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ASSESSMENT OF SPAWNING HERRING (*Clupea harengus pallasii*) STOCKS AT SELECTED COASTAL AREAS IN THE EASTERN BERING SEA

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ASSESSMENT OF SPAWNING HERRING (*Clupea harengus pallasii*) STOCKS AT SELECTED COASTAL WATERS IN THE EASTERN BERING SEA[1]

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

ABSTRACT

A 2-year study of Pacific herring, *Clupea harengus pallasii*, was conducted by the Alaska Department of Fish and Game along the eastern Bering Sea coast from Bristol Bay to Bering Strait to assess biomass and distribution of spawning populations as well as to collect other biological baseline data. Aerial surveys were used as the primary tool for gathering information on timing, distribution, and abundance, while ground crews deployed to selected areas along the coast obtained data on age, sex, size, and maturity composition using variable mesh gill nets to sample within major spawning areas.

Major herring spawning concentrations occurred in the Togiak District of Bristol Bay, Security Cove, Goodnews Bay, Nelson Island, and Cape Romanzof in the Yukon-Kuskokwim area, and at Klikitarik and Cape Denbigh in Norton Sound. Herring are known to spawn in the Shishmaref and Kotzebue areas, but occurrence of spawning and assessment of spawning biomass have not been documented north of Bering Strait. Generally, spawning occurred earliest in the Togiak District, and progressively later in northern areas. Older herring arrived on the spawning grounds and spawned earlier that younger herring. The arrival and peak of spawning was earlier in 1978 and 1979 than in prior years where data are available.

Migration corridors for adult, and feeding areas for juvenile herring have been tentatively identified in the Togiak District. Age composition of all stocks sampled indicated that the 1972, 1974, and 1976 year classes were strong in both study years. Sexual maturity was attained primarily at age 3 and 4 in 1978 and 1979; a larger proportion of age 2 herring were sexually mature in 1979 than in 1978. In general, sexual maturity is attained at an earlier age in the southern Bering Sea than in northern areas.

Abundance of herring in the eastern Bering Sea appears to have increased since 1978 in all major coastal areas. Total spawning biomass is estimated to have ranged from 187,210 to 334,723 mt in 1978, and from 258,079 to 637,583 mt in 1979, an indicated 27% increase at the lower range. The largest relative biomass increase since 1978 occurred in Security Cove and Goodnews Bay. Analysis of the distribution of the spawning biomass in 1979 shows that 84% of the total biomass spawned in the Togiak District, 13% in the Yukon-Kuskokwim area, and 3% in Norton Sound. Biomass distribution in 1978 was 92%, 5%, and 3%, respectively. Nearshore commercial fisheries in 1979 removed an estimated 5% of the total low range of spawning biomass; 5% in Bristol Bay, 1% in the Security Cove-Goodnews area, and 17% in Norton Sound.

INTRODUCTION

Background

This report presents results of the Alaska Department of Fish and Game (ADF&G) research on eastern Bering Sea herring (*Clupea harengus pallasii*) partially funded by the North Pacific Fishery Management Council (NPFMC) from March 1978 through September 1979, a period that included two herring spawning seasons. Lack of baseline information on eastern Bering Sea herring spawning stocks, together with responsibility of the NPFMC to develop a fishery management plan for this species within the offshore Fishery Conservation Zone (FCZ) prompted these studies. The Fishery Conservation and Management Act of 1976 requires the NPFMC to prepare a final management plan based upon the "best available" information.

The need for research is especially urgent in view of the rapidly growing inshore domestic fisheries. Following inception of the inshore herring sac roe fisheries in the eastern Bering Sea in the mid 1960's, herring catches and fishing effort remained low until recent years. Due to favorable market conditions and high prices for sac roe herring, both catch and effort have dramatically increased since 1977. A record domestic harvest of nearly 12,000 metric ton (mt) of herring and 200 mt of spawn-on-kelp with a combined ex-vessel value of nearly $8.5 million was landed in 1979.

As primary management agency for inshore fisheries, the ADF&G has acquired information on herring spawning stocks in the study area since the early 1960's. Consequently, ADF&G contracted with the NPFMC to conduct the studies forming the subject of this report.

Specific Objectives

Research objectives were to describe and monitor separate spawning stocks of herring and to evaluate their distribution, abundance, and spawning success along the eastern Bering Sea coast. A secondary objective was to evaluate abundance survey methods for validity, practicality, and future application. Some of the specific objectives were as follows:

1) Describe the spatial and temporal distribution and relative abundance of spawning herring at selected sites in the eastern Bering Sea;

2) Evaluate estimation methods of surface area and biomass of herring and other forage fish schools observed during aerial surveys;

3) Monitor age, sex, size, and relative maturity of herring stocks by gear types at selected sites in the eastern Bering Sea;

4) Interpret stock strength and determine to what extent stock strength is affected by commercial harvests;

5) Monitor type and extent of spawning substrates and spawn deposition at selected sites in the eastern Bering Sea; and

6) Integrate these studies with National Marine Fisheries Service (NMFS) offshore herring studies and supply supplemental data and specimens to NMFS to facilitate stock differentiation efforts.

STUDY AREAS

The study area was all coastal waters of the eastern Bering Sea from Port Moller to Bering Strait, a shoreline distance of approximately 4,000 km (Figure 1). Aerial surveys covered most of this coastline in 1978, but in 1979 was restricted to north of 58° N. latitude. The area south of 58° N. latitude was not surveyed in 1979 in view of the high monetary costs required together with the fact that very few spawning herring were observed in this region from 1976-1978. Shorebased studies were carried out at eight coastal locations from Bristol Bay to Port Clarence: Metervik Bay, Tongue Point, Security Cove, Goodnews Bay, Nelson Island, Cape Romanzof, Cape Denbigh, and Grantley Harbor. Goodnews Bay was only sampled in 1979 and Security Cove in 1978. Remaining areas were sampled in both years.

These eight locations typify major herring spawning areas in the eastern Bering Sea. With the exception of Grantley Harbor and Goodnews Bay, remaining areas can be described as rocky headlands which are exposed to extreme weather and sea conditions. The rockweed, *Fucus* sp., is the dominant intertidal vegetation and is subject to disturbance from frequent storms and possible ice scouring during winter months. Grantley Harbor is part of an extensive estuarine area formed by the mixing of freshwater from Imuruk Basin and marine waters of Port Clarence. Present data indicate spawning herring populations pass through Grantley Harbor enroute to Imuruk Basin, a shallow area where eelgrass (*Zostera* sp.) is a common substrate. Likewise, Goodnews Bay is a shallow body of water with a sand and mud bottom. Eelgrass is the dominant subtidal vegetation. Both Imuruk Basin and Goodnews Bay are subject to extensive ice scouring.

Coastal waters north of Cape Romanzof are less saline and remain ice covered for a longer period due to freshwater intrusion from several major rivers, the largest of which is the Yukon River.

METHODS

Aerial Surveys

At least three aerial reconnaissance surveys were flown throughout the study region following ice breakup to determine timing of spawning herring stocks. Sixteen index areas were established along the coast for analysis and presentation of aerial survey results (Table 1). Most index areas are adjacent to major herring spawning areas identified from prior research in the eastern Bering Sea. Surveillance of primary spawning areas was made as frequently as possible after arrival of herring. Additional surveys were conducted in major spawning areas to monitor size, effort, and distribution of commercial herring fleets.

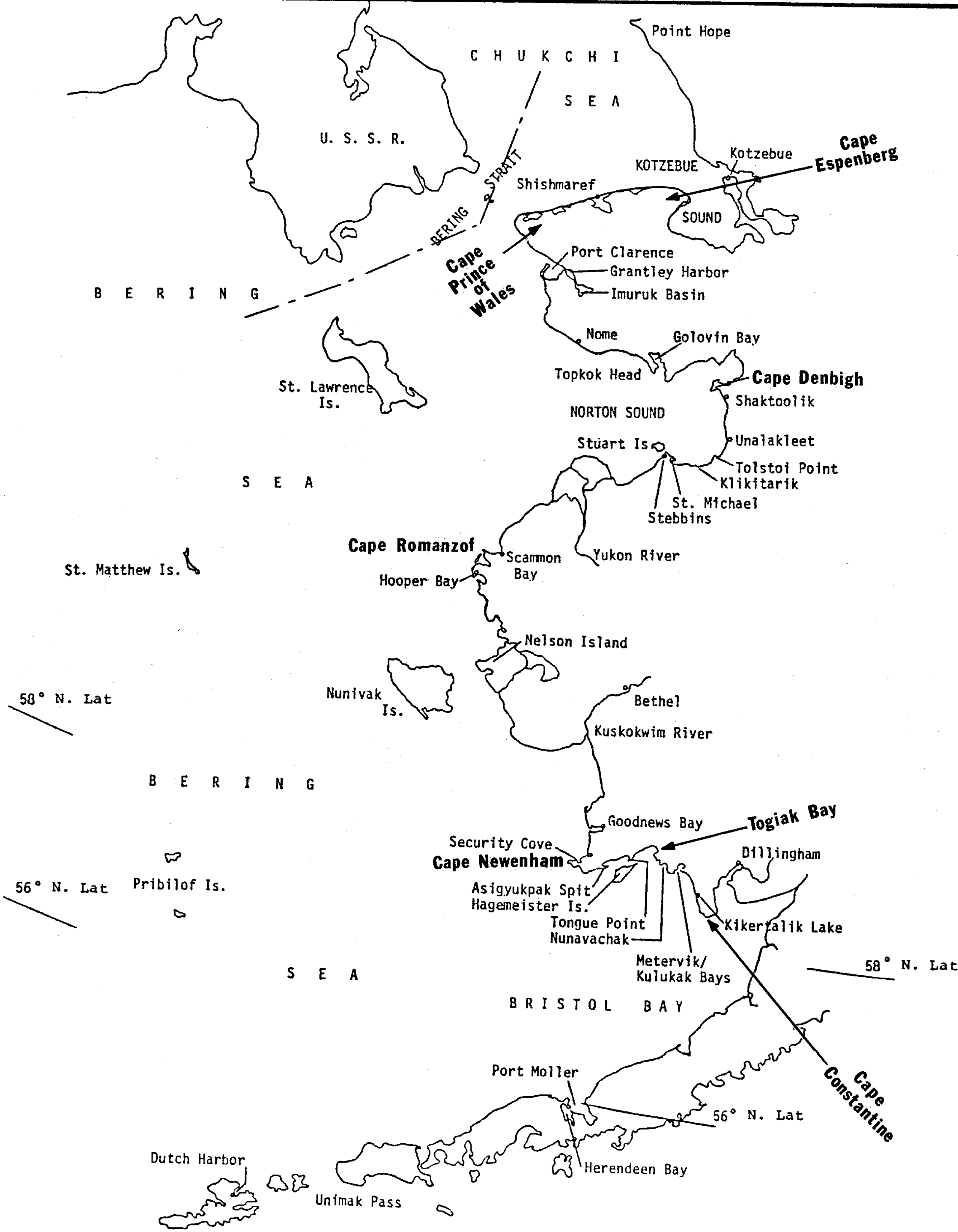

Figure 1. Eastern Bering Sea study area, 1978 - 1979.

Table 1. Eastern Bering Sea herring aerial survey index areas.

Index Area	Description
Nushagak	From approximately 10 miles south of Kikertalik Lake to west spit of Tvativak Bay.
Kulukak	From west spit of Tvativak Bay to Right Hand Point
Nunavachak	From Right Hand Point to Ungalikthluk Point.
Ungalikthluk	From Ungalikthluk Point to Togiak Point.
Togiak	From Togiak Point to Tongue Point.
Matogak	From Tongue Point to Asigyukpak Spit.
Security Cove	From Cape Newenham to entrance of Chagvan Bay.
Goodnews Bay	All waters of Goodnews Bay.
Nelson Island	From Kolavinarak River to Ninglick River (Hazen Bay).
Cape Romanzof	From Hooper Bay village to Scammon Bay village.
Klikitarik	From Cape Stebbins to Unalakleet River including Stuart Island.
Unalakleet	From Unalakleet River to Shaktoolik River.
Cape Denbigh	From Shaktoolik River to Point Dexter.
Norton Bay	From Bald Head to Cape Darby.
Golovin Bay	From Cape Darby to Rocky Point.
Bluff	From Rocky Point to Cape Nome.

Surveys were conducted from chartered single engine, fixed-wing aircraft at altitudes ranging from 75 to 500 m and airspeeds of about 160 to 260 km/hr. Data were recorded either directly onto aerial survey forms or into portable tape recorders for subsequent transcription onto forms. The number, size, and location of sighted fish schools were noted on aerial survey maps. Additional data collected during each survey included altitude, date, time, weather and sea conditions, occurrence of predators, and commercial and subsistence fishing effort. Polaroid sunglasses were used to reduce sun-glare and enhance water depth visibility. Each survey was given an overall rating by the observer ranging from excellent to unacceptable, based upon visibility conditions at the time the survey was flown.

The relative abundance of fish was estimated by recording sighted fish schools into one of five categories: (1) small schools (estimated surface area of less than 50 m^2), (2) medium 1 schools (surface area between 50 to 254 m^2), (3) medium schools (surface area between 50 to 450 m^2), (4) medium 2 schools (surface area between 255 to 450 m^2), and (5) large schools (surface area greater than 450 m^2). Further, the surface area of each large school was estimated and recorded. These same size categories were used in previous ADF&G herring surveys in the eastern Bering Sea (Barton 1978; Barton et al. 1977).

The following techniques were used in obtaining surface area estimates of fish schools: (1) observing schools through handheld grids calibrated for various altitudes, (2) traversing large schools at known airspeeds and using a stop watch to determine school size, (3) comparing school size with known distances between geographical land features, and (4) comparing school size with known surface areas marked or measured on the ground.

Daily fish school counts in each index area were weighted by surface area and an adjusted count was derived. Fifty square meters (the maximum size of a small school) was arbitrarily selected as the base. For example, two large schools with a total combined surface area estimate of 10,000 m^2 was adjusted to a count of 200, the equivalent of 200 schools each with a 50 m^2 surface area. All medium 1, medium, and medium 2 schools were adjusted by factors of 3, 5, and 7, respectively. This was done since the midpoint of each of these size categories is 3, 5, and 7 times greater, respectively, than 50 m^2. The daily adjusted school count was termed the relative abundance index (RAI).

Daily RAI's were related to fish abundance by applying tonnage conversion factors obtained from estimates made on changes in school surface area before and after removal of a known weight of fish by commercial purse seines.

Attempts were made during aerial surveys to differentiate herring from other fish species based upon school behavior and appearance. Test fishing records and commercial fishing reports were also evaluated to help determine species composition.

Test Gillnetting

Two or three-man crews sampled major herring spawning grounds at seven locations in 1979: Metervik Bay, Tongue Point, Goodnews Bay, Nelson Island, Cape Romanzof, Cape Denbigh, and Grantley Harbor. In addition, a single trip was made north of Bering Strait to collect herring samples for comparison with samples taken further south. All crews operated from either rubber rafts or open skiffs and sampled coastal waters with variable mesh gill nets. Gill nets were multifilament nylon consisting of six 8 m panels with the following stretch mesh sizes: 25, 38, 51, 64, 76, and 102 mm. Gill nets measured 48 m long by 3 m deep. These gill net specifications were selected to maintain consistency with gill net sampling by ADF&G on eastern Bering Sea herring in previous years.

Both sinking and floating sets were made. A few sets were made at high tide and picked on the following high tide. This occurred primarily in Bristol Bay and Goodnews Bay where larger tides exist, than farther north. When herring were abundant, gill nets were fished under constant attendance for short periods of time (tidal conditions permitting) to avoid net saturation and excessive catches. All nets were fished at random locations; no pre-established stations were utilized. Surface water temperatures were measured daily with pocket thermometers by each crew. Total catch by species was recorded for each gill net set along with date, location, and duration of each set.

A minimum of 800 herring were to be sampled at each location for age, sex, size, and relative maturity. Relative maturity was determined from criteria listed in Table 2. For data analysis, all herring of ages 1 or 2 were considered sexually mature only if their gonad index was 5 or higher. All age 3 herring were considered sexually mature which had gonad indices of 5 or higher plus 50% of all age 3 herring with gonad indices of 3 or 4. All age 4 herring were considered sexually mature which had gonad indices of 5 or higher plus 78% of all age 4 herring with gonad indices of 3 or 4. Herring of age 5 and older were recorded as sexually mature if gonads indices were 3 or higher. This rationale for determining relative maturity of age 3 and 4 herring as described above is based upon maturity findings on eastern Bering Sea herring by Rumyantsev and Darda (1970).

The first 400 herring captured were processed in the event no more were captured. Therefore, catches were subsampled when necessitated by volume of catch and physical limitation of sampling crews. Subsamples collected were weighted by the percentage of the total catch in each panel. Samples were generally processed within 48 hours. All herring were measured to standard length and scales were mounted on glass slides for subsequent aging.

Reid (1971) pointed out that new annuli on herring scales appear near the time of spawning. Consequently, herring were generally aged by counting the number of annual rings plus the outer edge of the scale to determine fish age in years. However, with some samples, a value judgment was made to count only annuli and not the outer edge of the scale. This occurred when it was determined that the portion of the scale from the outermost annulus to the scale's edge was a result of new summer growth (plus growth) of the current year. All herring scales were aged by two or more experienced ADF&G biologists.

Table 2. Characteristics and indices used to determine the relative maturity of Pacific herring.

Index	Key Characteristics
1	Virgin herring. Gonads very small, threadlike, 23 mm long. Ovaries wine red. Testes whitish or gray brown.
2	Virgin herring with small sexual organs. The width of ovaries and testes about 3-8mm. Eggs not visible to naked eye, but can be seen with magnifying glass. Ovaries a bright red color, testes a reddish gray color.
3	Gonads occupying about half of the ventral cavity. Width of sexual organs between 1 and 2 cm. Eggs small but can be distinguished with the naked eye. Ovaries orange; testes reddish gray or grayish.
4	Gonads almost as long as body cavity. Eggs larger varying in size, opaque. Ovaries orange or pale yellow; testes whitish.
5	Gonads fill body cavity. Eggs large, round; some transparent. Ovaries yellowish testes milkwhite. Eggs and sperm do not flow, but sperm can be extruded by pressure.
6	Ripe gonads; eggs transparent; testes white; eggs and sperm flow freely.
7	Spent herring gonads baggy and bloodshot. Ovaries empty or containing only a few residual eggs. Testes may contain remains of sperm.
8	Recovering spents. Ovaries and testes firm and larger than virgin herring in stage 2. Eggs not visible to naked eye. Walls of gonads striated; blood vessels prominant. Gonads wine red color. This stage passes into stage 3.

Gear Selectivity Studies

Gear selectivity studies were conducted at Metervik Bay and Tongue Point to examine differences in size and age composition between herring samples from variable mesh gill nets and commercial purse seines. Gill nets were deployed adjacent to purse seine vessels making commercial sets and samples collected from the catch of each gear type for subsequent analysis.

Substrate Mapping

Exposed beaches and shallow nearshore waters were examined at each study site, with the exception of Grantley Harbor and Shishmaref, for the presence of deposited herring spawn. Maps were prepared showing the distribution and density of herring spawn and vegetative substrates. Spawn density was estimated by the method of Humphreys and Hourston (1978) while distribution and relative density of vegetative substrates was subjectively evaluated as follows:

1) very light	1-10% coverage,
2) light	11-35% coverage,
3) medium	36-65% coverage, and
4) heavy	66-100% coverage.

