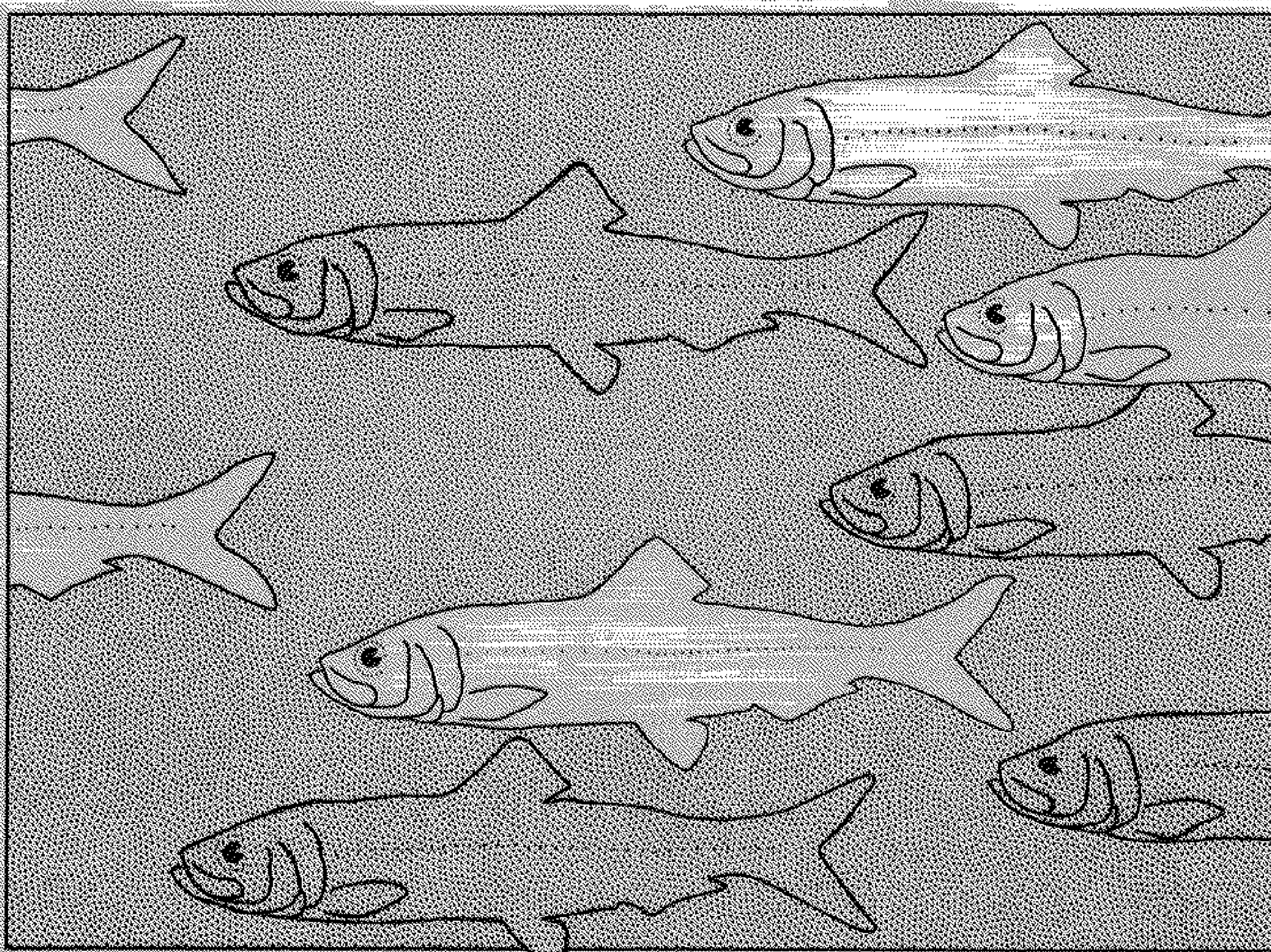
Proceedings

OF THE

Alaska Herring Symposium



Anchorage, Alaska

February 19-21, 1980

Alaska Sea Grant Report 80-4
October 1980

ALASKA SEA GRANT COLLEGE PROGRAM
University of Alaska
Fairbanks, Alaska 99701

PROCEEDINGS

of the

ALASKA HERRING SYMPOSIUM

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Compiled and Edited

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WELCOME

Jim Edenso
Office of the Governor
Bottomfish Coordinator
Juneau, Alaska

Welcome to the Alaska Herring Symposium. On behalf of Governor Hammond, it is my pleasure to present these opening remarks.

Herring is a very important element of Alaska's marine resources. The passage of the Fishery Conservation and Management Act of 1976, creating the 200-mile fishery conservation zone, has focused attention on all marine resources. Alaska has a vast (indeed the largest) fishery conservation zone. A recent report prepared for Governor Hammond in the establishment of an Alaska bottomfish development program indicates that "Alaska's continental shelf and upper slope to 200 fathoms (excluding the Arctic Ocean) covers 477,000 square land miles."

1) This area is equal to 81 percent of Alaska's land area of 600,000 square miles.
2) Finally, for the entire northern hemisphere, this amounts to approximately 19 percent of similar fishing areas. The vast area alone is a good indicator of the magnitude of the marine resource management problems for the federal and state governments as well as for the resident Alaskan.

