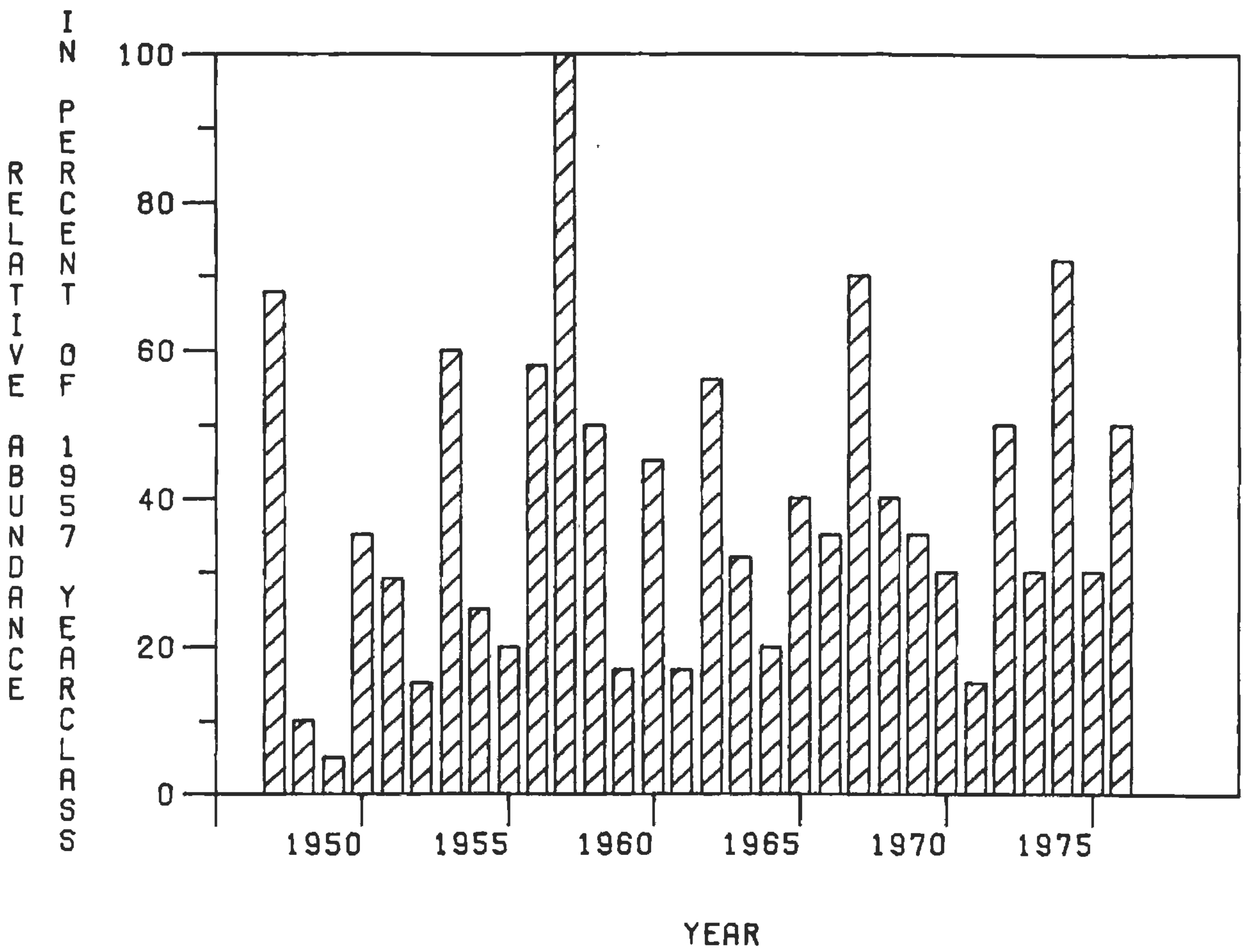

FIG. 12 Abundance of Pacific herring year-classes in the eastern Bering Sea relative to the 1957 year-class. (From Naumenko 1979.)

Hydroacoustic surveys in the nearshore areas just prior to or during spawning are probably not practical due to the many widely scattered schools that are constantly moving through the shallow waters. Optimum results can be expected on the winter grounds when herring are relatively stationary and concentrated. Results of surveys conducted during late winter-early spring could be applied in time for management of the roe fisheries.

Spawn surveys convert the amount of spawn deposited to the size of the adult population, using age-sex-size composition and fecundity data. Such surveys would have to be conducted immediately after spawning so as to not be affected by losses from predation and storms. The vast size of the area, including distances between spawning areas, lack of sub-tidal spawning information and various logistical problems, currently render this method impractical for the eastern Bering Sea.

In spite of limitations due to weather and narrow time-area coverage, aerial surveys may be one of the more cost-effective ways of measuring the abundance of spawning herring. Intensive testing should be made of school distribution within a limited area to determine if surveys are more effective at particular times and to investigate the variability of schools along sighting tracks. Also, aerial biomass estimation procedures and species identification procedures need to be developed. If a model of spawning school distribution could be developed, then statistical procedures could be used to overcome some of the weather and time limitations. Satellite technology may be a means of augmenting aerial surveys in that large schools may be observable at distances from the coast or spawn deposition (milt) may be observable from satellites. A combination of low level aircraft and satellite observations may provide answers to the effective coverage of tracklines and time-space distribution of schools.

Long-term fisheries management requires reliable forecasting of stock conditions. Until now, forecasts have been based mainly on past events, such as trends in abundance indices (CPUE's) and size and age composition of specific resources without any consideration of the interactions of these resources with each other and the environment. Studies need to be continued to determine for predictive purposes those factors that have major influences on the abundance, composition and distribution of resources. Monitoring certain oceanographic and climatological conditions (temperature, currents, etc.) in both the nearshore spawning-rearing grounds and the offshore wintering grounds may be very important in understanding fluctuations in herring abundance.

There is a critical need for annual pre-recruit surveys (i.e., of young fish before they enter the fisheries) so that a measure of their abundance can be used to forecast later contribution to the exploitable stock. Assessment of pre-recruit abundance could be made of juveniles in nearshore nursery areas or at a later age in more offshore waters. The major limitation for use of this method is the virtual absence of information relating to distribution of eastern Bering Sea herring during the first 2-3 years of their life cycle.

Basic biological research is needed to systematically investigate population parameters, such as age specific mortality rates, growth rates and recruitment rates. Investigations are also needed to establish the degree of utilization of herring in the diet of marine mammals, salmon and other predators so ecological effects of harvesting can be better evaluated.

Lastly, stock distribution needs to be investigated so that individual stocks within the eastern Bering Sea can be monitored with regard to relationship to other stocks and occurrence in fisheries.

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