Percent egg mortality and percent hatching was visually estimated from the frequency of opaque (dead) eggs and empty egg cases, respectively.

Stock Identification

In addition to field work and sampling methods discussed above, at least 200 herring were collected from each area, frozen, and shipped to the NMFS, Montlake laboratory in Seattle for subsequent stock separation analysis.

RESULTS

Aerial Surveys

A total of 38 individual aerial surveys were flown throughout the study area from 30 April through 28 June 1979. Surveys were initiated with arrival of spawning herring and intensified during peak spawning. Aerial surveillance totaled approximately 84 hours of airtime on 28 separate days. Coastal coverage amounted to more than 8,000 km of which about 47% of this effort was between Cape Constantine and Cape Newenham (Togiak District), 29% between Cape Newenham and Cape Romanzof, and 24% from Norton Sound to Cape Prince of Wales (Figure 1).

A total of 2,826 fish school sightings were recorded during the survey period in 1979 with the highest percentage (63% or 1,782 sightings) in the Togiak commercial herring fishing district. Only 12% (335 sightings) were in the Yukon-Kuskokwim Delta region. Twenty-three percent (652 sightings) were documented in coastal waters of Norton Sound from Stuart Island to Cape Nome, while 2% (57 sightings) were recorded north of Cape Nome. Only eight fish schools were seen north of Nome in 1979, but only two surveys were flown in that area as a result of budget limitations.

A number of schools judged to be capelin (*Mallotus villosus*) were excluded from a single survey flown on 14 May. These fish were excluded, due to intense commercial spotting air traffic, so more time could be spent in accurately assessing the numerous fish schools occurring in offshore areas. This survey included part of Goodnews Bay, Security Cove, and that part of the Togiak fishing district from Asigyukpak Spit to Cape Newenham. Schools excluded were only those occurring in very narrow bands (< 3 m in width) occupying immediate surf zones along sand and gravel beaches. Beach-stranded capelin carcasses were visible from the air. All schools not occupying the immediate surf zone were counted, regardless of species. Excluding the 14 May survey, it was estimated from aerial survey data alone, that at least 10% of recorded schools in 1979 in the southern portion of the study area south of the Yukon River were capelin.

North of the Yukon River, at least 172 (24%) of the 709 school sightings were estimated to have been non-herring species. The majority of these non-herring species were located along the coast of northern Norton Sound between Golovin Bay and Nome, an area where capelin, sand lance (*Ammodytes hexapterus*), and smelt (*Osmeridae*) are common (Barton 1978). No test fishing was conducted in that region in 1979.

Capelin appeared throughout the entire study area in large numbers in 1979. Areas where they were most abundant were in the western part of the Togiak fishing district, throughout the Security Cove and Goodnews Bay fishing districts, at Nelson Island, and coastal areas near Nome. Abundance of capelin, based on aerial survey data alone, was judged to have peaked from about mid to late May in 1979.

Togiak District:

Fifteen surveys were flown in the Togiak District from 30 April through 26 May 1979 (Table 3). A total of 1,782 herring schools were observed in six major index areas and each school was categorized by size.

A total of 36.4 km of milt (spawn) was recorded on 9 days. Peak of spawning based upon these observations occurred during the first week of May when more than 30 km of milt was recorded. This peak in spawning, based on aerial surveys, was nearly 2 weeks earlier than Togiak District peak spawning in 1978. In contrast to peak spawning, herring abundance in the Togiak District was estimated to have been greatest on 10 May 1979. Corresponding peak abundance in 1978 was estimated on 13 May.

An estimate was made in Ungalikthluk Bay on 5 May 1979, relating herring school surface area to biomass. An entire school of herring with a 298 m^2 surface area was removed by a commercial purse seiner. Total weight of the school was determined to be 14.5 mt (or 2.4 mt per 50 m^2 of surface area).

Table 3 . Relative size and abundance of fish schools in the Togiak District of Bristol Bay, based on aerial surveillance from 30 April through 26 May.

Area	Date	Survey Index 1/	Number of Fish Schools Observed by Size 2/ Small	Medium 1	Medium	Medium 2	Large	Total	Adjusted count (RAI) 3/
Nushagak Index	5/2	P						None	
	5/3	P		4		7		11	61
	5/4	G					6	6	17,355
	5/5	G-F					3	3	18,724
	5/7	P					1	1	981
	5/9	P-U						None	
	5/10	G	2	1			48	51	76,783
	5/12	P-U						None	
	5/14	G	6		48		6	60	340
	5/16	F						None	
	5/17	F-P				5	10	15	337
	5/21	P-U						None	
	5/24	G-F						None	
	5/26	G						None	
Total			8	2	48	12	74	147	
Kulukak Index	4/30	P						None	
	5/2	P						None	
	5/3	P-U						None	
	5/4	G-P		21		37	3	61	563
	5/5	F-P	4			54	34	92	29,918
	5/7	F-P	18	20		18	12	68	24,389
	5/9	P-U						None	
	5/10	G	4		19		7	30	12,312
	5/12	P						None	
	5/14	G-P		1				1	-
	5/16	F-P						None	
	5/17	F-P	2					2	-
	5/21	P						None	-
	5/24	G-F	6					6	-
	5/26	G-F						None	
Total			34	42	19	109	56	260	
Nunavachak Index	4/30	U				6		6	42
	5/2	F-P					3	3	900
	5/3	F-P		1				1	5
	5/4	G	3	11		5		19	71
	5/5	G	30	30			4	64	326
	5/7	F	12	6		3	1	22	91
	5/9	P-U	1		9			10	46
	5/10	G	6		3			9	21
	5/12	P	9		14			23	79
	5/14	G	25		2			27	31
	5/16	F-P			2			2	6
	5/17	F-P	22				2	24	62
	5/21	P-U						None	
	5/24	F	4	2				6	10
	5/26	G	21	2		1		24	34
Total			133	52	30	15	10	240	

Table Continued

Table 3 .(Continued) Relative size and abundance of fish schools in the Togiak District of Bristol Bay, based on aerial surveillance from 30 April through 26 May.

Area	Date	Survey Index [1/]	Number of Fish Schools Observed by Size [2/]						Adjusted count (RAI) [3/]
			Small	Medium 1	Medium	Medium 2	Large	Total	
Ungalikthluk Index	4/30	P	1	1		24	2	28	752
	5/2	F-P	2	17	70	17	6	112	1,004
	5/3	F-P	1	7		6	3	17	317
	5/4	G	15	2		37		54	280
	5/5	G	42	11		12		65	159
	5/7	F	4	18				22	58
	5/9	P					2	2	743
	5/10	U	Survey aborted - intense fishing and air spotting traffic						
	5/12	P-U	7		3			10+	+
	5/14	G	9		4			13	29
	5/16	F-P						None	
	5/17	F-P						None	
	5/21	P-U						None	
	5/24	G-F	1	16		1		18	56
	5/26	G				1		1	7
Total			82	72	77	98	13	342	
Togiak Index	5/2	F-P	14	19				33	71
	5/4	G	18	9		31	25	83	1,460
	5/5	G	18	20		24	24	86	486
	5/7	G-F	34	26		46	10	116	65,602
	5/10	G	27		50		7	84	46,956
	5/12	P	14				1	15	13,066
	5/14	G	32		78		27	137	2,522
	5/16	F-P					17	17	474
	5/17	G-F						+	
	5/24	G-F	5	1			15	21	2,768
	5/26	G			15		88	103	2,767
Total			162	75	143	101	214	695	
Matogak Index	5/7	F-P	19	16		27	18	80	932
	5/12	P-U			1			1	+
	5/14	G-F	5		5		2	12	699
	5/17	G-F						None	
	5/24	F						None	
Total			24	16	6	27	20	93	
Remaining areas in Togiak District	5/14	E					5	5	
TOTAL TOGIAK DISTRICT			443	262	323	362	392	1,782	

1/ Survey rating index: E - Excellent; G - Good; F - Fair; P - Poor; U - Unacceptable.

2/ Fish School Categorization: small - surface area less than 50 m^2.
medium 1 - surface area between 50-254 m^2.
medium - surface area between 50-450 m2.
medium 2 - surface area between 255-450 m^2.
large - surface area greater than 450 m2.

3/ RAI - Relative abundance index - adjusted school counts weighted by surface area using 50m2 as a base.

Security Cove District:

Aerial surveillance of the Security Cove fishing district in the Yukon-Kuskokwim Delta area included four surveys flown 8, 14, 17, and 24 May (Table 4). Peak herring abundance was estimated on 14 May. In addition, large concentrations of capelin were also observed on 14 May throughout most of the district's shoreline waters, particularly south of Goodnews Bay. Light patches of milt were observed in Security Cove on 14 May while 2 km of milt were recorded on 17 May.

Goodnews Bay District:

A total of five surveys were flown from 8 May through 24 May 1979, of the Goodnews Bay fishing district (Table 4). Peak herring abundance was estimated on 17 May when large concentrations were observed near Little Beluga Mountain. No milt was observed.

Nelson Island-Cape Romanzof:

Four surveys were flown of the Nelson Island area in 1979 from 14 May through 25 May and four surveys of Cape Romanzof from 16 May through 31 May (Table 4). All attempts were hindered by inclement weather or turbid water conditions. Abundance estimates could not be made for these areas. Other surveys were planned but were not attempted as a result of poor weather.

Norton Sound District:

A total of thirteen surveys were flown in Norton Sound from Stuart Island to Nome (Figure 1) from 15 May through 9 June 1979 (Table 5). Peak herring abundance from Stuart Island to Unalakleet was estimated on 21 May (Klikitarik Index Area). This differed from the peak estimate north of Unalakleet to Pt. Dexter (Unalakleet and Cape Denbigh Index Areas) by about one week. The highest estimate from Unalakleet to Shaktoolik (Unalakleet Index Area) was on 30 May and on 28 May at Cape Denbigh (Cape Denbigh Index Area). Herring abundance in Norton Bay (Norton Bay Index Area) and Golovin Bay (Golovin Bay Index Area) was estimated to be highest on 2 June. Nearly 82% of the estimated herring biomass in Norton Sound in 1979 was observed between Stuart Island and Cape Denbigh. However, this region received more intense aerial coverage than areas north of Cape Denbigh. Only 1.0 km of milt was recorded in Norton Sound in 1979.

Shorebased Studies

The periods of coverage of shorebased studies at seven coastal areas in 1979 were as follows:

1) Metervik Bay 4/29-6/10,
2) Tongue Point 5/8-6/5,
3) Goodnews Bay 5/12-6/8,
4) Nelson Island 5/15-6/12,
5) Cape Romanzof 5/12-6/8,
6) Cape Denbigh 5/24-6/14, and
7) Grantley Harbor 6/19-6/21.

Table 4. Relative size and abundance of fish schools in the Yukon-Kuskokwim Delta area based on aerial surveillance from 8 May through 31 May 1979.

Area	Date	Survey Index [1/]	Number of Fish Schools Observed by Size [2/] Small	Medium 1	Medium	Medium 2	Large	Total	Adjusted count (RAI) [3/]
Security Cove Index	5/8	E	4				2	6	-
	5/14	E	21	5		52	21	99	2,912
	5/17	E-G	2		3		1	6	135
	5/24	G	87	22		13	3	125	288
Total			114	27	3	65	27	236	
Goodnews Bay Index	5/8	F-P	1	3				4	10
	5/13	F	2					2	2
	5/14	G	6	2		1		9	19
	5/17	G	1				2	3	3,729
	5/24	U	1					1	1
Total			11	5	0	1	2	19	
Jacksmith Bay	5/24	G	7	3		15	17	42	1,297
Nelson Island Index	5/14	F	8	1		1		10	18
	5/28	G-U						None	
	5/22	F	6	1		1		8	16
	5/25	P	15					15	15
Total			29	2	0	2	0	33	
Cape Romanzof Index	5/16	U						None	
	5/22	P				1		1	7
	5/25	P	3	1				4	6
	5/31	U						None	
Total			3	1	0	1	0	5	
TOTAL YUKON-KUSKOKWIM AREA			164	38	3	84	46	335	

1/ Survey rating index: E - Excellent; G - Good; F - Fair; P - Poor; U - Unacceptable.

2/ Fish School Categorization: small - surface area less than 50 m^2.
medium 1 - surface area between 50-254 m^2.
medium - surface area between 50-450 m^2.
medium 2 - surface area between 255-450 m^2.
large - surface area greater than 450 m^2.

3/ RAI - Relative abundance index - adjusted school counts weighted by surface area using $50m^2$ as a base.

Table 5 . Relative size and abundance of fish schools in Norton Sound based on aerial surveillance from 15 May through 22 June 1979.

Area	Date	Survey Index 1/	Small	Medium 1	Medium	Medium 2	Large	Total	Adjusted count (RAI) 3/
			Number of Fish Schools Observed by Size 2/						
Klikitarik Index	5/15	E-F	50		7			57	85
	5/21	E-F	94	54		30	8	186	797
	5/27	-			Fleet Survey			-	
	5/30	U						None	
Total			144	54	7	30	8	243	
Unalakleet Index	5/15	F-P	9					9	9
	5/21	G	6					6	6
	5/23	P	3	1				4	6
	5/27	-			Fleet Survey			-	
	5/28	F	8	4		4	1	17	67
	5/30	F-P	35	12		3		50	92
	5/31	-			Fleet Survey			-	
Total			61	17	0	7	1	86	
Cape Denbigh Index	5/15	E-F						None	
	5/21	G	11	3		1		15	146
	5/23	P						None	
	5/24	G	7	3		3	1	14	48
	5/27	-			Fleet Survey				
	5/28	E	19	7		18	12	56	627
	5/30	E-U	4	5		1	1	11	212
	5/31	-			Fleet Survey				
	6/2	E	1	2				3	7
	6/9	E	1	3				4	10
Total			43	23	0	22	15	103	
Norton Bay Index	5/28	E	2					2	2
	6/2	E	9	6		5	2	22	62
	6/9	F	17	6		2		25	49
Total			28	12	0	7	2	49	
Golovin Bay Index	5/28	G						None	
	6/2	E	10	1		3		14	34
	6/9	G	8	4		1		13	27
Total			18	5	0	4	0	27	
Bluff Index	5/28	E-G	20	2				22	26
	6/2	E-G	33	8		5	2	48	103
	6/9	G-P	48	19		4	3	74	248
Total			101	29	0	9	5	144	
Cape Nome - Nome	5/28	G-F	24	3		10		37	103
	6/2	G	8	2		2		12	28
	6/9	P						None	
Total			32	5	0	12	0	49	
Port Clarence (Nome-Wales)	6/20	P-U						None	
	6/22	P	2	5		1		8	24
Total			2	5	0	1	0	8	
TOTAL NORTON SOUND AREA			429	150	7	92	31	709	

1/ Survey rating index: E - Excellent; G - Good; F - Fair; P - Poor; U - Unacceptable.

2/ Fish School Categorization: small - surface area less than 50 m^2.
medium 1 - surface area between 50-254 m^2.
medium - surface area between 50-450 m^2.
medium 2 - surface area between 255-450 m^2.
large - surface area greater than 450 m^2.

3/ RAI - Relative abundance index - adjusted school counts weighted by surface area using 50m^2 as a base.

Gill Net Catches:

A total of 227 variable mesh gill net sets were made from 29 April through 21 June at seven coastal areas between north Bristol Bay and Port Clarence in 1979 which produced a catch of 14,014 herring out of a total catch of 20,275 fish (Table 6). Duration of sets averaged 1.9 hours each, although actual soak time per set varied considerably between areas due to herring abundance, coastal morphology, weather, and tidal conditions. An additional four sets were made from 27 June through 2 July at selected stations between Shishmaref and Cape Espenberg in the Chukchi Sea which produced a total catch of 347 herring (Table 6).

Ten families of fish were represented in a total catch of 20,757 fish (Table 7). Herring represented 69% of the total catch in numbers and were the most abundant species captured in every area, ranging from 51% at Metervik Bay to as high as 90% at Port Clarence. Capelin, smelt, flounder (*Pleuronectidae*), and cod (*Gadidae*) constituted 28% of the fish caught. The remaining 3% consisted of other species.

Surface water temperatures ranged from 3.3 to 13.9° C throughout the study area (Table 8). Water temperatures averaged from 8.1° to 9.2° C at the five areas examined below the Yukon River, while significantly colder water temperatures (4.4° C average) prevailed at Cape Denbigh in Norton Sound during the period when herring were present.

Relative Maturity and Sex Ratio:

The relative maturity of herring collected from Bristol Bay to Shishmaref was examined in 1979 (Table 9). All age 1 herring and 41.6% of all age 2 herring examined from Bristol Bay to Shishmaref were determined to be sexually immature. Only 6.4% of age 2 herring were estimated to be sexually mature in samples collected near Shishmaref as opposed to 74.2% sexually mature age 2 herring from samples south of Bering Strait. By age 4 more than 97.8% of eastern Bering Sea and Chukchi Sea herring examined were sexually mature in 1979.

Analysis of sexually mature herring collected near Shishmaref revealed a very high percentage (70%) to be in a spent and recovering condition (gonad 8 index), as opposed to being more recent spawn-outs (gonad 7 index). The frequency of spent and recovering herring was much lower in samples south of Bering Strait.

The overall male to female ratio was 1.0:0.9 for all areas sampled in 1979 based upon gill net results. Goodnews Bay was the only area where females were more abundant than males (1.0:1.1).

Growth and Stomach Contents:

Plus growth was observed on herring scales collected from only two of nine areas examined in 1979: The Tongue Point area of Hagemeister Strait and an area of southern Chukchi Sea just north of Shishmaref. Limited new summer growth was observed on scales collected at Tongue Point from herring of ages 1, 2, and 3. Percent occurrence of plus growth for these age groups

Table 6. Variable mesh gillnet effort, total catch and herring catch at seven coastal areas, spring, 1979.

Area	Number of sets	Total hours fished	Total catch (Numbers)	Total herring catch (Numbers)
Metervik Bay	53	237.4	6,182	3,166
Tongue Point	28	92.1	3,529	3,036
Goodnews Bay	13	18.1	2,107	1,847
Nelson Island	39	36.7	3,460	1,785
Cape Romanzof	77	29.5	3,870	3,273
Cape Denbigh	16	17.0	785	600
Port Clarence	1	1.5	342	307
Bering Sea Total	227	432.3	20,275	14,014
Shishmaref (Chukchi Sea)	4	58.9	482	347
TOTAL	231	491.2	20,757	14,361

Table 7. Variable mesh gillnet catch composition by fish family at seven coastal areas in the eastern Bering Sea, spring 1979.