While I have recently been introduced to Alaska's groundfish, or bottomfish, species, I have had a long and tasteful acquaintance with Alaska's herring resources. I, like many Alaskan Natives, have utilized the herring and herring roe as important subsistence food sources and trade commodities. Alaska's social and economic fabric is very closely entwined with the marine resources found in the waters adjacent to its coastal communities. Indeed, this environment impacts the communities located hundreds of miles up the major river systems of the state.

With the exception of Fairbanks, Alaska's major communities are located on its coasts. The harvesting, processing and marketing of seafood represent the second largest industry in the state behind the oil and gas industry. The seafood industry provides more jobs on an annual basis than any other private sector industry. The 1979 revenues generated in the private sector by the seafood industry exceeded $1 billion. These revenues were generated exclusive of two largely undeveloped major fisheries: the bottomfish industry, and the Bering Sea herring fishery. The interest of the state lies in two oftentimes conflicting policy areas: the marine resource biomass management category, and the social and economic categories for deriving benefit from the utilization of the state's marine resources.

While it is understandable that biomass management and socio-economic utilization management policies and goals may occasionally conflict, it is also apparent that both share the same common objective: The benefit of the Alaskan resident. The purpose of this symposium is to share information pertinent to the biomass management area. The importance of this meeting and the agenda topics cannot be overemphasized. The wealth of experience of the symposium participants, as well as the data and information, will help the herring fishery resource management personnel to prepare better resource management plans for both the preservation of Alaska's herring resource stocks and the socio-economic benefits derived from the utilization of this important marine resource. Alaska's Bering Sea herring fishery is in the embryonic growth stage. It is vitally important that every effort be made to create and foster the environment for the exchange of scientific marine information to help manage these stocks.

Alaska has adopted a policy for fishery management which provides its residents with opportunities to benefit from the resource utilization. Ten of the 12 Native regional corporations have major coastal property. Five of the Native regional corporations have investments in the fishing industry. These same corporations are the largest private landholders in the state. Most of the Native populations have depended on marine resources initially for subsistence and also for income and employment. Historically, marine resources have played an important part in the state's economy. The results of your participation in this symposium will assist Alaskan policy makers in assuring that the herring resource will continue to provide benefits in the long-term.

TECHNICAL PAPERS

MANAGEMENT OF PACIFIC HERRING IN THE EASTERN BERING SEA

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ABSTRACT

Man has fished for herring in the eastern Bering Sea for over 2,000 years, but until very recently, there has been little or no effort to manage the stocks. Stocks have historically demonstrated great fluctuations in abundance, but there is little biological knowledge concerning the cause of these year class failures or of the total biomass. Evidence suggests that stocks were depleted in the early 1970s, but presently appear to be recovering. Current world market conditions favor exploitation by the domestic industry and in a period of three years fishing effort and processing capacity have rapidly expanded in the near shore areas. The North Pacific Fishery Management Council is responsible for management of herring offshore (200 mile limit), and the State of Alaska manages the stocks within three miles of the coast as they move near shore to spawn. Current management efforts and future strategies are discussed.

INTRODUCTION

During 1977, 1978 and 1979, there has been rapid expansion of the domestic commercial harvest of herring in the eastern Bering Sea. This increase in domestic participation was affected by world-wide shortages of herring believed to be the result of over-exploitation in traditional areas and from recruitment failure or adverse environmental changes. These shortages were further increased after implementation of 200 mile fishing zones by several nations, thus curtailing some countries that were targeting on herring outside their home waters. In the case of the United States, the Fishery Conservation and Management Act of 1976 (Public Law 94-265) gave additional protection and incentive to domestic fishermen.

At this same time, the value of the United States dollar dropped relative to the Japanese yen. The Japanese are the primary consumers of herring sac roe and roe-on-kelp on the international market. This combination of factors spurred the domestic fishing industry to pioneer exploratory efforts in Bristol Bay and other areas further north.

SUBSISTENCE

Archaeological excavations in the Cape Denbigh area of Norton Sound indicate a strong reliance on net fishing for subsistence as far back as 500 B.C. (Hemming et al., 1978). This tradition continues among coastal Eskimos even today (Table 1). Villages between the Yukon and Kuskokwim rivers depend heavily on herring as a major food source, having few alternative subsistence foods (Figure 1, Barton 1978).

The importance of subsistence has been recognized as the highest priority use by the Legislature, the Alaska Board of Fisheries, and the North Pacific Fishery Management Council. A large area of the coast around Nelson Island has been closed to commercial fishing by the State of Alaska, and the North Pacific Council has included specific language in the Bering-Chukchi Sea Herring Management Plan to further protect the subsistence way of life.

HISTORY OF COMMERCIAL EXPLOITATION

Early commercial fishing for herring in the northeastern Bering Sea dates back to the gold rush days at the turn of the century. Marsh and Cobb (1910) reported that a small fishery developed in Grantley Harbor on the Seward Peninsula about 1906 to supply salt herring to Nome. Prior to 1909, another small herring fishery developed in Golovin Bay, Norton Sound (Rounsefell, 1930). The Grantley Harbor operation lasted until 1917, but Golovin Bay continued to pack herring until 1941.

A salt herring operation began on the Alaska Peninsula in 1928 at Unalaska. The peak harvest occurred in 1937 when 2,277 metric tons were processed (Barton, 1978). This fishery ended in 1946 when prices fell and demand for salt herring declined (Wespestad, 1978a).