Area	Catch By Family (Numbers of fish)											
	Clupeidae	Osmeridae 1/	Osmeridae 2/	Cottidae	Pleuronectidae	Hexagramidae	Agonidae	Stichaeidae	Salmonidae	Gadidae	Coregonidae	Total
Metervik Bay	3,166	832	1,018	151	733	67	44	40	45	82	4	6,182
Tongue Point	3,036	265		57	130			35	3	3		3,529
Goodnews Bay	1,847	137	35	1	48			4	4	29	2	2,107
Nelson Island	1,785	296	1,016	9	33	4	14			296	7	3,460
Cape Romanzof	3,273	84	102	30	272					78	31	3,870
Cape Denbigh	600	4		4	81				1	55	40	785
Port Clarence	307	5							1	8	21	342
Shishmaref	347	1	51	23	24					34	2	482
Total	14,361	1,624	2,222	275	1,321	71	58	79	54	585	107	20,757
Percent	69%	8%	11%	1%	6%	Tr.	Tr.	Tr.	Tr.	3%	1%	-

1/ Smelts

2/ Capelin

Table 8. Surface water temperatures (°C) at selected coastal areas in the Eastern Bering Sea, spring 1979.

	South of Yukon Delta					North of Yukon Delta
DATE	METERVIK BAY	TONGUE PT.	GOODNEWS BAY	NELSON ISLAND	CAPE ROMANZOF	CAPE DENBIGH
5/3	7.8					
5/4	7.8					
5/5	7.8					
5/6	7.8					
5/7	7.2					
5/8	5.6					
5/9	5.0					
5/10	5.6					
5/11	6.7					
5/12	7.2	7.2				
5/13	8.9	7.2			6.7	
5/14	7.8	7.2	4.4		6.7	
5/15	7.2	7.2	6.7		6.7	
5/16	7.8	8.9				
5/17	7.2	8.9	7.2		6.7	
5/18	7.2	6.1	5.0	5.0	6.7	
5/19	6.1	5.0	4.4	5.6		
5/20	6.7	6.1	7.2		6.7	
5/21	7.2	6.1	6.7	5.0	7.8	
5/22	7.2	7.2	6.7	5.3	7.8	
5/23	7.8	7.8	10.0			
5/24	9.4	8.9	10.0	6.7	10.0	
5/25	12.4	8.9	7.8	7.2	10.0	4.4
5/26		8.9	9.4	6.7		4.4
5/27	12.8	10.0	9.4			6.1
5/28	13.3	10.0	12.2	10.0		5.5
5/29	12.2	11.1	10.0	9.2		5.5
5/30	12.2	10.0	12.2	10.6	10.6	5.5
5/31	12.2	11.1	13.3			4.4
6/1	12.2	11.1		10.0	11.1	4.4
6/2	12.2	8.9	10.6	10.0	13.9	5.0
6/3	11.1	10.0	8.3	10.6	11.1	4.0
6/4	11.1	10.0	14.4	8.9	11.1	3.3
6/5		11.1	7.8	12.2	10.6	3.8
6/6			5.6	10.1	10.6	3.3
6/7			12.2	12.5	10.0	3.3
6/8				10.6		3.8
6/9						3.8
6/10						4.3
6/11						4.3
6/12						5.0
Average	8.8	8.9	8.1	8.6	9.2	4.4

Table 9. Sexual maturity (percent) by age class of spring herring sampled from Bristol Bay to southern Chukchi Sea, 1979.

Area Sampled	Percent sexually mature herring by age class								Sample Size
	I	II	III	IV	V	VI	VII	VIII	
Metervik Bay	0	88.8	95.8	97.0	99.5	100.0	100.0	100.0	2,379
Tongue Point	0	0	76.3	100.0	99.3	100.0	100.0	100.0	285
Goodnews Bay		0	86.6	96.6	99.1	100.0	100.0	100.0	354
Nelson Island		81.2	98.1	100.0	98.7	98.3	98.2	100.0	1,097
Cape Romanzof	0	92.8	97.6	100.0	100.0	100.0	100.0	100.0	807
Cape Denbigh		100.0	97.0	92.2	100.0	100.0	100.0	100.0	439
Port Clarence		96.9	98.4	100.0	100.0	100.0	100.0	100.0	252
South of Bering Strait	0	74.2	94.9	98.1	99.4	99.8	99.7	100.0	5,613
North of Bering Strait[1]		6.4	60.0	91.7	97.9	75.0	96.4	100.0	201
TOTAL	0	58.4	94.2	97.8	99.4	99.5	99.5	100.0	5,814

[1] Samples from Shishmaref.

was 71, 47, and 6, respectively. In comparison, plus growth was present on herring as old as 7 years from samples near Shishmaref. For age groups 2, 3, 4, and 6, the percentage of scales exhibiting substantial plus growth was 100, 71, 46, and 10, respectively. No plus growth was observed on age 5 herring and only 4% of age 7 fish for this area. Tongue Point samples were collected from 8 May through 5 June while samples near Shishmaref were collected from 29 June through 2 July.

Cursory field examination of stomachs from herring collected near Shishmaref in 1979 revealed the majority to be at least partially full. Nearly 22% of the stomachs examined were distended from ingested material. Contents from three of the distended stomachs were examined and consisted entirely of adult mysid shrimp.

Age Composition of Gill Net Catches:

Age determination from herring scales collected at seven coastal areas from Bristol Bay to Port Clarence in variable mesh gill nets indicated that the 1974 year class (age 5 in 1979) had the greatest frequency of occurrence in catches from all areas in both 1978 and 1979 (Figures 2, 3, and 4). Representation in the samples ranged from 42% at Goodnews Bay to 58% at Nelson Island in the 1979 catches. The strong relationship between the occurrence of age 4 herring in 1978 and age 5 in all areas underscores the relative strength of the 1974 year class.

The 1976 year class (age 3 in 1979) was second in frequency of occurrence at the Metervik, Tongue Point, and Cape Denbigh sampling sites in 1979.

In 1972 year class (age 7 in 1979) contributed strongly to catches at several areas north of Cape Newenham where it was second in relative abundance at Security Cove-Goodnews Bay, Nelson Island, Cape Romanzof, and Port Clarence. It was strongly represented in Cape Denbigh samples in 1978 but not in 1979. In a small sample taken from Shishmaref in 1979, the 1972 year class was most abundant, followed by 1974 and 1977.

Representation of the 1973 (age 6 in 1979) and 1975 (age 4 in 1979) year classes in gill net samples was poor in both 1978 and 1979. The frequency of occurrence of the 1973 year class was apparently greatest at Metervik Bay, Tongue Point, and Port Clarence where they comprised from 13-15% of the catches. Occurrence in all other areas was less than 10%. Occurrence of the 1975 year class in 1979 catches was less than 10% in all areas sampled.

Age 2 herring, the 1977 year class, occurred infrequently at all areas examined south of Bering Strait. The most significant showing of that age group occurred at Tongue Point in the Togiak District of Bristol Bay where it comprised about 8% of the catch. Age 1, the 1978 year class, was found only in the Togiak District and at Cape Romanzof where they made up less than 1% of the catches.

Occurrence of the 1971 and earlier year classes in catches at all sites was less than 5% except at Port Clarence where several older age classes contributed between 5 and 10% of the catches. The oldest herring aged from gill net catches in 1978 and 1979 was from Shishmaref; a single, age 13 individual from the 1966 year class.

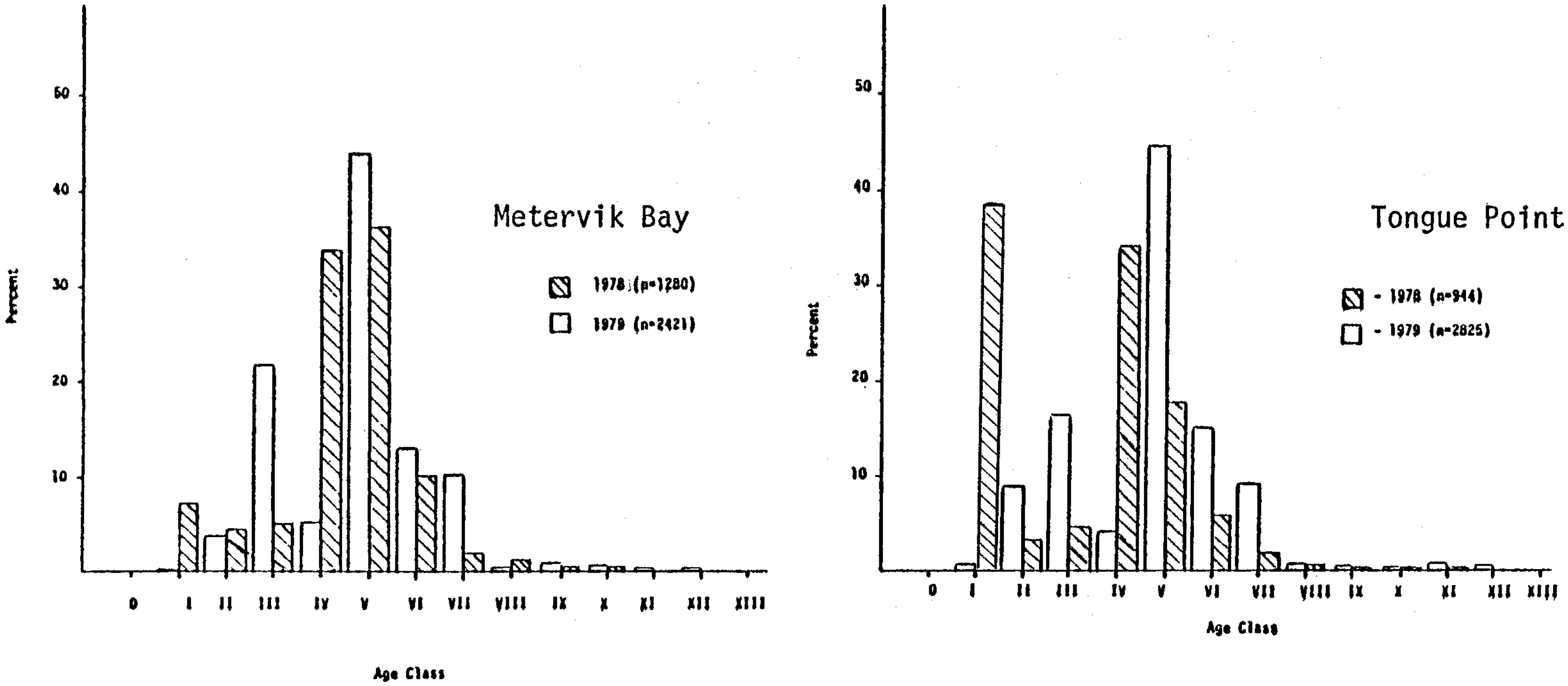

Figure 2. Percent age composition of herring captured at Metervik Bay and Tongue Point with variable mesh gillnets, spring 1978 and 1979.

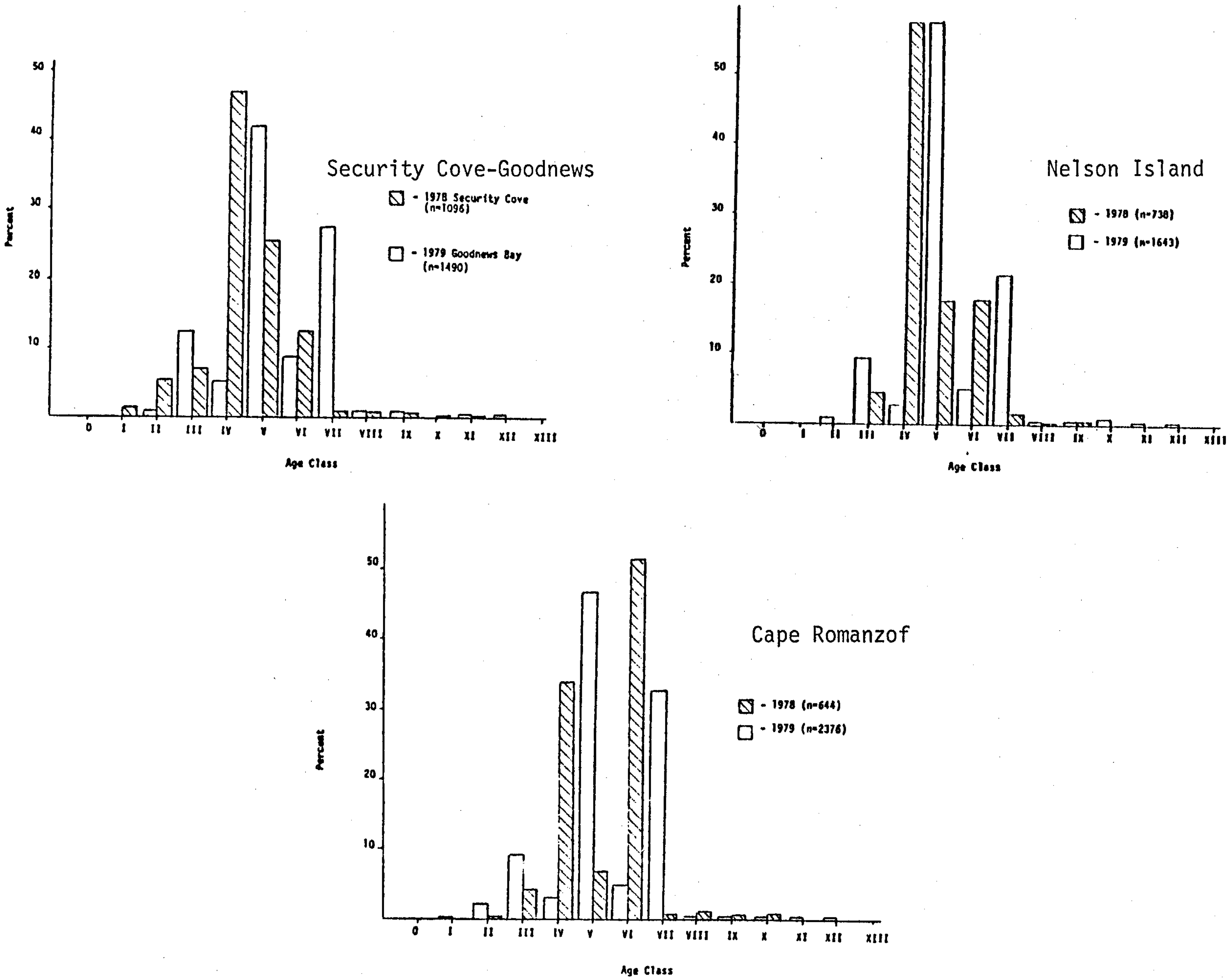

Figure 3. Percent age composition of herring captured at Security Cove (1978), Goodnews Bay (1979), Nelson Is., & Cape Romanzof with variable mesh gillnets, spring 1978 and 1979.

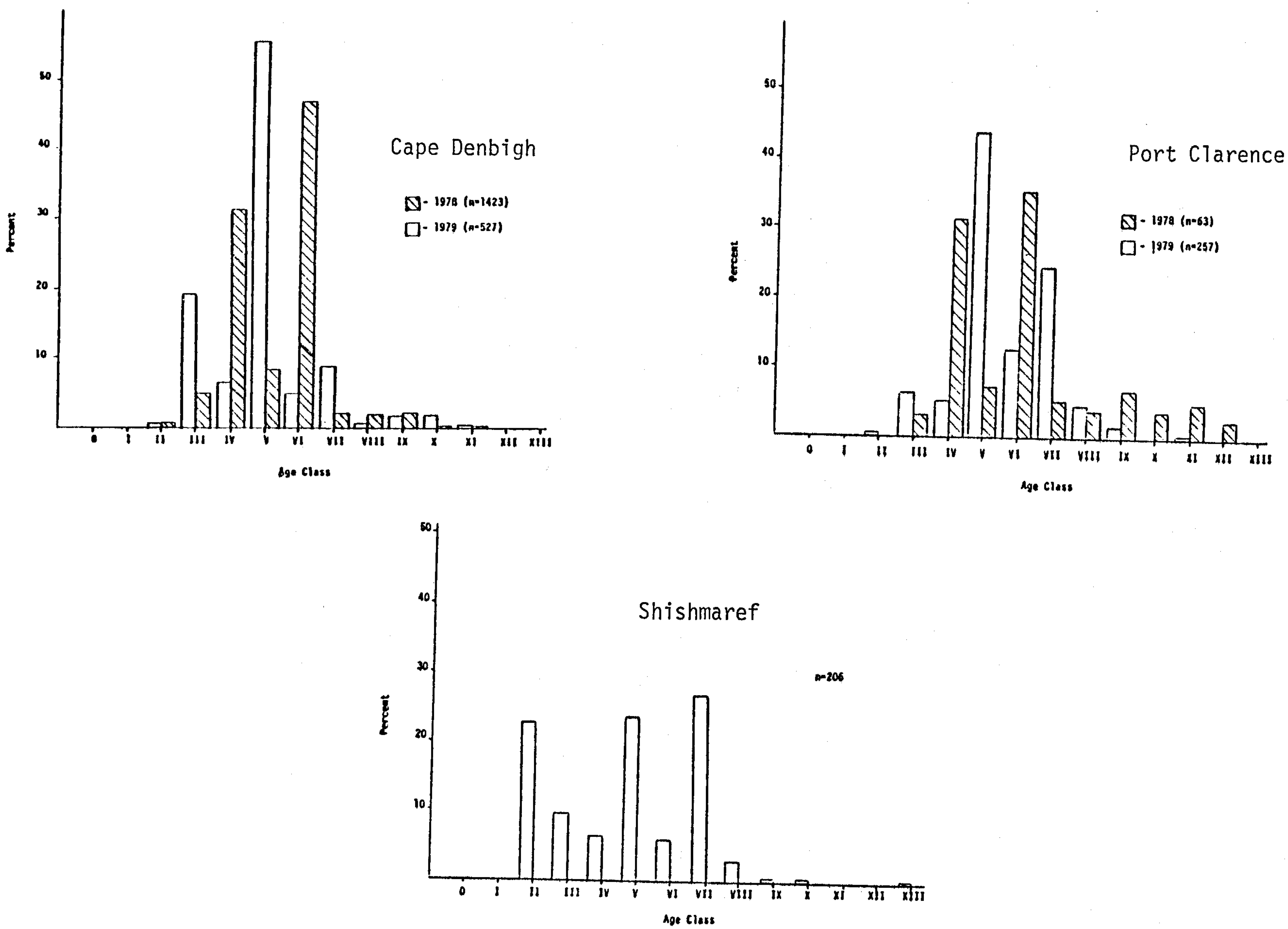

Figure 4. Percent age composition of herring captured at Cape Denbigh, Port Clarence, and Shishmaref with variable mesh gillnets, spring 1978 and 1979.

Size Composition of Gill Net Catches:

Analysis of length at age data from 1978 and 1979 indicated a general coastwide trend for decreasing size from south to north (Table 10, Figure 5). The trend was most evident in the extreme southern population sampled (Metervik Bay) and in the most northerly ones (Kotzebue and Shishmaref). A separate analysis of size-at-age for specific year classes has not been attempted.

Gear Selectivity:

A commercial purse seine vessel made a set west of Tongue Point in Hagemeister Strait on 15 May approximately 350 m from where two variable mesh gill nets were fishing. An estimated 65 tons of spawned-out herring were captured by the purse seine, from which a sample of 98 fish were taken prior to release of the remaining catch. The two variable mesh gill nets were retrieved later after a combined soak time of 7.2 hours. All gill net caught herring (48 fish) and the sample obtained from the seine catch were examined for age and size composition. Results showed very similar age and sex composition for both gear types (Figure 6). A Chi-square test revealed the two samples were not significantly different ($P< 0.01$) in age composition (Table 11).

A similar study was conducted in Metervik Bay on 24 May when intense commercial fishing by gillnetters and purse seiners was observed. A variable mesh gill net was deployed adjacent to one of the commercial purse seine vessels. Herring samples from both the purse seine and variable mesh gill nets were collected and examined for size and age comparison (Figure 7). The purse seine sample (130 fish) contained a much higher proportion of age 3 herring (72%) than the variable mesh gill nets (39%). Variable mesh gill net samples (78 fish) contained a much higher proportion of age 5 herring (35%) than the purse seine (17%). A Chi-square test applied to the data revealed the two samples to be significantly different ($P< 0.01$) in age composition.

Spawning Habitats:

Substrate Distribution. The rockweed *Fucus* sp. was found to be the dominant intertidal vegetative substrate throughout the Togiak District in areas examined from Tvativak Bay to Togiak Bay and near Tongue Point. *Rhodomella* sp., *Zostera* sp. and *Laminaria* sp. were also observed, presumably washed ashore from subtidal regions. Scattered beds of *Fucus* were found throughout Kulukak Bay except at the head of the bay, which is primarily a tidal mud flat devoid of vegetation. Heavy beds of *Fucus* occurred throughout most of the intertidal zone from Metervik Bay (Kulukak Point) to Togiak Bay with the exception of two beaches in Nunavachak and Ungalikthluk Bays. Distribution of *Fucus* throughout the Togiak District was nearly always associated with rocky (often exposed) coastlines, where little or no beach zone was present; regions apparently most suitable for vegetative attachment (Figures 8 through 11).

The dominant vegetative substrate in Goodnews Bay was found to be eelgrass (*Zostera* sp.). Eelgrass was observed primarily in shallow subtidal zones although its distribution did extend to intertidal areas in some locations. Eelgrass beds were most prominant inside the South Spit and extended along

Table 10. Mean standard length (mm) at age of herring sampled from test gillnets at selected coastal areas in the eastern Bering Sea from 28 April through 2 July 1978 and 1979.

		Age Class												
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	N
Kotzebue	1979		126	143	174							222		29
Shishmaref	1979		165*	182*	186*	200*	187	194*	218	223	203			208
Port Clarence	1978			164	187	173	189	227	232	230	207	232	214	63
	1979		165	172	182	208	196	221	228	235		280		256
Cape Denbigh	1978		159	177	207	226	236	242	257	264	271	267		756
	1979		168	191	216	227	237	244	268	258	269	276		458
Cape Romanzof	1978		199	180	205	231	237	247	262	278	268			561
	1979	92	161	189	216	229	253	253	279	275	266	285	277	821
Nelson Island	1978			197	215	239	245	247	280	287				738
	1979		165	192	215	230	244	253	277	271	274	276	280	1123
Goodnews Bay	1979		170	198	217	232	250	258	260	279		286	279	586
Security Cove	1978	120	178	200	217	242	248	250	288	283	293	295		1095
Tongue Point	1978	112	190	207	221	241	248	269	282	289	283	295		944
	1979	110*	172*	200*	227	237	254	261	268	282	278	289	294	753
Metervik Bay	1978	113	183	208	228	239	243	262	274	279	323			1280
	1979	119	181	207	224	239	258	264	281	278	289	293	286	2406

* Samples in which new summer growth was observed during scale analysis.

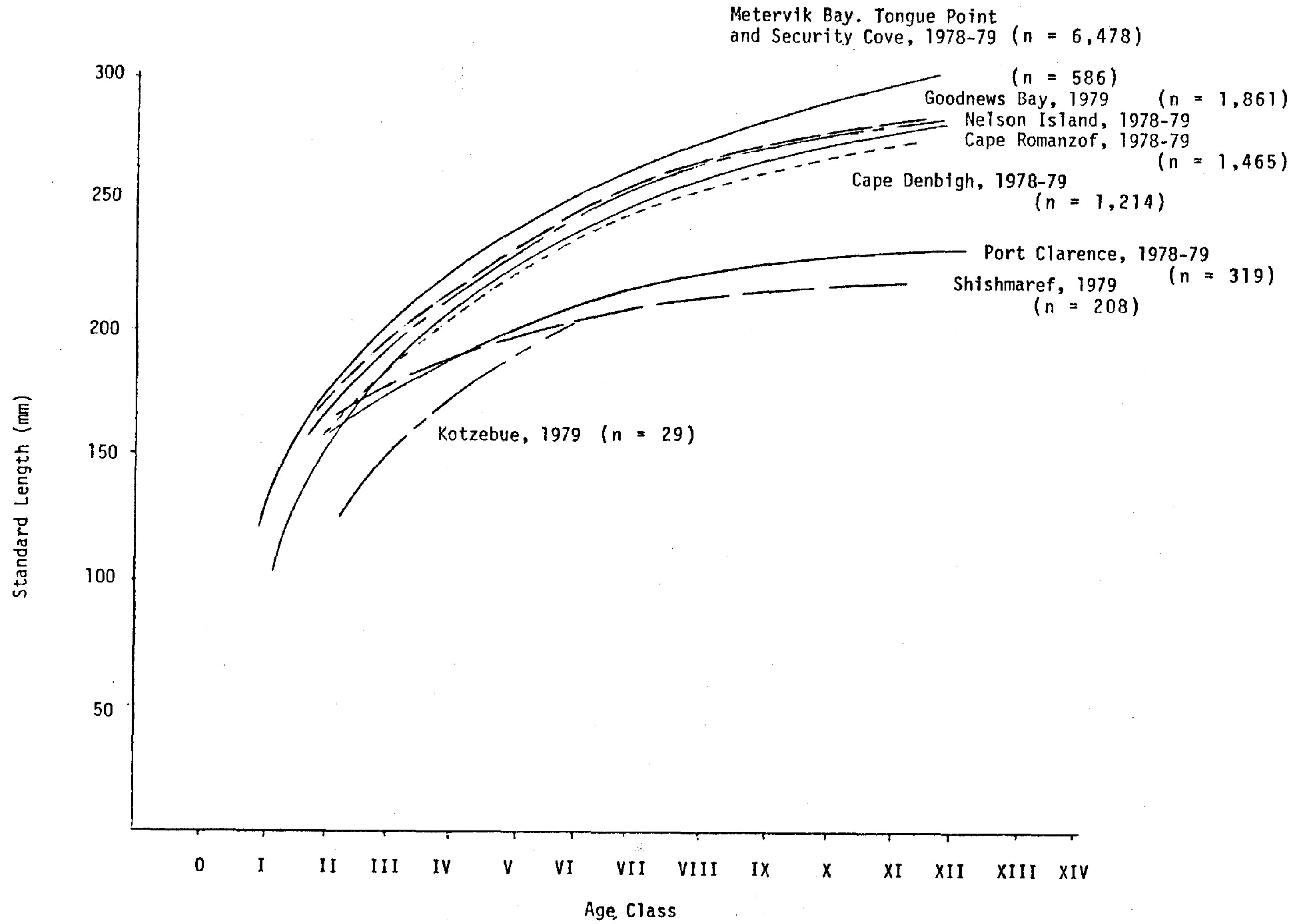

Figure 5. Mean size-at-age of herring captured at selected coastal areas in the eastern Bering Sea, spring 1978-79.

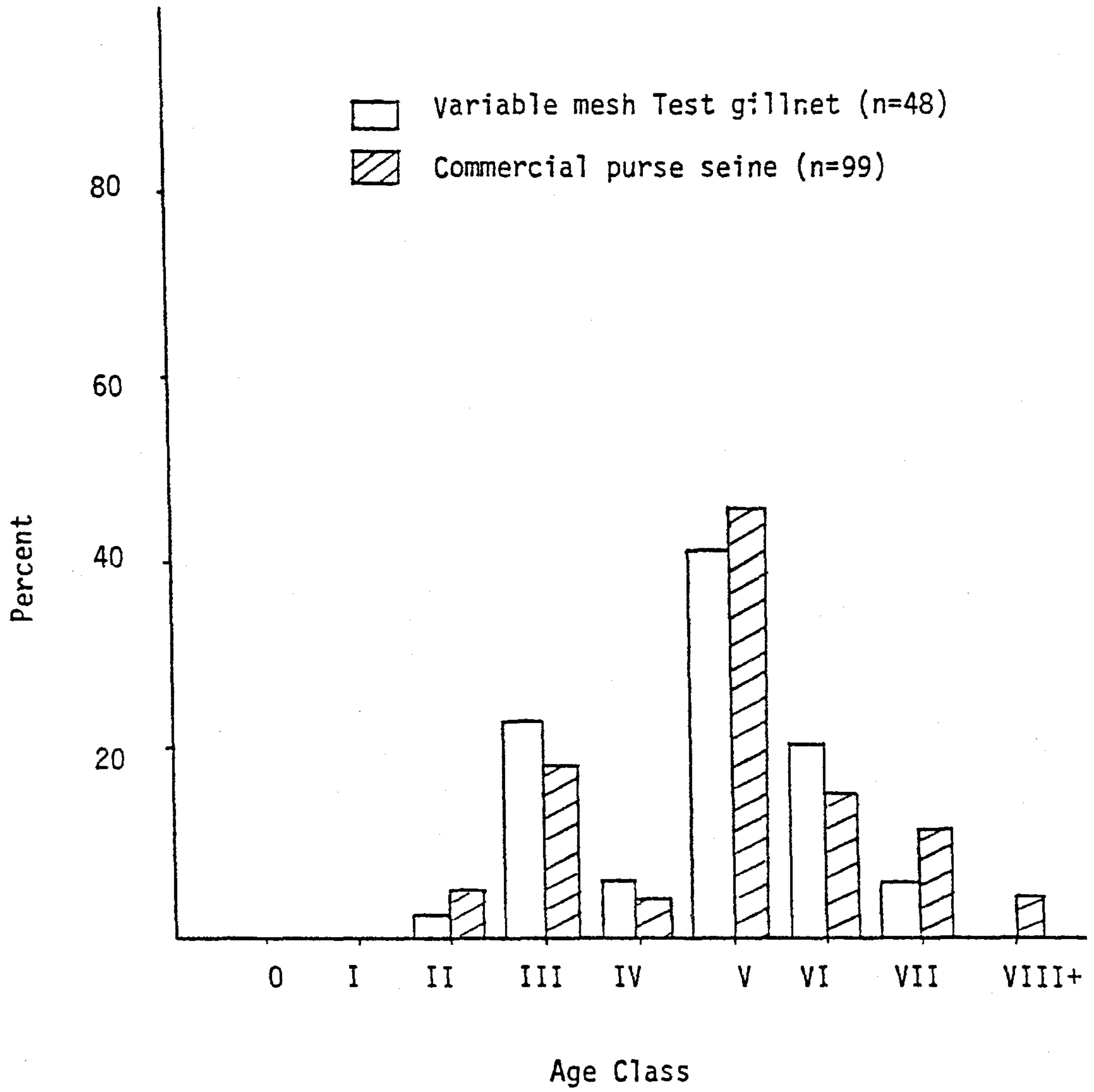

Figure 6 . Comparison of age and sex compositions of herring sampled with variable mesh gillnets and commercial purse seines at Tongue Point on 15 May 1979.

Table 11. Age composition and statistical comparisons of herring sampled with variable mesh gillnets and purse seines at selected coastal areas in the eastern Bering Sea, 1979.

Area	Gear Type	Age Classes 1/							Total	Chi-Square Values	Degrees of Freedom
		II	III	IV	V	VI	VII	VIII			
Metervik Bay	variable gillnet (25-102mm)	3	29	3	27	10	5	1	78	23.54 2/	4
	commercial purse seine		94	5	22	5	4		130		
Tongue Point	variable gillnet (25-102mm)	1	11	3	20	10	3		48	2.90	5
	commercial purse seine	5	18	4	45	15	11	1	99		

1/ Ages with no observations or sex unknown were not used in comparisons.

2/ Significant difference ($P < 0.01$).

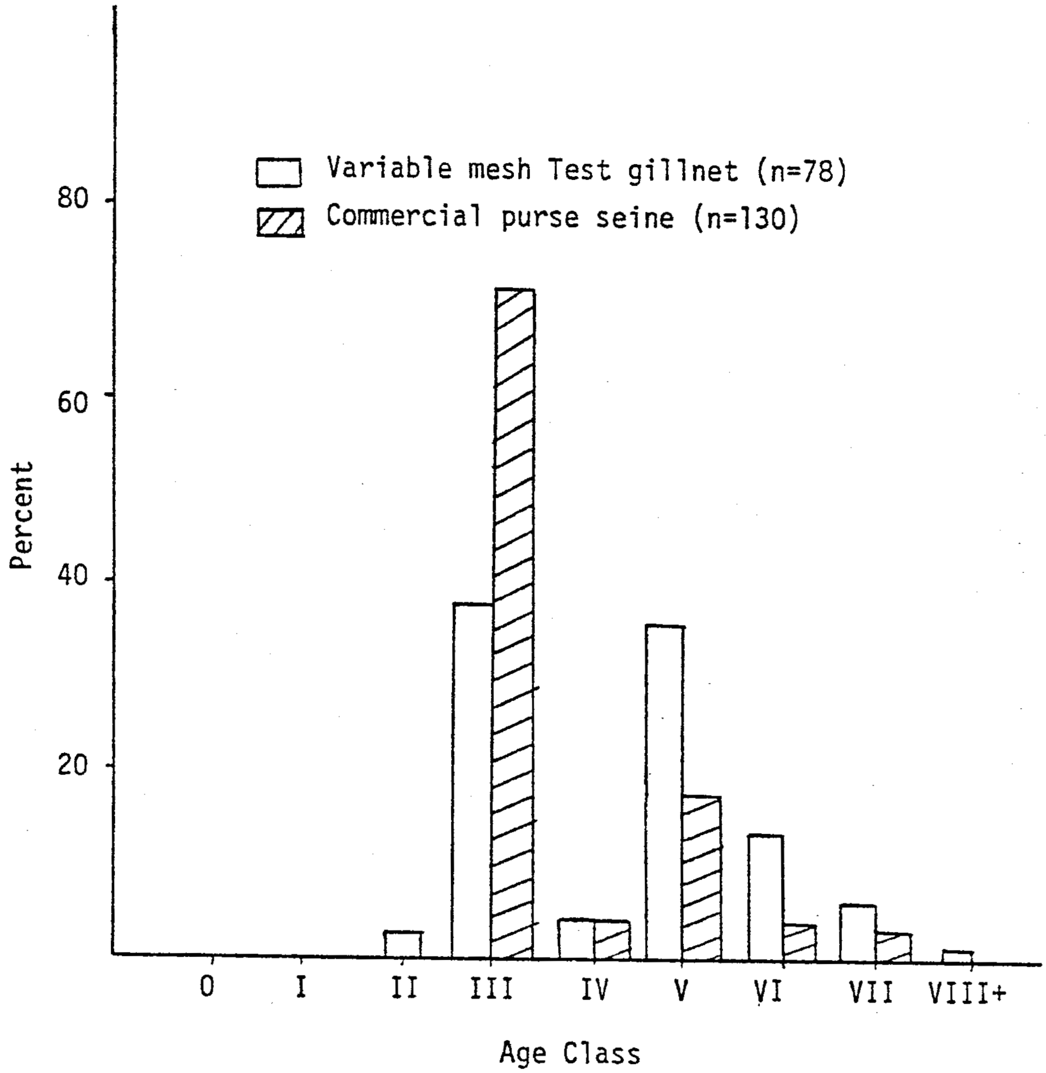

Figure 7. Comparison of age and sex compositions of herring sampled with variable mesh gillnets and commercial purse seines at Metervik Bay on 24 May 1979.

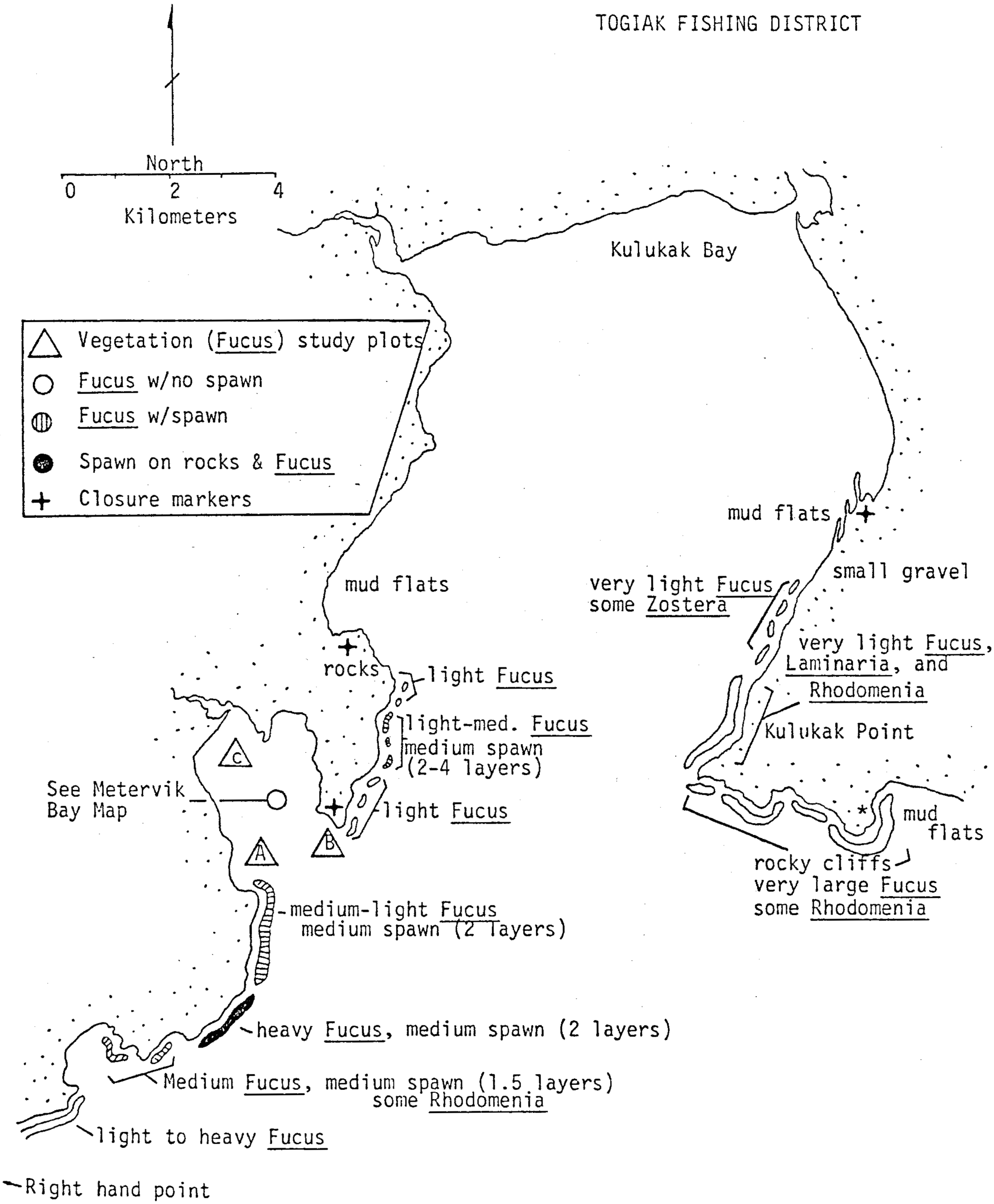

Figure 8. Distribution of *Fucus* sp. and herring spawn in the Kulukak Bay area, 5-11 May 1979.