FOREIGN FISHERIES

During the period from 1946, when the saltery operation at Unalaska terminated, until 1959 there was no major commercial effort for herring in the eastern Bering Sea. In 1959, Soviet trawlers began operating when they located wintering herring northwest of the Pribilof Islands (Figure 2). They were followed by the Japanese who began a trawl operation

Table 1. Nelson Island Herring subsistence catch, 1975-1979. 1/

Village	1975		1976		1977		1978		1979	
	lbs.	m.t.	lbs.	m.t.	lbs.	m.t.	lbs.	m.t.	lbs.	m.t.
Tanunak	43,565	19.8	30,593	13.9	114,425	51.9	76,400	34.6	68,376	31.0
Umkumiut	65,898	30.0	18,660	8.5	6,075	2.8	22,965	10.4	16,453	7.5
Toksook Bay	68,405	31.0	85,675	38.8	42,600	19.3	73,908	33.5	102,564	46.5
Totals	177,868 (109) 2/	80.8	134,928 (42)	61.2	163,100 (90)	74.0	173,273 (83)	78.5	187,393 (54) 3/	85.0

1/ 1975-77 and 1979 data from Alaska Department of Fish and Game; 1978 data from Hemming et al. 1978.

2/ Numbers in parenthesis indicate the number of herring fishing families or heads of households that reported catches.

3/ No estimate of households fishing was obtained for Toksook Bay in 1979.

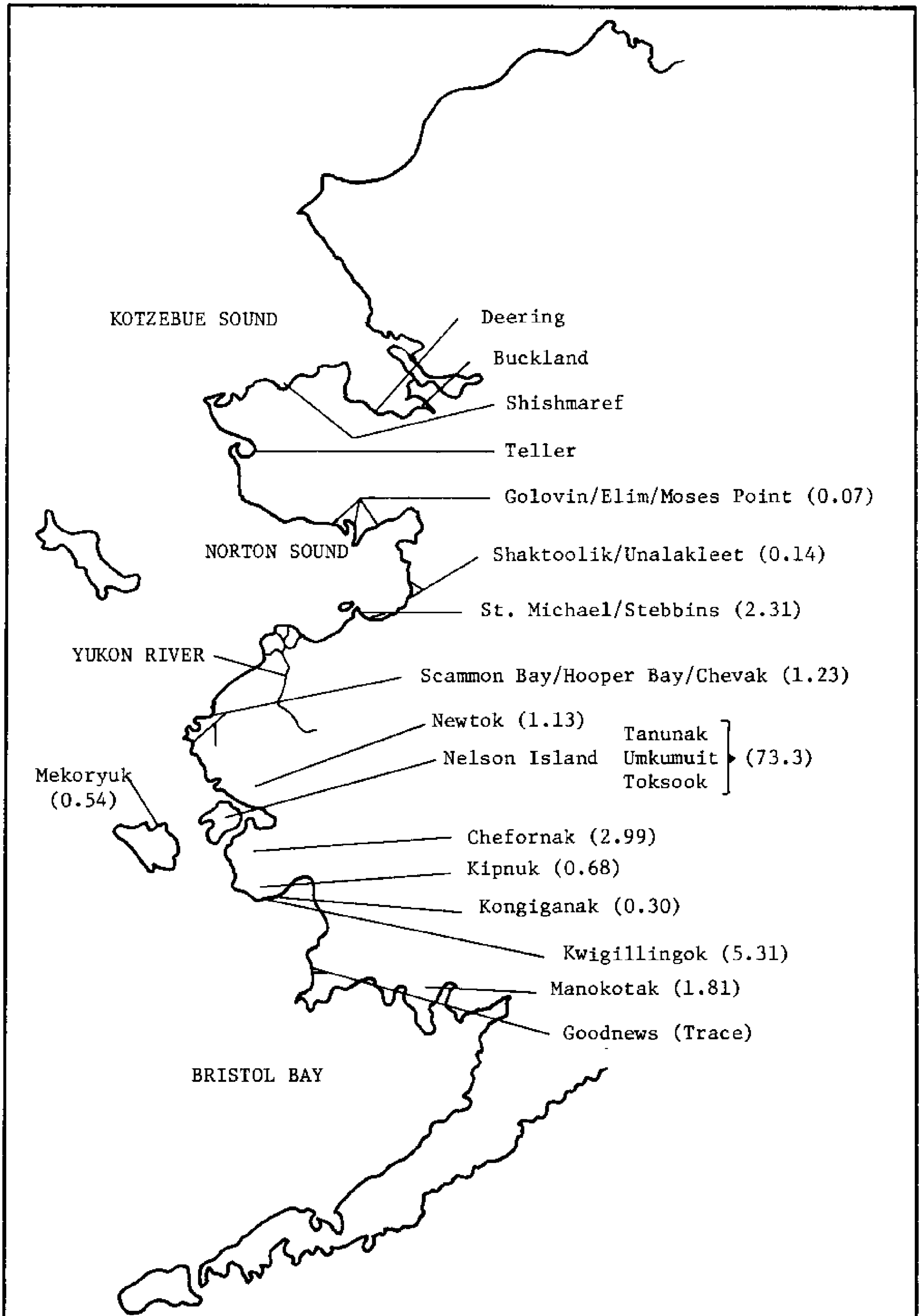

Figure 1. Average annual subsistence herring harvests (in metric tons) by eastern Bering Sea coastal villages, 1975-1978.