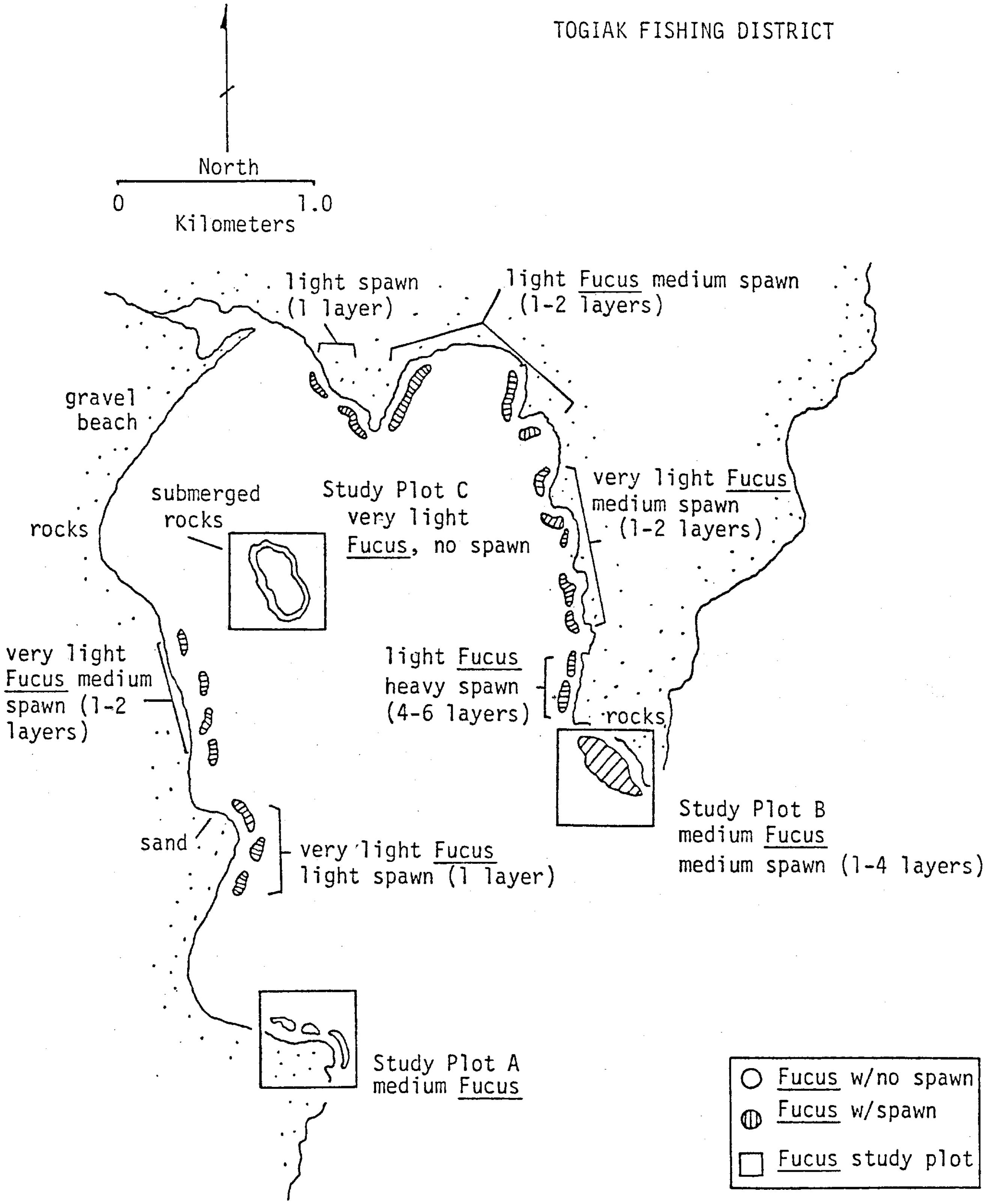

Figure 9 . Vegetation study plots, distribution of *Fucus* sp., and herring spawn at Metervik Bay, 7 May 1979.

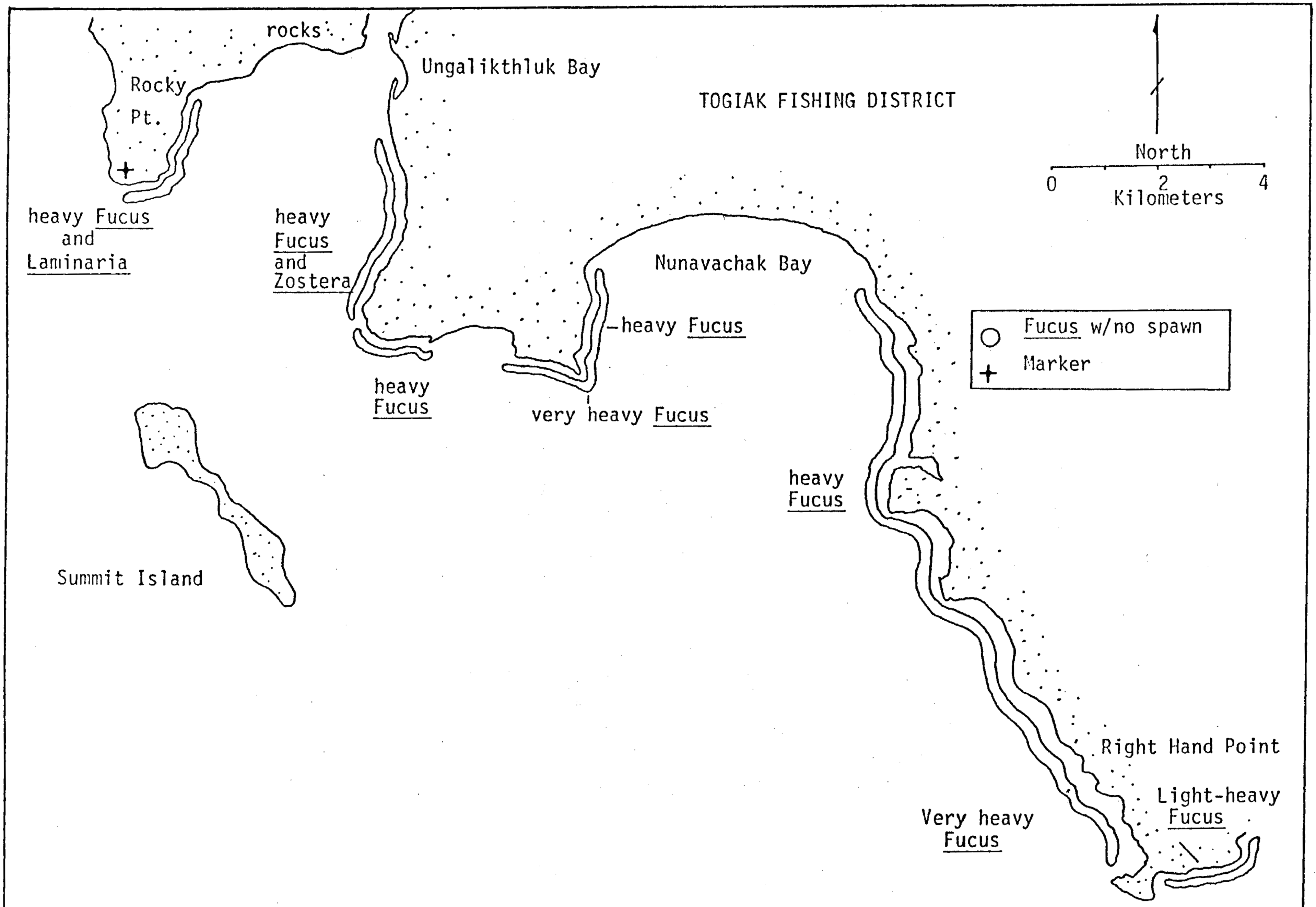

Figure 10. Distribution of *Fucus* sp. in Ungalikthluk and Nunavachak Bays, 6-7 June 1979.

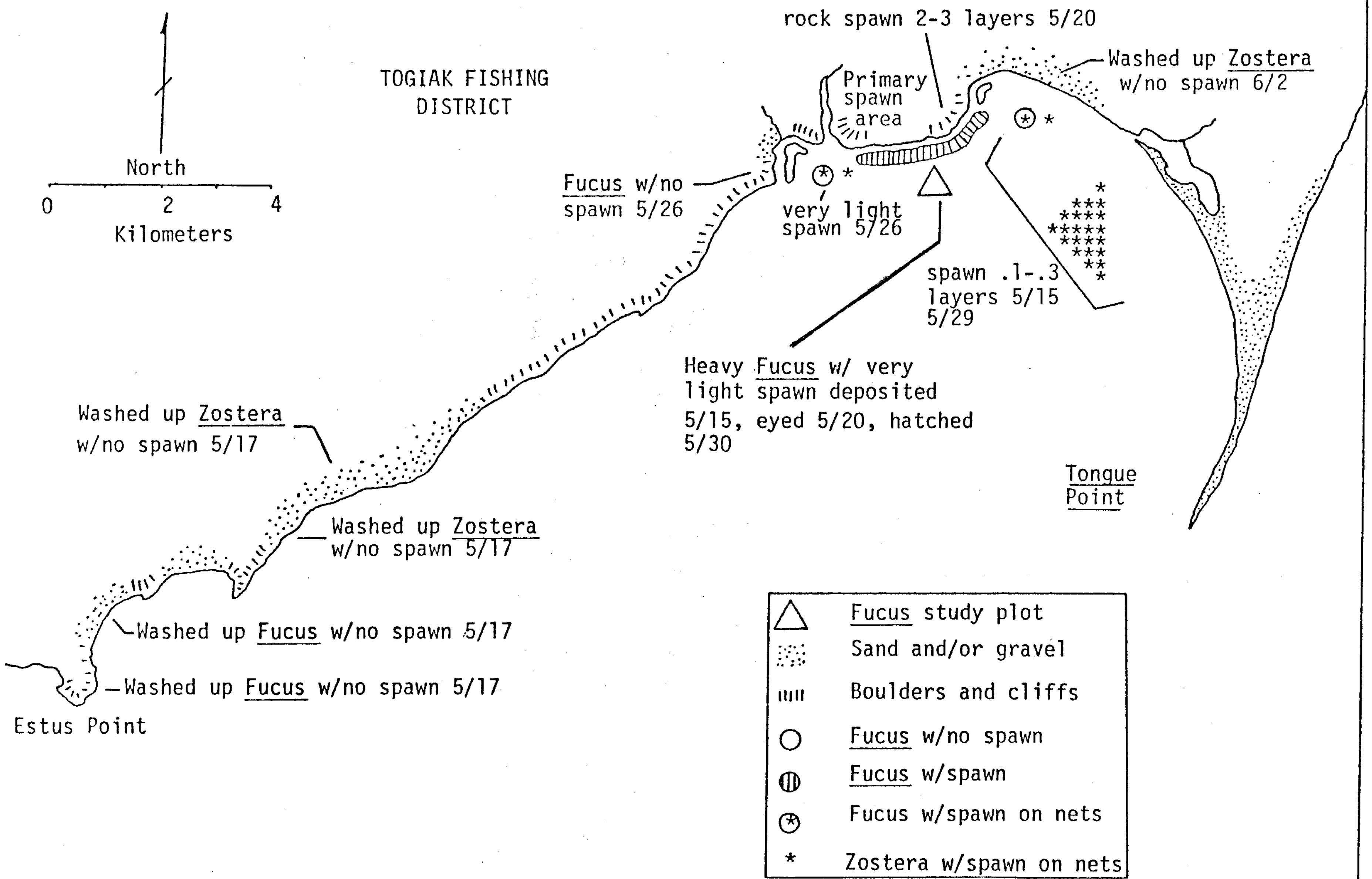

Figure 11 . Distribution of *Fucus* sp., *Zostera* sp., and herring spawn at Tongue Point, spring 1979.

the southern coastline of Goodnews Bay to Little Beluga Mountain (Figure 12). Lesser quantities were present inside the North Spit. Clumps of eelgrass washed ashore were a common occurrence along most coastal areas of Goodnews Bay, excluding the eastern half where extensive intertidal mud flats exist.

Fucus was determined to be the dominant vegetative type along the intertidal zone at Nelson Island, Cape Romanzof, and Cape Denbigh (Figures 13 through 15). *Zostera* was found only to occur in the latter area. *Fucus* beds were most abundant at Nelson Island from Cape Vancouver to Chinit Point and along the intertidal zones of northern Kokechik Bay at Cape Romanzof. Distribution of *Fucus* at Cape Denbigh consisted of small scattered beds from Point Dexter to about 2 or 3 km west of the Sineak River. In all three areas, *Fucus* was invariably associated with rocky coastlines which are mostly exposed to violent wind and surf action. *Zostera* was found growing in the Cape Denbigh area only in a shallow (2-3 m) subtidal region near Point Dexter, although it was commonly found washed ashore in other areas.

Spawn Distribution and Density. Spawning herring were first observed in Metervik Bay during the last week of April in 1979. A study plot was established and spawn of two to four layers in deposition was recorded on 5 May. Most of the eggs were eyed by 14 May and hatched by 23 May (a period of 18 days). Surface water temperatures monitored during this period ranged from 5 to 8.9° C. This equates to an estimated 62 degree-day units for eyeing and 134 degree-day units for hatching.

Spawn of two to six layers was present on *Fucus* along the west side of Kulukak Bay while one to four layers of spawn were observed from Metervik Bay to Right Hand Point. Aerial survey observations in early May showed the region from Right Hand Point to Unaglikthluk Bay to be a major spawning area, however no eggs were found when surveyed by foot in June. Shorebased crews observed large schools of unidentified larvae present in tidal pools of the Nunavachak-Ungalikthluk region during the first week of June.

Herring spawn was found only on *Fucus* in the Tongue Point region, with deposition of one to two layers on 15 May 1979. Eyed eggs were observed on 20 May and hatching was estimated to have occurred sometime between 29 May and 2 June.

Herring had spawned prior to 13 May when field sampling was initiated in Goodnews Bay. One layer of spawn was observed on *Zostera* on 17 May 1979. Eyeing was estimated to have occurred on 23 May and hatching by 31 May. Water temperatures ranged from 7.2-10.0° C during this period.

Local residents of Nelson Island reported that the first spawning run of herring preceded arrival of sampling crews on 16 May. This was evident from large subsistence catches of herring which had already occurred and the presence of empty egg cases near Chinit Point on 21 May. Herring persisted in this area throughout the sampling period. Herring spawn was found about equally distributed over *Fucus* and bare rocks in the Nelson Island area. The heaviest deposition of spawn occurred north of Cape Vancouver, particularly at Chinit Point. A second deposition of herring spawn was observed at Chinit Point on 30 May. Eyeing was recorded on 8 June in water

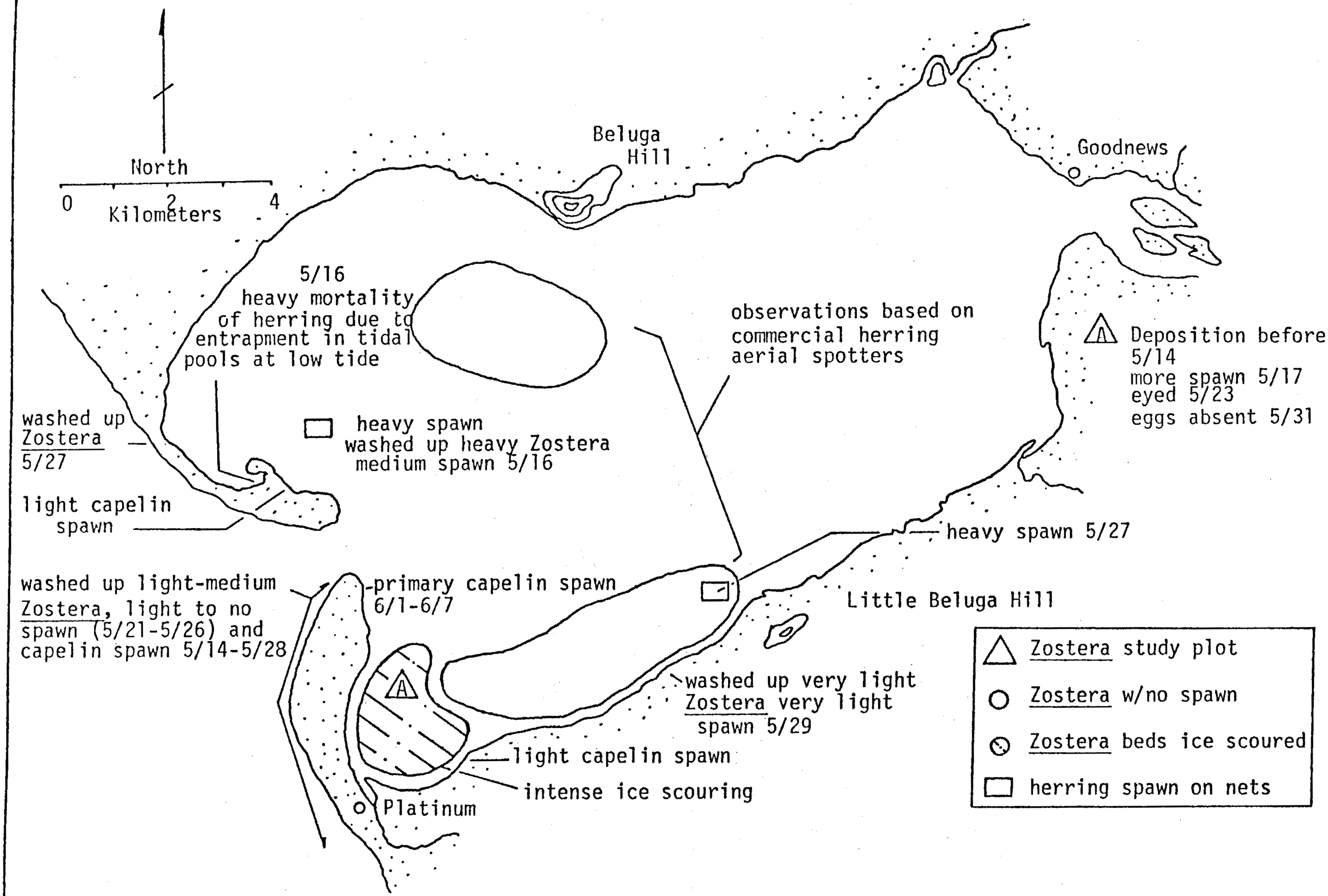

Figure 12. Distribution of Zostera and herring and capelin spawn at Goodnews Bay, spring 1979.

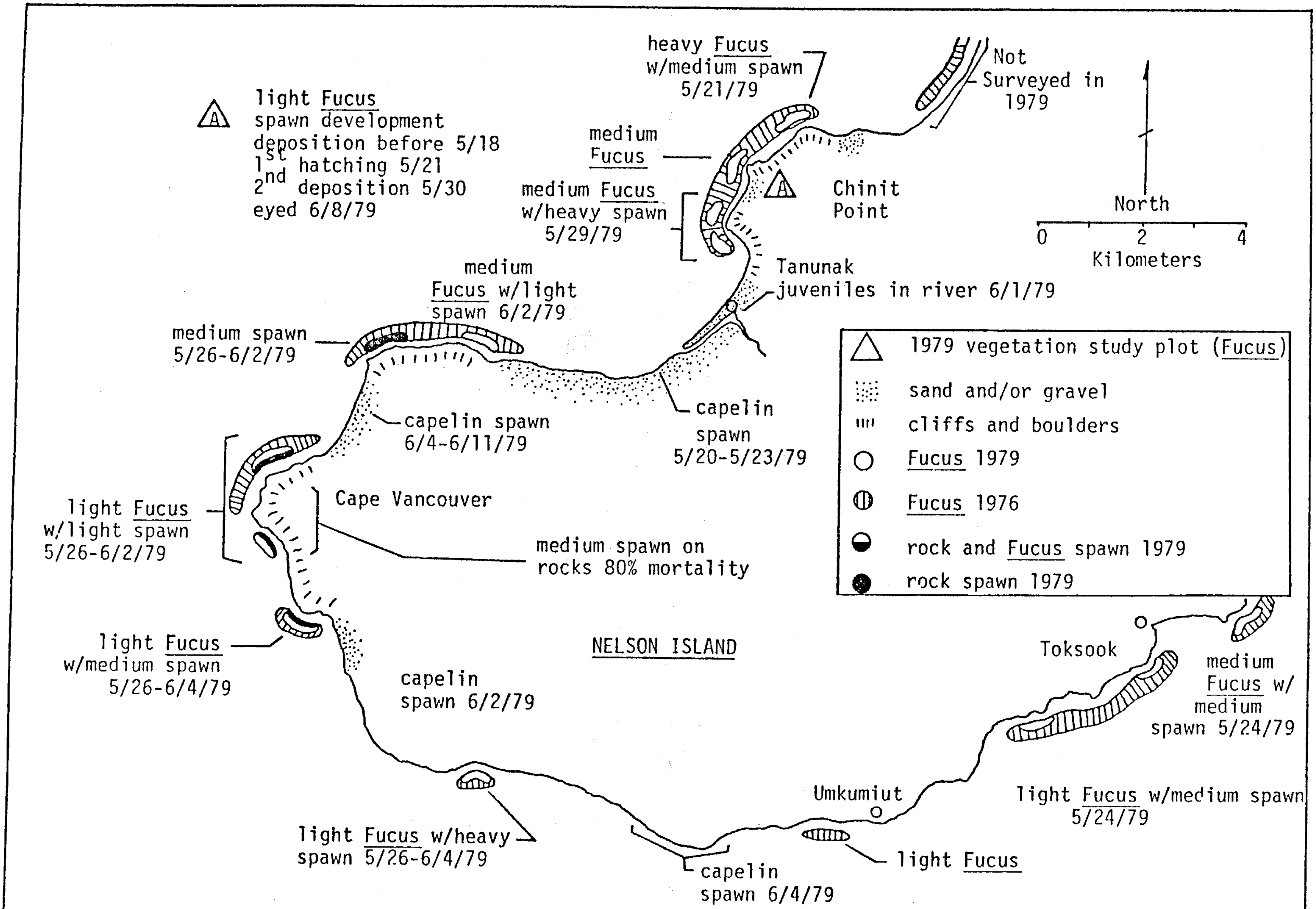

Figure 13. Distribution of Fucus sp. and herring spawn at Nelson Island, spring 1976 and 1979.

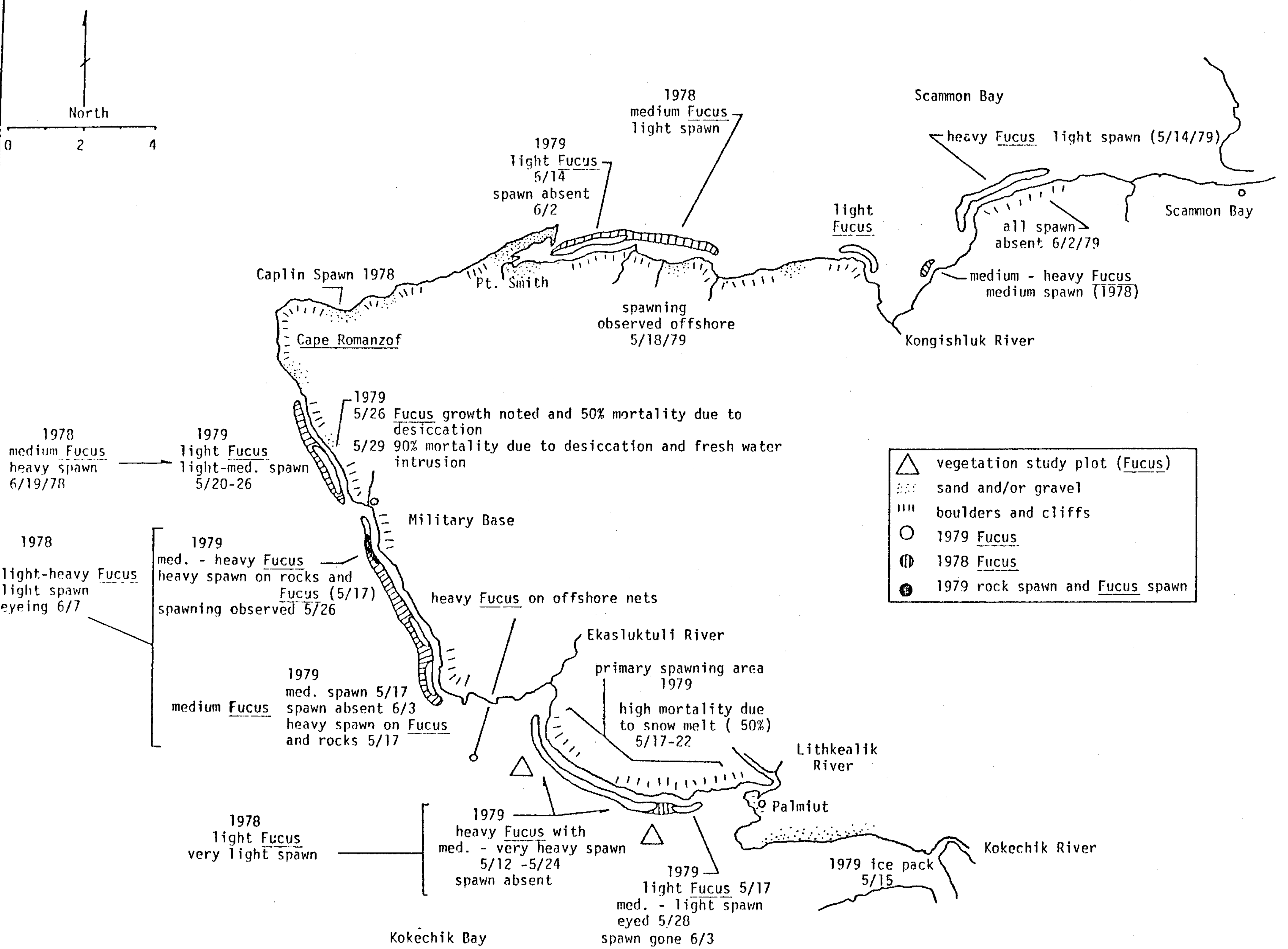

Figure 14. Distribution of *Fucus* spp. and herring spawn in the Cape Romanzof area, spring 1978 and 1979.

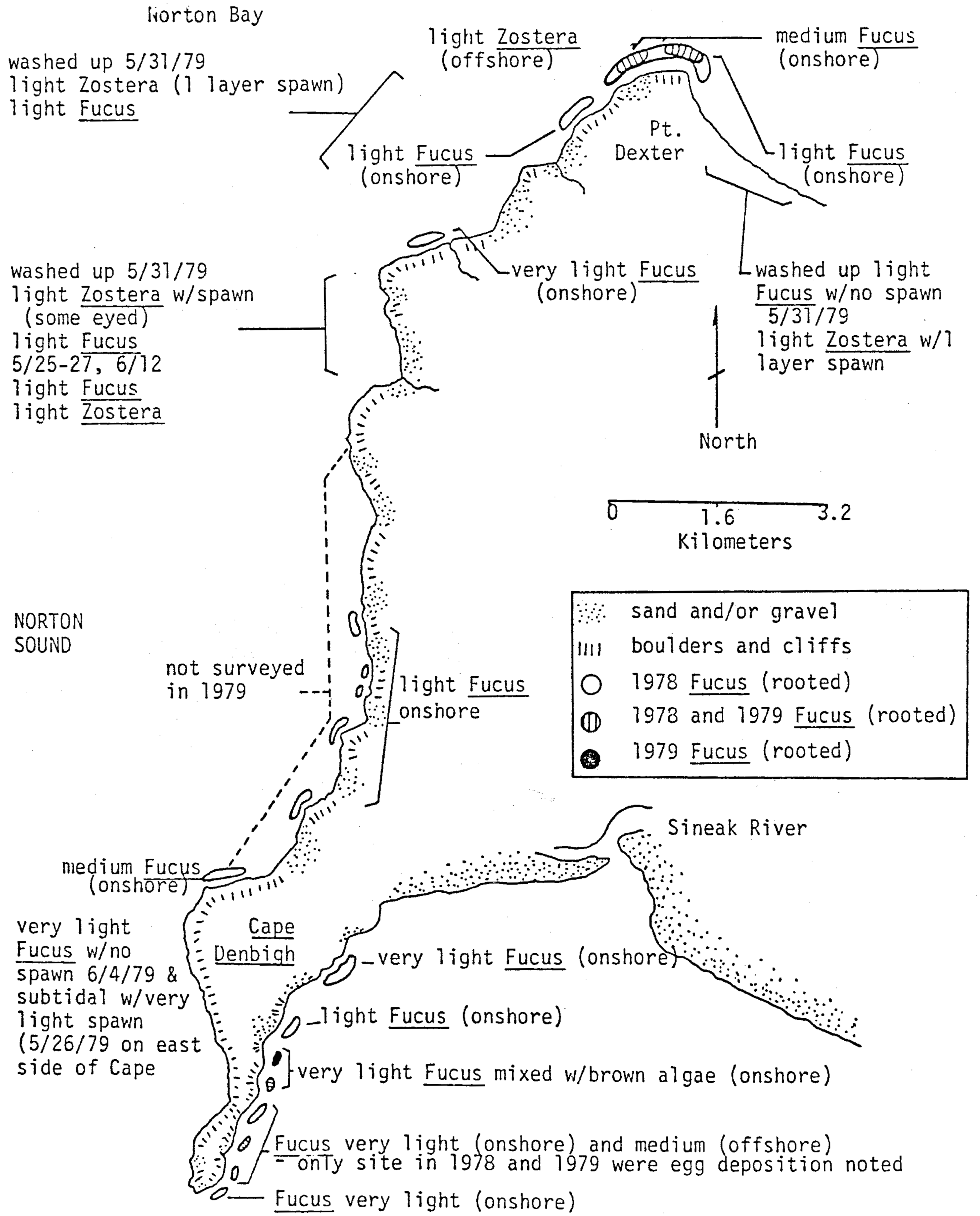

Figure 15. Distribution of Fucus sp. and Zostera sp. in the Cape Denbigh intertidal area, spring 1978 and 1979.

temperatures ranging from 10 to 12.0° C. Limited data indicated about 99 degree-days for eyeing. The project was terminated before hatching commenced.

Fucus was again observed as the dominant spawning substrate in the Cape Romanzof area. Spawn deposition ranged from light to heavy throughout the study area with the heaviest concentrations in northern Kokechik Bay. Although spawn deposition was light on *Fucus* in most intertidal areas, heavier concentrations of spawn were frequently found entangled in the webbing of adjacent gill nets.

Herring spawn of light density was present in most areas of Cape Romanzof when field sampling began on 12 May. Estimates on the time required for eyeing was about 113 degree-days in temperatures ranging from 6.6-10° C. Extensive eyeing was observed only in Kokechik Bay in 1979 and none between Cape Romanzof and Scammon Bay. Little spawn was observed in the Cape Romanzof area after 24 May 1979.

Very little herring spawn was reported in the Cape Denbigh area in 1979. Small amount of washed up *Fucus* and *Zostera* possessing herring spawn of light intensity were observed prior to 9 June. Larger concentrations of *Zostera* with light spawn were observed on the north side of Cape Denbigh after a 3-day storm which lasted from 9 to 11 June. Beach sampling revealed *Zostera* present in greater amounts than *Fucus* suggesting it to be an important spawning substrate in subtidal areas.

Habitat Destruction and Spawn Mortality. Uprooted or torn *Fucus* and *Zostera* plants were a common occurrence along most coastal areas examined in 1978 and 1979. Often those plants were covered with herring spawn. A 3-day storm was reported at Metervik Bay from 17-19 May 1979, coinciding with hatching of herring eggs at the study site. Some destruction of *Fucus* beds by violent wave action was observed. Similar observations were reported at Nelson Island, Cape Romanzof, and Cape Denbigh. Washed up vegetation was often covered with heavier spawn than that deposited in the intertidal areas, suggesting that severe storms disturbed portions of the subtidal spawning habitats.

Severe ice scouring was evident inside the South Spit of Goodnews Bay based on aerial surveillance of this region at low tide. Denuded areas in the eelgrass beds created by the abrasive action of winter sea ice were visible as long ridges of mud.

In addition to the loss of herring spawn from destruction of substrate beds from spring storms, interdial egg loss was also observed from desiccation of both eggs and *Fucus*. This was especially common at Cape Romanzof in late May, where dehydration was attributed to exposure to sunlight and wind at low tides. Mortality of herring spawn at Cape Romanzof was also attributed to melting snowbanks which created an influx of cold, freshwater onto intertidal spawn. This was significant in view of the fact that the Cape Romanzof area received more than 250 cm of snowfall in 1978-79, leaving snowbanks 4-5 m high along the entire coastline from Kokechik River to Scammon Bay Village. Repeated coastal observations revealed that spawn survival in this region was low and that the most prevalent cause of egg mortality was from desiccation.

Nelson Island crews reported that about half of the spawn found in that area was on rocks. They reported that the highest mortality (up to 80%) of eggs was found on rock substrates, whereas, less than 10% mortality was estimated for spawn on *Fucus*.

Predation by sea-birds, fish, and other animals was another important cause of mortality to herring spawn in most areas. Yellowfin sole (*Limanda aspera*), other flounder species, and Dolly Varden (*Salvelinus malma*) were among the primary fish species observed feeding on herring eggs. At Metervik Bay and Cape Romanzof, snails were also observed as predators. The density of snails in the study site at Metervik Bay was estimated at 109 per square meter of beach. Crab species were also included among herring spawn predators at Metervik Bay.

DISCUSSION

Timing

Barton et al. (1977) and Barton (1978) reported that timing of coastal spawning by herring in the eastern Bering Sea was influenced by climatological conditions and was generally found to commence when spawning grounds became ice free. Average spawning dates were estimated as late May to early June in the Togiak, Security Cove, and Goodnews Bay region; around mid June in the Yukon-Kuskokwim Delta region; during June in the Norton Sound region; and late June to early July at Port Clarence.

Prokhorov (1968) found that approximate time of spawning in the western Bering Sea was related to winter and spring water temperatures with early maturation in warm years and delayed development in cold years. The past two winters (1977-78 and 1978-79) had been especially mild, and eastern Bering Sea herring arrived on the spawning grounds earlier than average in both years. Aerial surveys flown in 1978 indicated arrival of herring and peak spawning from Bristol Bay to Nelson Island occurred about mid May. Gilmer (1978, unpublished report) found spawning prior to 22 May and continuing through 2 June at Cape Romanzof in 1978.

Both aerial and shorebased surveys showed that herring arrived in areas south of the Yukon River even earlier in 1979. Intense spawning in the Togiak District occurred during the first 2 or 3 days of May, while timing based on aerial survey data alone, in the Security Cove-Goodnews Bay area was similar to 1978. However, it is known that some spawning had occurred prior to mid May in Goodnews Bay as light spawn was observed on eelgrass as early as 12 May 1979, when shorebased sampling began.

Ground studies at Nelson Island and Cape Romanzof revealed that spawning occurred prior to mid May. This is based on the observation that herring subsistence catches at Nelson Island had been completed by 16 May and the presence of eyed herring eggs on 28 May at Cape Romanzof. Burns (1979, unpublished report) reported that herring spawn of light density was already present along most coastal areas of Cape Romanzof when sampling began on 12 May.

Timing differences of spawning stocks in the eastern Bering Sea in 1978 and 1979 compared to previous years agree with Prokhorov's (1968) findings for western Bering Sea herring stocks; i.e., early timing coincided with warmer water temperatures on the spawning grounds. To illustrate Barton et al. (1977) reported peak spawning in Metervik Bay in 1976 occurred in late May and early June when water temperatures averaged 4° C. In contrast, peak spawning in Metervik Bay in 1978 and 1979 occurred in mid May and early May, respectively. Corresponding water temperatures for those periods ranged from 6-8° C in 1978, and averaged 7.8° C in 1979, respectively. Similarly, spawning and surface water temperatures along coastal areas north of Bristol Bay to Cape Romanzof were earlier than average in 1978 and 1979.

Water temperatures measured in Norton Sound at Cape Denbigh from 25 May through 7 June averaged 9.5° C and 4.5° C in 1978 and 1979, respectively. That mild spring conditions existed in Norton Sound in 1978 and 1979 is evident from the absence of sea ice during the month of May in those years. Barton (1978) reports extensive ice coverage in Norton Sound throughout the first week of June in both 1976 and 1977 and that spawning was first observed at St. Michael in mid June in both years. He reported that the average water temperature from Cape Stebbins to Tolstoi Point on 12 June 1977 was 1.3° C. The water temperature at St. Michael on 15 June 1976 was 5.6° C (Barton 1977).

Aerial surveys in Norton Sound indicated little difference in timing between herring runs in 1978 and 1979 although timing was earlier than average in both years. Herring generally arrive and spawn first along the southern coastline from Stuart Island to Tolstoi Point. Spawning apparently occurs several days later in the Cape Denbigh area with herring migration in a northerly direction along the coast from Unalakleet to Shaktoolik. It cannot be inferred that peak herring abundance and spawning observations of 21 May 1979 along the coast area from Stuart Island to Unalakleet was earlier than in 1978, since the first survey of that area in 1978 was not flown until 25 May. Commercial spawn-on-kelp operations near St. Michael in 1978 revealed herring spawn in intertidal areas prior to the first survey on 25 May. Peak herring abundance from Unalakleet to Cape Denbigh was estimated to occur from 28 to 30 May in both 1978 and 1979. Alaska Department of Fish and Game files indicate that peak spawning in Norton Sound usually occurs from 1-14 June.

Waves of spawning were observed in most areas studied in 1978 and 1979. Analysis of herring samples from Metervik Bay in both years revealed that temporal differences in herring size and age composition occurred. Older herring were the first to arrive on the spawning grounds while younger herring appeared later (Figure 16). Herring were primarily dominated by age 5 and older individuals prior to mid May, after which 3-year-olds began to appear in significant numbers. Kasahara (1961) has pointed out that (concerning Pacific herring) in most spawning areas early spawners have a higher proportion of older fish.