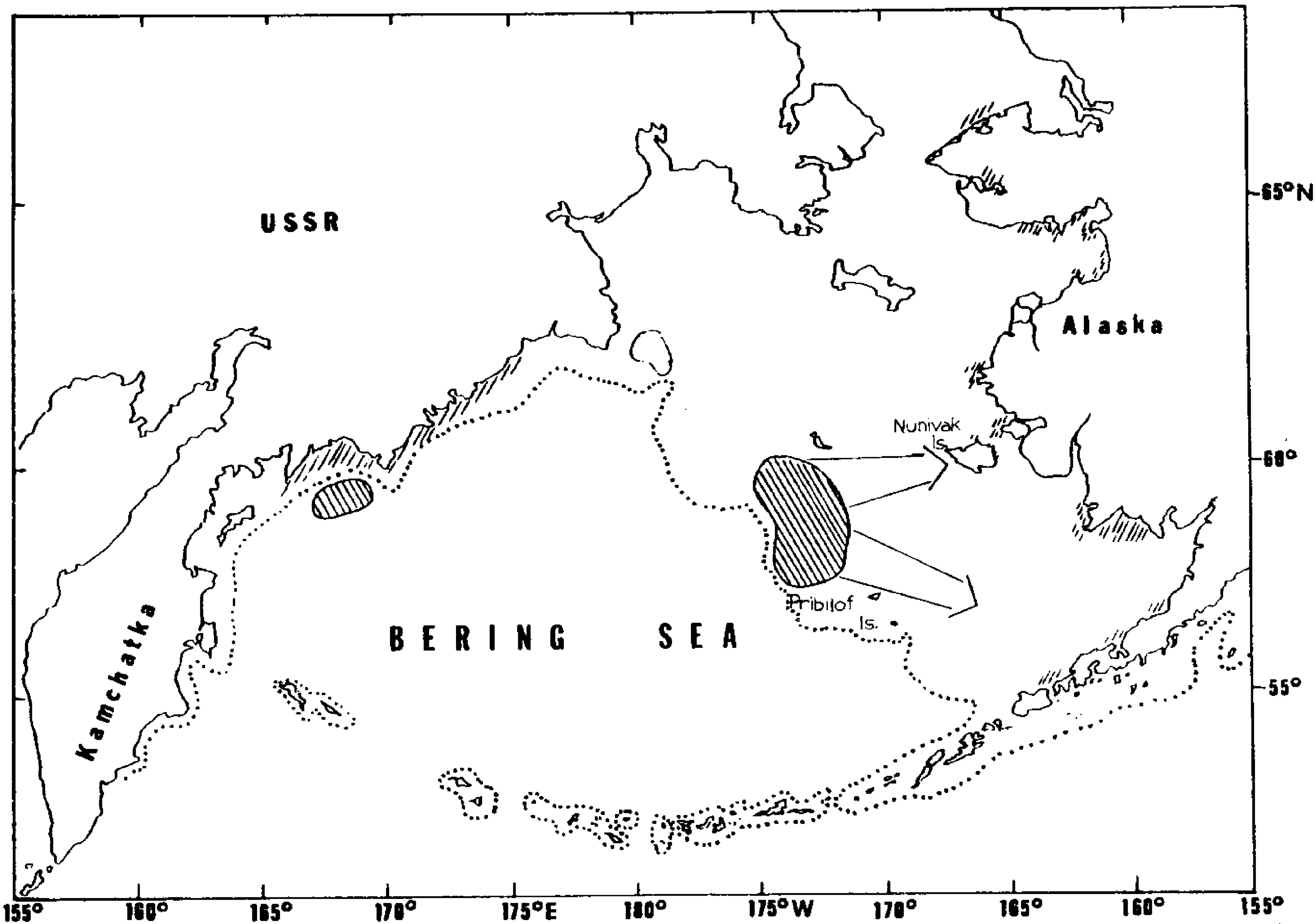

Figure 2. Location of the spawning and winter grounds (oval areas) of main eastern and western Bering Sea herring stocks and routes of migration of eastern stocks to spawning areas. (from Bering-Chukchi Sea Herring Draft Fishery Management Plan, August 1979).

targeting on the wintering stocks in the late 1960s. Japan also established a nearshore gillnet fishery off the western Alaska coast in 1968 (Wespestad, 1978b).

These foreign harvests reportedly peaked in the 1969-70 fishing year (Table 2), but precise information is lacking or unavailable on the early years of the Soviet operation. In 1977, an area closure on foreign operations was initiated east of 168° W longitude and north of 58° N latitude to protect Native subsistence fisheries. This closure was extended in 1978 to include the Alaska Peninsula (i.e.: east of 168° W longitude).

With the advent of the 200 mile limit promulgated under the Fishery Conservation and Management Act of 1976, an allowable catch of about 21,000 metric tons of herring was established under a preliminary management plan. This served to further reduce foreign harvests which are dependent upon any surplus subsequent to the domestic fisheries.

The Bering-Chukchi Sea herring draft fishery management plan is presently in the final stages of preparation. Contingent on the final management plan, foreign allocations will be made yearly, based upon estimates of remaining biomass and in season performance of domestic fisheries. It is presently proposed that allocations will be ranked in the following order: 1) subsistence, 2) near shore domestic roe fishery, 3) offshore domestic food and bait fishery, 4) foreign fisheries.