Distribution

In general, distribution of spawning herring throughout the study area in 1978 and 1979 was consistent with previous work conducted by ADF&G (Barton

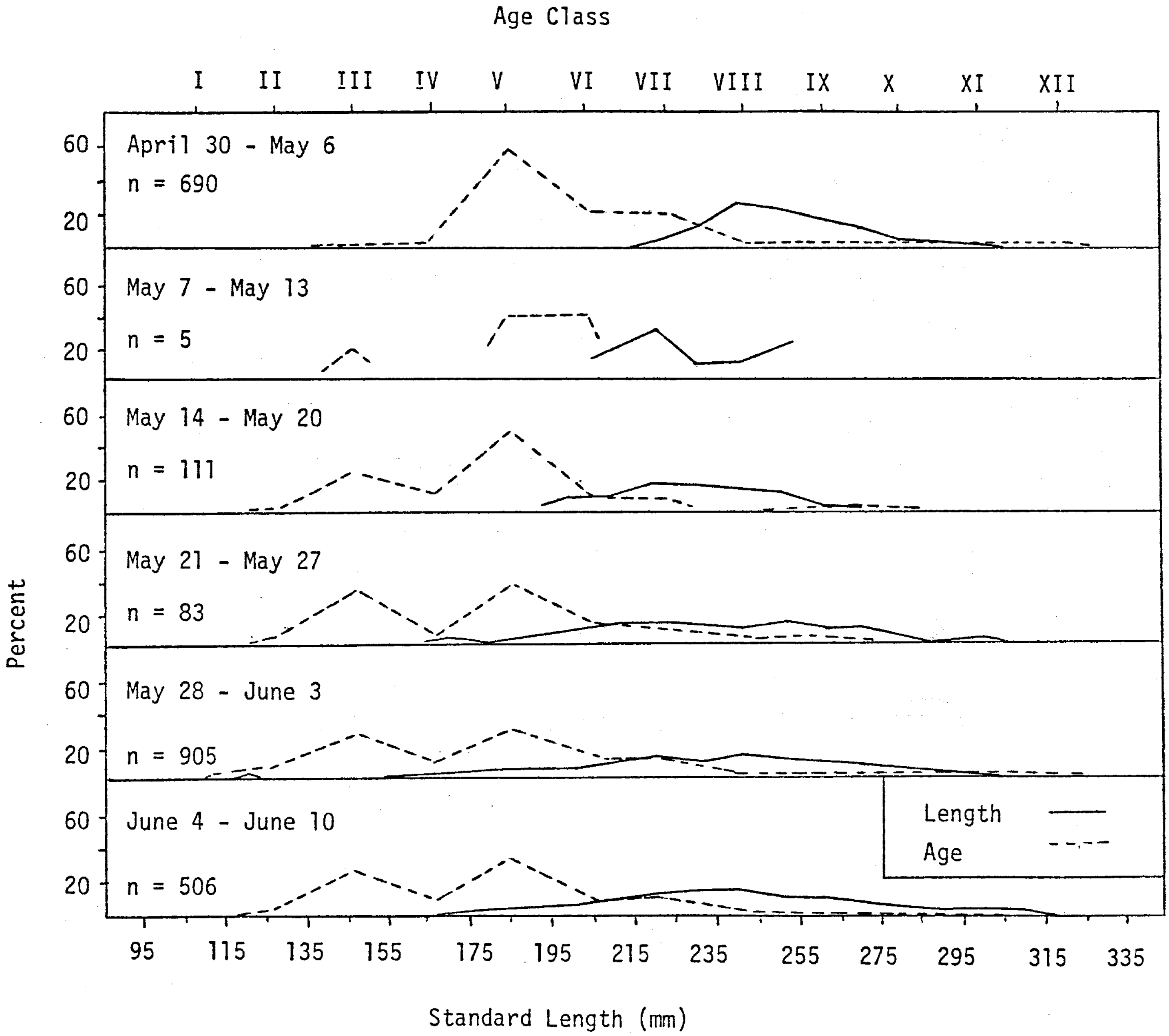

Figure 16. Temporal changes in length and age composition of spawning herring runs observed from 30 April through 10 June in Metervik Bay, 1979.

et al. 1977; Barton 1978). However, distribution and occurrence of yearling herring and other juvenile age groups in coastal waters of the eastern Bering Sea are poorly understood and remains a large gap in the data base. Barton (1978) reported herring of age groups 0, 1, and 2 present in significant numbers in the Port Clarence area in 1977 from August through freezeup (October). In 1978 more than 30% of the herring captured with variable mesh gill nets at Tongue Point were yearlings (age 1). This age group was also present in Metervik Bay and Security Cove in 1978 but in lesser numbers. These data from 1978 suggest that the Hagemeister Strait area of Bristol Bay may be a nursery area for yearling (pre-recruit) herring. Age 1 herring were again found at Tongue Point and Metervik Bay as well as at Cape Romanzof in 1979 but only in very small numbers. This age group was not found in any other area sampled in either 1978 or 1979.

Age 2 herring were present at all areas examined in both 1978 and 1979 except at Nelson Island and Port Clarence in 1978. Limited gill net samples suggested this age group was most abundant in the Togiak District. However, the frequency of age 2 herring in limited sampling north of Bering Strait near Shishmaref in 1979 was 22%. It was estimated that 74% of age 2 herring captured in areas south of Bering Strait were sexually mature in 1979, while only 6% were determined to be sexually mature from samples collected north of Bering Strait. Examination of herring samples collected near Shishmaref for age, maturity, growth, and stomach contents suggests that this area may be an important feeding region for both juvenile and post-spawning herring.

Abundance

Abundance estimates of herring in the eastern Bering Sea are rather limited and difficult to quantify. 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.

The eastern Bering Sea herring biomass was estimated to be 2.16 million mt based on a Soviet hydroacoustic survey of the wintering grounds in 1962-63 (Shaboneev 1965). 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 in 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 waters. The revised estimate of 0.5 fish/m^3 was based on densities observed in subsequent surveys of herring concentrations on the winter grounds northwest of the Pribilofs during 1969-71 (Wespestad, NMFS, Northwest and Alaska Fisheries Center, Seattle, personal communication). Densities derived are questionable and 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.

More recently, a numerical ecosystem model was applied to estimate biomass of eastern Bering Sea herring (Laevastu and Favorite 1978). This model estimated herring abundance based on the amount of herring needed to sustain the diet of herring predators at reported rates of consumption. Modeling suggested that a minimum stock size of 2.49 million mt of herring was 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. However, results cannot be used for management since the accuracy of input parameters, such as predator population size and consumption rates, has not been sufficiently evaluated.

Aerial surveys have been flown by the ADF&G in the past several years along the eastern Bering Sea coast during the spawning period and the number of fish schools recorded. However, it must be recognized that herring abundance, biomass, and proportion of other fish species are not reflected in a mere count of fish schools. Consequently, all 1978 and 1979 aerial survey and associated data were evaluated to establish methods for more precisely quantifying herring abundance.

Specific methods used to interpret data are predicated upon certain assumptions, which if not considered, would result in large errors in estimating spawning herring biomass. Consequently, results are only as valid as the assumptions made and measures taken to account for each. The assumptions which have been made are as follows:

1) That significant changes in herring density among index areas occur as a result of relative water depth and individual school characteristics, necessitating the application of a range of biomass conversion factors;

2) That movement and mixing of pre-spawning, spawning and post-spawning herring are substantially greater in the Togiak District resulting in a high chance of double counting fish schools;

3) That at least two important post-spawning migration routes for adult herring in the Togiak District exist: one in a south and easterly direction along the Nushagak Peninsula, and one in a westerly direction toward Cape Newenham. Such a situation would also increase the possibility of double counting fish schools;

4) That movement and behavior of spawning herring north of Goodnews Bay are such that fish abundance can be more easily assessed (i.e., a lesser probability of double counting fish schools);

5) That other species of schooling fish (smelt, capelin, and cod) coincide with the timing of spawning herring; and

6) That schools of juvenile herring occur in certain areas of the Togiak District during the spawning season, particularly in Hagemeister Strait.

Perhaps the most critical step in estimating biomass from aerial survey data is the application of tonnage conversion factors. The conversion of surface area to biomass is at present based upon only three samples of seined herring in the Togiak District: 6.7 mt and 11.0 mt per 50 m^2 of school surface area in Nunavachak Bay in 1978; and 2.4 mt per 50 m^2 in the Ungalikthluk Bay in 1979. Daily ranges in fish biomass for each index area were obtained by multiplying RAI's by the tonnage conversions shown in Table 12. No bathymetry charts exist for most of the major spawning areas and none in the areas from where seine biomass observations were made. Actual conversions varied among areas and were value judgments made by aerial surveyors to compensate for differences in relative water depth.

The largest probability of error associated with application of tonnage conversion factors exists in the Togiak District, particularly in Togiak Bay and perhaps along the Nushagak Peninsula. These two areas are believed to be quite shallow in comparison to Nunavachak and Ungalikthluk Bays, which possibly accounts for why they are the only regions where extremely large fish schools (5-20 miles long) were generally observed. Further, most aerial surveys in the Togiak District were flown at or near low tide. Fish schools would have a greater surface area, in shallow water.

In consideration of assumptions 2 to 4 above, aerial survey data were analyzed in an attempt to calculate the best estimate of fish abundance from recorded observations. It is generally recognized that the largest biomass of herring throughout the study area occurs south of the Yukon River, with the greatest proportion spawning along a coastal area of about 125 to 150 km from Kulukak Bay to Togiak Bay. This relatively small coastal area is characterized by several large bays, including Kulukak, Nunavachak, and Ungalikthluk, where intense spawning occurs. Two areas, Togiak Bay and the nearshore waters west of the Nushagak Peninsula, are believed to be major staging areas for post-spawning herring prior to departure from the Togiak region. This is based on information obtained from the commercial fisheries during the past few years. Purse seine catches from these areas consisted mostly of spawned out herring. Little spawning has been observed in these areas compared to other bays in the Togiak District.

Mixing of pre-spawners, spawners, and post-spawners during the spawning season in the Togiak District cannot be quantified but is believed to be substantial. Because of the probability of error associated with double counting fish schools, fish abundance was estimated by analyzing daily ranges of biomass for all six areas combined. The best estimate of true abundance was considered to be the highest daily range in the district. Fish biomass in 1978 was estimated at 230,170 to 411,030 mt based on results of the 13 May survey (Table 12). The 1979 fish abundance estimate was 283,153 to 744,021 mt based on results of the 10 May survey, but because poor survey conditions existed in Ungalikthluk Bay on that day and no survey was made of the Matogak index area, the 9 May estimate for Ungalikthluk (1,783 to 4,978 mt) and the average of 7 May and 14 May estimates for Matogak (4,075 to 8,965) were added to the observed 10 May estimate. Therefore, fish abundance for the Togiak District in 1979 was estimated to be 289,010 to 757,874 mt (Table 13). It should be pointed out that the dates on which fish abundance was determined do not necessarily coincide with dates of peak spawning in the Togiak District.

Most herring spawning in Norton Sound occurs along a coastline which has a relatively straight morphology unlike that of the Togiak District which is

Table 12. Biomass estimates in metric tons by index area of eastern Bering Sea herring spawning stocks, 1978.

Index Areas	Conversion factors	Date	RAI	Fish Biomass Estimates low	Fish Biomass Estimates high	Herring Biomass Estimates[1] low	Herring Biomass Estimates[1] high
Nushagak	2.0-6.7	5/13	6,323	12,646	42,364	9,484	31,773
Kulukak	6.7-11.0	5/13	15,130	101,371	166,430	76,028	124,822
Nunavachak	6.7-11.0[2]	5/13	14,404	96,506	158,444	72,379	118,833
Ungalikthluk	2.4-6.7[2]	5/13	893	2,143	5,983	1,607	4,487
Togiak	1.0-2.0	5/13	3,499	3,499	6,998	2,624	5,248
Matogak	5.0-11.0	5/13	2,801	14,005	30,811	10,503	23,108
TOGIAK DISTRICT TOTAL			43,050	230,170	411,030	172,625	308,271
Security Cove	6.7-11.0	5/30	246	1,648	2,706	1,236	2,029
Goodnews Bay	2.4-3.0	5/13	241	578	723	433	542
Nelson Island	6.7-11.0	5/17,30	1,079	7,229	11,869	5,421	8,901
Cape Romanzof[3]	6.7-11.0	-	539	3,611	5,929	2,708	4,446
YUKON-KUSKOKWIM TOTAL			2,105	13,066	21,227	9,798	15,918
Klikitarik	5.0-11.0	6/1,8,9	129	645	1,419	483	1,064
Unalakleet	5.0-11.0	5/30	84	420	924	315	693
Cape Denbigh	5.0-11.0	5/30	160	800	1,760	600	1,320
Norton Bay	5.0-11.0	5/30	265	1,325	2,915	993	2,186
Golovin Bay	5.0-11.0	5/27,6/13	59	295	649	221	486
Bluff	5.0-11.0	5/30,6/13	580	2,900	6,380	2,175	4,785
NORTON SOUND TOTAL			1,277	6,385	14,047	4,787	10,534
EASTERN BERING SEA TOTAL			46,432	249,621	446,304	187,210	334,723

1 These estimates have been reduced by 25% to compensate for the occurrence of non-herring species.
2 One half of the Nelson Island estimate was used.
3 Actual estimates made from purse seine catches.

Table 13. Biomass estimates in metric tons by index area of eastern Bering Sea herring spawning stocks, 1979.

Index Areas	Conversion factors	Date	RAI	Fish Biomass Estimates low	Fish Biomass Estimates high	Herring Biomass Estimates[1] low	Herring Biomass Estimates[1] high
Nushagak	2.0-6.7	5/10	76,783	153,566	514,446	115,174	385,834
Kulukak	6.7-11.0[2]	5/10	12,312	82,490	135,342	61,867	101,574
Nunavachak	6.7-11.0[2]	5/10	21	140	231	105	173
Ungalikthluk	2.4-6.7[2]	5/9	743	1,783	4,978	1,337	3,733
Togiak	1.0-2.0	5/10	46,956	46,956	93,912	35,217	70,434
Matogak	5.0-11.0	5/7,14[3]	815	4,075	8,965	3,056	6,723
TOGIAK DISTRICT TOTAL			137,630	289,010	757,874	216,756	568,471
Security Cove	6.7-11.0	5/14	2,912	19,510	32,032	19,510[4]	32,032[4]
Goodnews Bay	2.4-3.0	5/17	3,729	8,949	11,187	6,711	8,390
Nelson Island[5]	6.7-11.0	-	1,079	7,229	11,869	5,421	8,901
Cape Romanzof[5]	6.7-11.0	-	539	3,611	5,929	2,708	4,446
YUKON-KUSKOKWIM TOTAL			8,259	39,299	61,017	34,350	53,769
Klikitarik	5.0-11.0	5/21	797	3,985	8,767	2,988	6,575
Unalakleet	5.0-11.0	5/30	92	460	1,012	345	759
Cape Denbigh	5.0-11.0	5/28	627	3,135	6,897	2,351	5,172
Norton Bay	5.0-11.0	6/2	62	310	682	232	511
Golovin Bay	5.0-11.0	6/2	34	170	374	127	280
Bluff	5.0-11.0	6/9	248	1,240	2,728	930	2,046
NORTON SOUND TOTAL			1,860	9,300	20,460	6,973	15,343
EASTERN BERING SEA TOTAL			147,749	337,609	839,351	258,079	637,583

1 These estimates have been reduced by 25% to compensate for the occurrence of non-herring species with the exception of Security Cove.
2 Actual estimates made from purse seine catches.
3 The recorded RAI's on 7 and 14 May were averaged (815) to estimate abundance in the Matogak index area.
4 These estimates have not been reduced by 25% since large concentrations of capelin were excluded from the 14 May survey in the Security Cove index area.
5 The 1978 estimates were used.

characterized by bays and coves. Schools of herring may be scattered for nearly 800 km from Stuart Island to Port Clarence and herring abundance is quite small in comparison to that in the Togiak area. The movement of fish schools through areas in Norton Sound is considered to be more readily detectable. Fish biomass for each index area was assessed as the highest range of daily biomass estimates plus additional estimates separated temporally from the highest estimate by 10 to 15 days. In other words, schools observed within 10 to 15 days of one another in each index area were generally considered to be the same fish. Fish abundance in Norton Sound was assessed at 6,385 to 14,047 mt in 1978 and 9,300 to 20,460 mt in 1979 (Tables 12 and 13).

Fish biomass in the Nelson Island index area was evaluated in the same manner as in Norton Sound and estimated to be 7,229 to 11,869 mt in 1978 (Table 13). Since aerial survey conditions were such that no estimates of fish abundance could be made at Nelson Island in 1979, the 1978 estimate was used (Table 13). Excluding Nelson Island and Cape Romanzof, results showed an increase in fish biomass from 1978 to 1979 at all other coastal spawning areas. Shorebased studies at Nelson Island in 1978 and 1979 suggested the same phenomenon occurred there. This increase was substantiated by local subsistence fishermen. Consequently, the 1979 estimate for Nelson Island may be conservative.

No estimate of fish abundance in the Cape Romanzof index area could be made from aerial survey data in either 1978 or 1979. In both years fish biomass was considered to be at least one half of that at Nelson Island, or about 3,611 to 5,929 mt (Tables 12 and 13). These estimates may also be conservative since shorebased sampling at Cape Romanzof suggested at least as much spawning took place there as at Nelson Island based on observations of spawn deposition.

Fish biomass in the Goodnews Bay and Security Cove index areas was estimated as the highest daily range of biomass in each index area.

A very critical factor which must be considered in assessing herring abundance from aerial survey observations is the occurrence of other fish species, the timing of which coincides with herring spawning runs. Such species include capelin, smelt, sand lance, and possibly cod. No aerial surveyor can consistently distinguish between these species; at best, there are a few instances when capelin schools can be accurately differentiated from other species. Such occasions usually arise when schools are observed immediately adjacent to sand and gravel beaches, particularly if observed in the surf zone. Beach stranded capelin carcasses are often visible under such circumstances.

That species composition and identification is a problem throughout the study area is borne out by the fact that commercial aerial spotters mistakenly directed their purse seiners to schools of fish in the Togiak District in 1979 that resulted in catches of capelin and smelt. Capelin were also mistaken for herring in the Norton Sound area in 1979. On one occasion, near Cape Denbigh, schools of cod were mistaken for herring by a commercial aerial spotter.

The National Marine Fisheries Service investigated herring in Norton Sound and the Chukchi Sea in 1976 and also reported on the occurrence of herring and other pelagic species in southeastern Bering Sea demersal fish surveys in 1975 and 1976 (Wolotira et al. 1977; Pereyra et al. 1976). No inferences can be made from these surveys on the proportion of pelagic species since sampling was designed to examine demersal fish populations. However, herring and smelt were generally found throughout the survey areas and often mixed, particularly in the fall.

More recent investigations by Laevastu and Favorite (1978), as pointed out above, have estimated eastern Bering Sea herring biomass at 2.49 million mt. They further estimated the biomass of other pelagic fish species, consisting primarily of capelin and sand lance, to be 3.9 million mt based on the same ecosystem model. They state that capelin and sand lance constitute an important food source in the Bering Sea based on stomach analysis of mammal and fish predators.

Capelin in large numbers have been observed to spawn all along the western coast in shallow water, the timing of which coincides somewhat with spawning herring runs (Barton et al. 1977; Barton 1978; Baxter 1975 unpublished). These data support the concept of reducing fish biomass estimates to compensate for the presence of non-herring species to estimate herring biomass from aerial survey data. Unfortunately, data are not available regarding the exact proportion of herring, capelin, smelt, and other non-herring pelagic species occupying nearshore coastal waters during the spring.

Although gill nets are an effective method of capturing fish, it is realized that several factors affect their use and efficiency. Mesh size and dimensions, duration and depth fished, fish size and morphology, and size of teeth and mouth parts are probably most important. However, for lack of more definite data on the species composition of fish schools observed from the air, catch data from the test gill nets were utilized. The percent composition of herring captured in variable mesh gill nets in 1979 is shown by location in Table 14.

The proportion of herring ranged from 53 to 96% among the areas sampled and averaged 76% for the areas combined. The remaining 24% consisted of 12% capelin, 9% smelt, and 3% cod. The proportion of capelin may possibly be low as Ricker (1975, p. 72) points out, "experimental [variable mesh] gillnetting over many years has shown that really small meshes catch far fewer fish than somewhat larger ones, whereas fish of the sizes best caught by small meshes must generally be more numerous than larger ones". On the other hand, the true proportion of smelt may be over estimated from gill net catches. Most smelt captured were Arctic smelt (*Osmerus dentex*) which have large canine teeth, possibly making them more vulnerable to gill nets.

The above data exclude catches of other species such as pricklebacks (*Stichaeidae*), flounder, greenlings (*Heragrammidae*), and cottids (*Cottidae*); those not likely to be observed from aircraft. The overall proportion of herring captured in 1978 with test nets throughout the study area was 75%. Unfortunately, neither the aerial survey nor the test fishing data base is such that would permit applying a percent species composition factor to each index area for the entire season, much less on a daily basis. Consequently, the average percent composition was considered as the basis for making adjustments to aerial counts to compensate for the occurrence of non-herring species.

Table 14. Variable mesh gillnet catch, total fish and herring, and percent herring, 1979.

Test Fish Site	Total Catch	Total Herring Catch	% Composition Herring
Metervik Bay	5,098	3,166	62
Tongue Point	3,304	3,036	92
Goodnews Bay	2,048	1,847	90
Nelson Island	3,393	1,785	53
Cape Romanzof	3,537	3,273	93
Cape Denbigh	659	600	91
Port Clarence	320	307	96
TOTAL	18,359	14,014	76

To obtain an estimate of herring biomass in 1978 and 1979 shown in Tables 12 and 13, the range of biomass estimates has been reduced by 25% for each index area, with the exception of Security Cove for 1979 (Table 13). Fish biomass in the Security Cove index area was estimated on 14 May 1979; the aerial survey in which large concentrations of capelin were excluded. Consequently, no reduction was made of that range in estimates of herring abundance.

Estimates of herring biomass are considered to be the spawning biomass, although there was some evidence gathered during the course of these studies which suggests that certain areas in the Togiak District are occupied by an unknown proportion of juvenile herring. No measures have been taken to compensate for this possibility due to the lack of precise data. If juvenile herring were present in great numbers on the spawning grounds then the estimates of spawning biomass presented here may be high.

Age Composition and Recruitment

The requirements for an idealized sampling scheme to determine population age structures in all major eastern Bering Sea spawning locations were not met in this study. The primary sampling tool used, the variable mesh gill net, is biased in some circumstances, as sampling effort was not spread in a weighted fashion throughout the spawning runs at sampling sites, and sample sizes were inadequate in some instances.

The variable mesh gill net was chosen for this study to provide a standard gear type that could be utilized in parts of the study area where purse seines were not, or could not be used by the commercial fleet, and in areas closed to the use of purse seines. Gill nets are inexpensive, easily transported, and easily fished by small crews from small watercraft. Sampling was possible in many remote major spawning locations that otherwise would not have received attention.

On the other hand it must be noted that data collected with variable mesh gill nets have certain limitations. It is inappropriate, for example, to use catch per unit of effort data from this gear type as an indicator of abundance. Schooled pelagic fishes can quickly saturate available meshes of the appropriate size if they happen to move into a set.

Species composition data may also be inaccurate because of the relative catchability of certain schooling species. Capelin, for example, because of their fusiform morphology, are not sampled in proportion to their actual occurrence since they gill at a low rate.

With regard to herring population age structure, a sampling problem exists when a wide range of age classes are present and a large proportion are smaller, younger (age 3 and less) fish. In such instances, variable mesh gill nets may underestimate the actual frequency of small fish in the population and overestimate larger ones (Ricker 1975).

Results in 1979 indicated that this size selectivity may have been a problem in some areas. Comparison of gill net and purse seine samples taken in the

Tongue Point area showed no difference in age composition between gear types (Table 11). However, a predominant proportion of that population was, during the sampling period, age 5 herring. Age 5 and older age classes comprised greater than 69% of the samples from both types of gear. However, at Metervik Bay, purse seine catches sampled on 24 May consisted of a high proportion (72%) of age 3 herring, while gill net catches in the area at the same time measured a significantly ($P < 0.01$) lower proportion (37%) of that age.

Clearly, the strength of pre-recruit age classes of herring, (ages 1, 2 primarily) was not adequately measured by inshore sampling methods. Although they may occur in feeding concentrations inshore along the inner Bering Sea shelf, they have not been located. There are some preliminary indications that juvenile herring may occur in numbers in the vicinity of Tongue Point and Hagemeister Strait area of Bristol Bay. Locating and assessing the abundance of juvenile herring may require the use of trawl survey methods similar to those utilized in the North Sea (Dragesund 1970). Until pre-recruit herring can be assessed, the strength of recruiting year classes cannot be predicted with accuracy.

Regarding the validity of existing age composition data in the present study, it is recognized that inherent limitations restrict the interpretations that can be made. However, it is felt that while the analysis may underestimate age 2 and 3 herring in some locations and at certain times during the period of the run, it is sufficiently sensitive to detect major year class strengths and weaknesses, especially in the fully recruited age classes. The age structure of the entire spawning population at each sampling location is not precisely known. However, results infer strongly that relatively strong year classes exist from 1974 in all areas. The 1976 year class was strong in Bristol Bay and Norton Sound and the 1972 year class was strong north of Cape Newenham. Further, results infer that weak age classes existed from the 1973 and 1975 brood years in all areas. Only in Port Clarence did age classes older than 7 contribute in a significant way to the population, probably because the population has been subjected to very little fishing pressure, which tends to selectively remove larger herring.

It is anomolous that the 1972 year class figured prominently in the 1978 Cape Denbigh gill net samples, but not in 1979. The most plausible explanation for the failure of the year class to appear strongly in 1979 is that severe stormy weather prevented gillnetting operations 5-7 days after peak commercial catches were made in the area. Due to the known tendency for older herring to arrive and spawn before younger age classes, it is reasonable to assume that the 7-year-olds had spawned and moved offshore by the time gillnetting commenced.

Relative year class abundance observed in this study in 1978 and 1979 is substantiated by Naumenko (1979, unpublished). This work analyzes foreign fishery catches offshore in the wintering areas of eastern Bering Sea herring since 1947. The 1972, 1974, and 1976 year classes are indicated as relatively large compared to 1973 and 1975, with the 1974 year class the most abundant since 1967.

Ultimate causes of year class survival and abundance are not fully understood. Many Soviet and American scientists believe that heat budget variations in the Bering Sea play a role in determining survival values, particularly for pre-recruit herring. There appears to be good correlation between the survival of juvenile herring and the influx of warmer Pacific Ocean water into the Bering Sea (Naumenko 1979, unpublished). Laevastu and Favorite (1978) point out that herring year class survival is more dependent upon internal ecosystem consumption factors than upon the actual size of the spawning escapements. It seems clear that internal ecosystem consumption rates would in turn be influenced by the oceanographic effects of warm and cold water masses. Warmer water temperatures in the Bering Sea over the past 3 years could well favor the survival of the next recruiting year class from 1977.

Foreign trawl catches of Bering Sea herring peaked in the late 1960's and declined rapidly after 1971. Length and age frequency data indicate that those catches were composed of larger and older herring than have been observed in inshore catches of recent years (Wespestad 1978, unpublished). This suggests that the foreign fishery was based upon strong year classes known to have been produced in 1960, 1962, and perhaps as early as 1957 and 1958. Poor recruitment during the early and middle 1970's and overfishing on few strong year classes apparently produced decreased herring abundance and a greatly reduced foreign catch and effort after the peak years. Increased recruitment of the 1972, 1974, and 1976 year classes, coupled with reduced mixed stock foreign fisheries in the Bering Sea are probably responsible for the observed increase in abundance in 1978 and 1979. The early foreign fishery was based upon previously unexploited stocks and since the decline in the offshore fishery, catch statistics to compare present abundance are not available. In addition the spawning biomass was not surveyed adequately in those years and, therefore, it is not possible to compare recent biomass estimates with the late 1960's and early 1970's. It cannot be stated with assurance that present biomass levels are of the magnitude of those prevailing from 1968-1971, but the available evidence indicates that herring stocks in the eastern Bering Sea are at their highest levels since that period.

Maturity

Ripening of mature eastern Bering Sea herring as evidenced from spawn timing is apparently advanced by warm sea temperatures. The onset of sexual maturity in young herring may also be advanced by warm seas. Rumyantsev and Darda (1970) in 1964 found that eastern Bering Sea herring stocks become mature primarily at ages 3 (50% mature) and 4 (78% mature). They found that 95% of the age 5 herring were mature. Barton (1978) found essentially the same for spawning stocks in Norton Sound and Port Clarence in 1976 and 1977.

Based on gill net sampling, nearly 74% of the age 2 herring captured throughout the study area in 1979 were determined to be sexually mature, while 95% of age 3 were mature (Table 9). These data suggest a greater than average spawn production from these two age groups in 1980. Such an occurrence may be more likely in the Bristol Bay area since about 75% of age 2 herring captured in 1979 were from this region.

Maturity data collected near Shishmaref in 1979 suggests that sexual maturity of herring in this region may occur later in life than herring stocks further south. Although data show 94% age 4 herring to have been mature, not a single age group was found to be 100% mature until age 8 (Table 9). Barton (1978) captured 16 herring near Shishmaref in 1977 in mid July and 15 of the fish were found to be age 5; all were determined to be sexually immature.

Stock Investigations

Grant (1979) found no evidence of distinct genetic stocks of herring in the central part of the eastern Bering Sea based on an electrophoretic analysis of samples collected in 1978 at five coastal spawning areas from Bristol Bay to Port Clarence. However, this analysis did indicate that herring from Port Clarence may be different from herring further south or alternately may contain fish from an Arctic group. He also found that separation of Bering Sea and Gulf of Alaska herring was possible. Additional herring samples were collected in 1979 from nine coastal spawning areas from Bristol Bay to Kotzebue Sound for subsequent electrophoretic analysis. Results are pending.

As part of this study, standard and fork length relationships and length-at-age relationships of herring from various spawning areas were analyzed. A total of 2,276 herring were examined for fork and standard length comparisons. Samples were represented by herring from eight coastal areas collected from 1977 through 1979 from Bristol Bay to Kotzebue Sound. Results were plotted and linear regression calculated for each sex by area. No significant difference between males and females was observed at any area ($P < 0.05$). Further analysis revealed the slope and intercept of the regression plotted for Tongue Point samples differed significantly ($P < 0.05$) from those plotted for samples collected from two areas north of Bering Strait. No significant difference between Tongue Point samples and those examined at Goodnews Bay, Nelson Island, or Port Clarence was observed.

The results of standard to fork length analysis compare favorably with results of analysis of size-at-age. The mean size-at-age of herring sampled from Bristol Bay to Norton Sound were similar, although size-at-age was found to progressively decrease in a northerly direction (Table 10 and Figure 5). Mean size-at-age of herring sampled at Port Clarence, Shishmaref, and in Kotzebue Sound were significantly smaller. Barton (1978) suggested that spawning herring in the northeastern Bering Sea and north may be distinct from those found in more southern areas. Mean size-at-age of herring along the western coast of North America to Bristol Bay increases progressively from British Columbia to the Bristol Bay and Yukon-Kuskokwim Delta area of Alaska and then decreases northward to Bering Strait. Rounsefell (1930) reported similar results using mean number of herring vertebrae.

Further evidence that herring north of the Yukon River Delta differ from those south of the Delta was observed from differences in scale characteristics (Rowell, ADF&G, Juneau, personal communication). Herring scale analysis may be a potential method for examing stock differences within the Bering Sea and that research should be pursued.

Spawning Habitats and Egg Mortality

Information gathered on herring spawning habitats during the course of these investigations agreed with previous studies in the eastern Bering Sea (Barton 1978). Two habitat types were found: exposed rocky headlands where spawn was deposited on *Fucus*, the dominant intertidal vegetation; and shallow lagoons and bays where spawning occurred primarily in shallow subtidal zones on *Zostera*. Rocky headlands are far more extensive than bays and it is this type that is used the most extensively for spawning in the eastern Bering Sea. Goodnews Bay and the Port Clarence-Grantley Harbor complex were the only areas examined in 1978 and 1979 with characteristics of the second habitat type. By contrast, it is estimated that approximately 275-300 km of rocky coastline occurs from north Bristol Bay to cape Romanzof, while more than 400 km characterize most of Norton Sound from Stuart Island to Cape Nome. Spawning herring utilize this habitat over most of the entire range.

The extent of subtidal spawning throughout the entire study area is not known, nor its significance related to that of intertidal spawning. However, it is known to occur as evidenced from the frequent occurrence of storm-washed, spawn-covered plant substrates such as *Fucus* and *Zostera*, and to a lesser extent *Laminaria*. The availability of suitable spawning substrates may be a major limiting factor on the biomass of spring herring runs to the Norton Sound region.

Excluding predation, our studies revealed that loss of spawn through disruption of habitats from spring storms was significant in most areas, while heavy loss at Cape Romanzof was attributed to desiccation of *Fucus* and eggs from excessive exposure to sunlight and wind during periods of low tide. Highest mortality at Nelson Island was observed on spawn deposited on bare rocks and exposed at low tide.

Effects of Harvests on Stock Strength

Harvest of sac roe herring from the Bering Sea totaled 7,300 mt in 1978 and 11,800 mt in 1979. These harvests constitute 2.2 to 3.9% and 1.8 to 4.6% of the estimated spawning herring biomass ranges described in this report. The highest exploitation rate, 7.6 to 16.8%, occurred in the Norton Sound District in 1979 (Table 15). Although these rates of exploitation are, with the possible exception of Norton Sound, well below those which have been permitted in the management of most other Pacific herring fisheries, the rapid rate of development of Bering Sea herring fisheries and the inadequate knowledge of the stocks warrant a conservative management approach. Consequently, in view of the variables associated with determining herring biomass from aerial surveillance, the low range of estimates presented in this report are considered as the best estimate of spawning biomass.

Further, in the Togiak and Norton Sound Districts spawn-on-kelp fisheries occur which have further direct and perhaps indirect effects on herring populations. The spawn-on-kelp harvest in the Togiak District in 1979 removed roughly the equivalent of spawn production from 1,700 mt of herring (McBride and Clark 1979, unpublished). The Norton Sound 1979 spawn-on-kelp harvest was only 12 mt (equivalent to the spawn production of about 110 mt).

Table 15. Biomass (mt), nearshore commercial harvest and exploitation rate of eastern Bering Sea herring in 1978 and 1979.

Area	Year	Commercial Harvest (mt)	Herring Biomass Estimates low	Herring Biomass Estimates high	Exploitation Rate (%)
Togiak District	1978	7,030	172,625	308,271	2.2 - 4.0
Security Cove- Goodnews Bay	1978	259	9,798	15,918	1.6 - 2.6
Norton Sound District	1978	14	4,787	10,534	0.1 - 0.3
Total	1978	7,303	187,210	334,723	2.2 - 3.9
Togiak District	1979	10,115	216,756	568,471	1.8 - 4.6
Security Cove-Goodnews Bay	1979	466	34,350	53,769	0.1 - 1.4
Norton Sound District	1979	1,173	6,973	15,343	7.6 - 16.8
Total	1979	11,754	258,079	637,583	1.8 - 4.6

The exploitation rate on subsistence caught herring was less than 0.5% in both 1978 and 1979.

Subsistence harvests removed less than 0.05% of the estimated eastern Bering Sea herring biomass (lower range) in both 1978 and 1979.

CONCLUSIONS

1. Spawning of the Pacific herring occurs discontinuously along the coastline of the eastern Bering Sea from Bristol Bay to Bering Strait, commencing in late April and May in the Togiak District and progressively later to the north.

2. Post-spawning herring appear to concentrate in "staging areas" in the Togiak and Nushagak sections of the Togiak District. Yearling herring were abundant in variable mesh gillnet catches in the Hagemeister Strait area of Bristol Bay, suggesting this region to be an important feeding ground for juvenile herring.

3. Arrival of herring on the spawning grounds and peak of spawning were generally earlier than normal in both 1978 and 1979 and may have been the result of warm winter and spring water temperatures in the Bering Sea.

4. Temporal differences in spawn timing occur between age classes in the eastern Bering Sea, with older herring arriving before younger herring.

5. The relative abundance of Pacific herring in the nearshore waters of the eastern Bering Sea increased from 1978 to 1979 based on aerial estimates of biomass.

6. Herring abundance on the spawning grounds of the eastern Bering Sea is expected to be high again in 1980 based on their high abundance in 1978 and 1979, strong recruitment from the 1974 and 1976 year classes, and probable strong recruitment of the 1977 year class.

7. Sexual maturity of herring in the eastern Bering Sea is attained primarily at age 3 or 4. A high proportion of age 2 herring were found to be mature in 1979 which may have resulted from warmer winter and spring sea temperatures.

8. Studies of the selectivity of variable mesh gill nets and purse seines to herring size and age suggest that in some instances variable mesh gill nets may underestimate the actual frequency of small fish in the population and overestimate larger ones. However, in view of the small sample sizes obtained, more studies may be warranted.

9. Herring stocks are deemed "healthy" at the present time due to recent increases in recruitment and the reduction of foreign offshore, mixed stock fisheries. Fisheries impacts will be most severe upon older year classes of herring such as the 1972 and 1974 year classes.

10. Rockweed (*Fucus* sp.) is the primary intertidal herring spawn substrate in the eastern Bering Sea. Eelgrass (*Zostera* sp.) is the primary spawn substrate where herring spawn subtidally in shallow lagoons.

11. Mortality of intertidal spawn was attributed to predation by birds, fishes, crabs, and snails, and desiccation, freshwater immersion from snow melt, wave action during storms, and to commercial spawn-on-kelp harvest. Loss of herring spawn and spawn substrates due to winter and spring storms and ice scouring was possibly very substantial.

12. Analysis of herring size-at-age indicated that herring spawning north of Norton Sound are slower growing from those spawning south of Norton Sound. Herring in the Chukchi Sea appeared to attain sexual maturity at an older age on the average than those in the Bering Sea.

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