SAC-ROE HERRING FISHERIES

RECENT DOMESTIC COMMERCIAL HARVEST

There have been limited domestic commercial harvests of herring in the Norton Sound area since 1964 and in Bristol Bay since 1967. These catches averaged less than 100 metric tons per year until 1977 when over 2,500 metric tons were taken primarily for the sac roe market. Economic conditions on the world market and additional incentive afforded by the "200 mile limit" encouraged the domestic industry and fishermen to experiment in this fishery. At this same time it appears that the stocks were beginning to rebound from the lows of the early 1970s and several strong year classes emerged (Figure 3).

As a result of the successful 1977 season, catching and processing efforts greatly expanded in 1978 and 1979 in the Togiak area of Bristol Bay (Table 3). Security Cove, Goodnews Bay, Norton Sound and Port Clarence also had commercial herring operations in 1979 and harvested a total of approximately 1,600 metric tons.

Table 2. Annual herring catches (mt) by Japan and the USSR in the eastern Bering Sea (from Wespestad 1978).

Fishing year (July-June)	Trawl fishery USSR	Trawl fishery Japan	Gillnet fishery Japan	Total trawl and gillnet catch--fishing year	Total trawl and gillnet catch--calendar year: Year	Total trawl and gillnet catch--calendar year: Catch
1964-65	a/	1,362	--	b/	1965	b/
1965-66	a/	3,117	--	b/	1966	b/
1966-67	a/	2,831	--	b/	1967	b/
1967-68	9,800	9,486	818	20,104	1968	65,805
1968-69	75,379	50,857	1,949	128,185	1969	130,117
1969-70	92,228	23,901	1,585	117,714	1970	145,547
1970-71	60,126	24,236	4,603	88,965	1971	46,130
1971-72	67,546	13,143	472	81,162	1972	60,458
1972-73	39,999	346	1,878	42,223	1973	36,274
1973-74	16,810	219	3,337	20,366	1974	25,435
1974-75	15,039	2,663	736	18,438	1975	16,015
1975-76	9,518	3,119	2,668	14,914	1976	23,330
1976-77	18,097	3,449	551	22,097 c/	1977	18,737
1977-78	4,888 d/	2,353	a/			

a/ Not available.

b/ Incomplete.

c/ Preliminary.

d/ Preliminary USSR and Japanese catch through December 1977.

Data Sources: To 1977 - Japanese fisheries--Japan Fisheries Agency Data.

USSR fishery--1967-1977, furnished by the USSR under provisions of US - USSR fisheries agreements.

1977 - Data provided to the US by Japan and the USSR in compliance with provisions of P. L. 94-265.

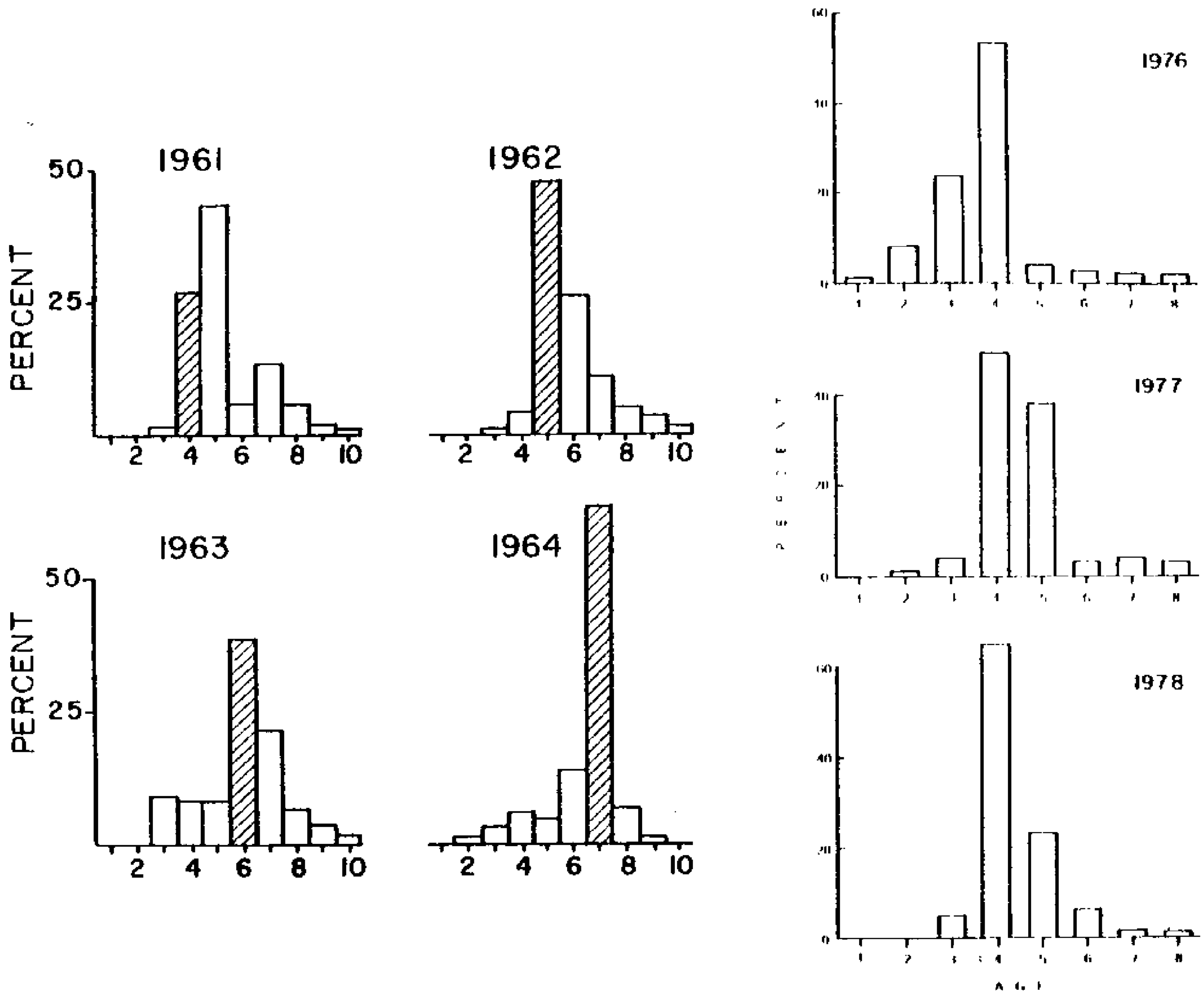

Figure 3. Annual variations observed in herring year class strength of USSR and domestic commercial harvests in the eastern Bering Sea, 1961-1964 (USSR) and 1976-1978 (Togiak). (from Alaska Dept. Fish & Game 1978)

Table 3. Inshore commercial catch of sac roe herring in the Togiak district, Bristol Bay, 1967-1979[1].

Year	Number of Processors	Units of Gear		Catch in Pounds			M. Tons
		Gill Net	P. Seine	Gill Net	P. Seine	Total	
1967	1	27	0	268,902	0	268,902	122
68	2	35	2	136,900	44,865	181,765	82
69	2	22	1	36,231	58,250	94,481	43
70	3	16	1	37,195	18,000	55,195	25
71	0	0	0	0	0	0	0
1972	1	18	1	64,929	97,505	162,434	74
73	2	26	1	102,147	0	102,147	46
74	3	10	1	38,256	208,000	246,256	112
75	2	39	0	111,185	0	111,185	50
76	0	0	0	0	0	0	0
1977	6	43	6	614,839	4,974,610	5,589,449	2,535
78	16	40	25	1,240,158	14,261,821	15,501,979	7,030
79[2]	33	437	208	8,939,528	13,364,102	22,303,630	10,115[3]
Average	5	55	19	891,559	2,540,550	3,432,109	1,556

[1] Catch not entirely comparable, as harvest prior to 1973 reflects females only; most males were discarded and not weighed. The 1973-79 catches include both sexes.

[2] Preliminary. Estimates of effort are from fish tickets and are not consistent with aerial survey counts and/or on the grounds effort estimates (Fish ticket effort is higher than in-season estimates).

[3] Includes 817 metric tons taken for bait.

HARVEST BY AREA AND GEAR TYPE

An apparent trend of a gradual westward shift of the Togiak herring fishery has been observed. In 1977 approximately 90 percent of the harvest came from Kulukak section, in 1978 over 75 percent came from Nunavachak section, and in 1979 Togiak section contributed 39 percent of the catch and accounted for the largest portion in the district (Figure 4). However, this is difficult to quantify because of low effort levels in 1977 and 1978. The westward shift in fishing effort may be the result of heavy stresses exerted on the stock by the presence of so many vessels in a relatively small area. Another indication of possible stress was the large number of small fragmented schools in the near shore area at Togiak during the 1979 season. This may have contributed to the marked changes in catch by gear type (Table 3). Evidence suggests that large schools were broken into smaller segments due to boat traffic. These small schools weren't as available or attractive to the purse siene vessels, dependent on spotter aircraft for direction, so gillnet efforts were enhanced.

It may be possible to correlate changes in catch location with fleet activity, weather patterns, substrate conditions or other environmental changes as more data becomes available.

ECONOMIC VALUE OF THE SAC-ROE FISHERIES

In calculating the value of these fisheries, the usual method is to multiply the average price paid to the fishermen by the quantity harvested. In 1979 in Bristol Bay, this ex-vessel value was approximately $6,500,000 for sac roe herring and $180,000 for bait. In the Security Cove, Goodnews Bay and Norton Sound areas, the ex-vessel value of the herring was an additional $1,550,000.

The $8,200,000 received by the fishermen was only part of the total value. In Bristol Bay alone there were an estimated 4,000 people on the grounds who were directly involved in the fishery. This did not include the support people who were indirectly employed. The expanding domestic effort in the Bering Sea herring fisheries has generated considerable income for some of the nearby coastal villages through various support activities, including fuel and food sales, air support and some employment in processing the harvest.

FISHERY MANAGEMENT PROBLEMS

The biggest problem facing herring managers in the eastern Bering Sea is a lack of knowledge about the stock. Three years ago in Bristol Bay, the total regulations concerning this resource read as follows: "There is no closed season on herring."

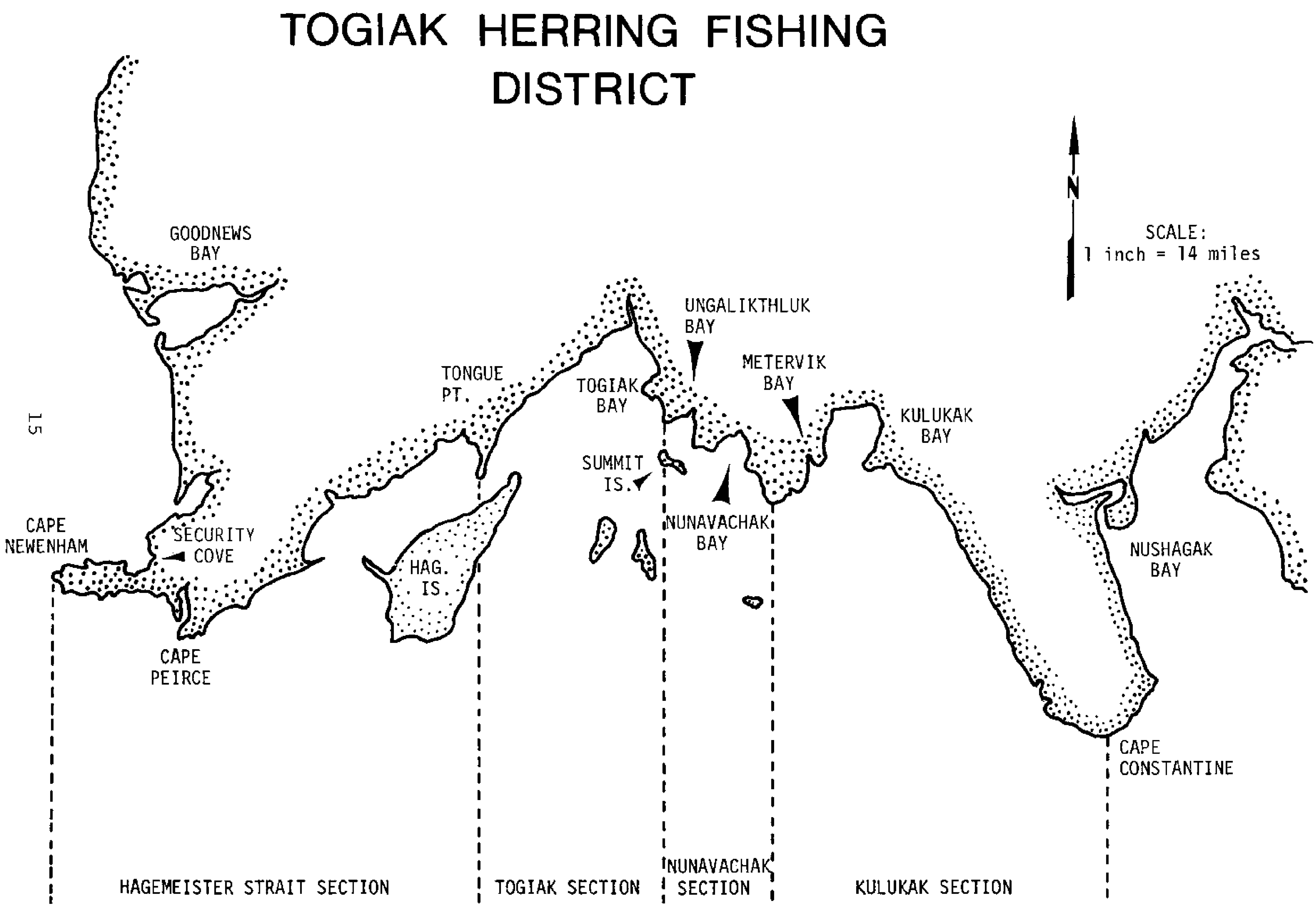

Figure 4. Geographic area of Togiak Herring Fishing District, Bristol Bay, Alaska.

In 1979, Bristol Bay had the largest sac roe fishery in the state of Alaska with several hundred boats participating. The Fish and Game staff was faced with "instant management" of a complex resource in a large remote area with very little historical data concerning the stock.

The Alaska Board of Fisheries has enacted several regulations concerning herring during the past three years at the request of the staff and the public. Most of these regulations concern boundaries, gear specifications and catch reporting. A required "on the grounds" registration of all processors will enable the staff to accurately assess the catch by area and gear type on a daily basis.

In the interest on conservation, the Board of Fisheries has directed the Commercial Fisheries staff to manage this resource at a harvest rate of 10 to 20 percent of the available biomass. Because there is currently no method of determining a pre-season forecast of abundance, the staff must assess the stock "in-season." In Bristol Bay a guideline harvest range of between 20,000 and 40,000 metric tons was adopted, based on the biomass estimate from the 1979 season. The fishermen and the industry are advised that if the herring run is strong and the spawning is widely distributed, the harvest could be within this range. However, if it is determined that the run is weak, or if survey conditions prohibit adequate assessment, the fishery would be curtailed or closed. A "guideline harvest range" guarantees no fixed quota. The total harvest, therefore, will be determined in season as the run develops.

North of Cape Newenham, the areas open to commercial herring fishing have guideline harvest levels and can also be adjusted in season via emergency order, depending on the aerial biomass estimates of the stock and performance of the fleet.

Presently, biomass estimates of herring are based on aerial surveys. Due to the open exposure of the entire coastline, weather conditions can dramatically affect the ability to make aerial estimates as well as limit the performance of the fishery.

The State has also adopted a policy of a "single stock management approach", (i.e.: to harvest the fish near shore where the stocks are segregated rather than on the high seas). This technique is used to avoid possible inadvertent over-exploitation of an individual population while the herring are mixed on the wintering grounds. This appears to be in conflict with a permit recently issued by the North Pacific Council for an offshore trawl effort in the Pribilof area. Unless there is close coordination between state and federal agencies, management of this fishery will be very difficult.

FISHING EFFORT AND PROCESSING CAPACITY IN 1980

Fishing effort will be difficult to estimate until the spring pre-season processor survey is completed. However, with the number of inquiries received daily by the Department of Fish and Game and the National Marine Fisheries Service, there is continuing interest in this fishery. There was considerable discussion concerning Bering Sea herring at the State Board of Fisheries meeting in Anchorage, Alaska in December 1979 and a large audience particiapted.

In view of the extensive preparation by the Bristol Bay herring marketing association in Dillingham and several village cooperatives in communities further north, the Alaska Department of Fish and Game anticipates that a large number of gillnet units will be present in 1980. The possibility of marketing problems during the salmon season is an added incentive for local fishermen to become involved in the herring fishery. The number of non-local fishermen will not be known until just prior to the season and will depend heavily on the success or failure of the sac-roe fisheries in California and British Columbia, and the prices that evolve from them.

With the tremendous increase in fishing effort, there has also been a large increase in the number of processors (Table 3). In 1979 it was estimated that the on-grounds processing capacity in the Togiak area was in excess of 36,000 metric tons. Due to an expected poor market for salmon in the 1980 season, many domestic processors are also looking at the developing herring fisheries as a possible source of additional revenue. If the market for sac roe herring remains strong this spring, processing capacity at Togiak will likely exceed 40,000 metric tons during the 1980 season.

There is also considerable interest in the development of expanded fisheries north of Bristol Bay with herring operations planned for Security Cove/Goodnews Bay, Cape Romanzof, Norton Sound, Port Clarence and the Kotzebue district.

FUTURE MANAGMENT STRATEGIES/POLICIES

The basic staff policy concerning management of Bering Sea herring is "to encourage full utilization of the resource while maintaining and enhancing the condition of the affected stocks." The number one priority use of all resources is for subsistence purposes, as defined by the Legislature and the Board of Fisheries. Recognizing that information concerning Bering Sea herring is very limited necessitates a conservative approach to management.

Within the constraints of our presently limited data base and management capabilities, Alaska Department of Fish and Game intends to implement measures to maximize the harvestable surplus of herring by the domestic fishery and reduce the foreign catch to an incidental level. Whenever possible, management measures will attempt to maximize the economic value of the harvest, reduce the interception of mixed stocks, and allow all runs to build to peak production levels.

Previously, no attempt has been made by Alaska Department of Fish and Game to allocate catches to a given user group. Allocation would be difficult without a pre-season forecast, but the Alaska Board of Fisheries has offered a policy directive designed to more evenly distribute the catch, (see Appendix A).

ROE-ON-KELP FISHERIES

HISTORY OF EXPLOITATION

The first Bering Sea herring roe-on-kelp fishery originated in Bristol Bay in 1968 and has operated annually since that date (Table 4). In 1977, a small roe-on-kelp operation was initiated in Norton Sound and processed less than one metric ton. This gradually increased to three metric tons in 1978 and 12 metric tons in 1979.

The majority of the Bering Sea kelp harvest is produced in Bristol Bay and the primary species picked is rockweed, (Fucus sp.). Other varieties of flora are present in the intertidal zone, both Zostera sp. and Lamineria sp., but do not appear to be the preferred spawning substrate. Future research is planned to identify and quantify sub-tidal plants and any spawning.

As indicated in Table 5, there has been a steady increase in the harvest. In 1979, the number of pickers in Bristol Bay decreased but the number of buyers was four times higher than average. The majority of the effort was concentrated in the Metervik Bay area (Figure 4) because it offers the most protection from the weather and is the main area of historical harvest. This large concentration of effort in a relatively small area resulted in two emergency order closures in 1979 to protect Fucus from over-harvest.

In-season analysis of the harvest conclusively demonstrated that present levels of effort, when not regulated, are capable of significantly depleting individual kelp beds.

Table 4. Yearly harvest and effort for the Bristol Bay herring roe-on-kelp fishery (from Alaska Dept. Fish & Game 1979).

Year	Harvest (pounds)	Number of Fishermen	Harvest Per Fishermen
1968	54,600	1	54,600
1969	10,100	3	3,400
1970	38,900	5	7,800
1971	52,000	12	4,300
1972	64,200	12	5,300
1973	11,600	10	1,200
1974	125,600	26	4,800
1975	111,100	44	2,500
1976	295,800	49	6,000
1977	275,800	75	3,600
1978	330,000	160	2,100
1979	414,700	100	4,100
Total	1,783,900	455	3,920

Table 5. Comparison of the relative value to the fishermen of the Bristol Bay herring roe-on-kelp and sac roe fisheries between 1977 and 1979.

	Value:		Percent of Total Value:	
Year	Roe-on-kelp	Sac Roe	Roe-on-kelp	Sac Roe
1977	$116,000	$ 446,000	21	79
1978	120,000	2,635,000	4	96
1979	269,000	8,200,000[1]	3	97

[1] Includes a harvest of 817 metric tons of bait herring.

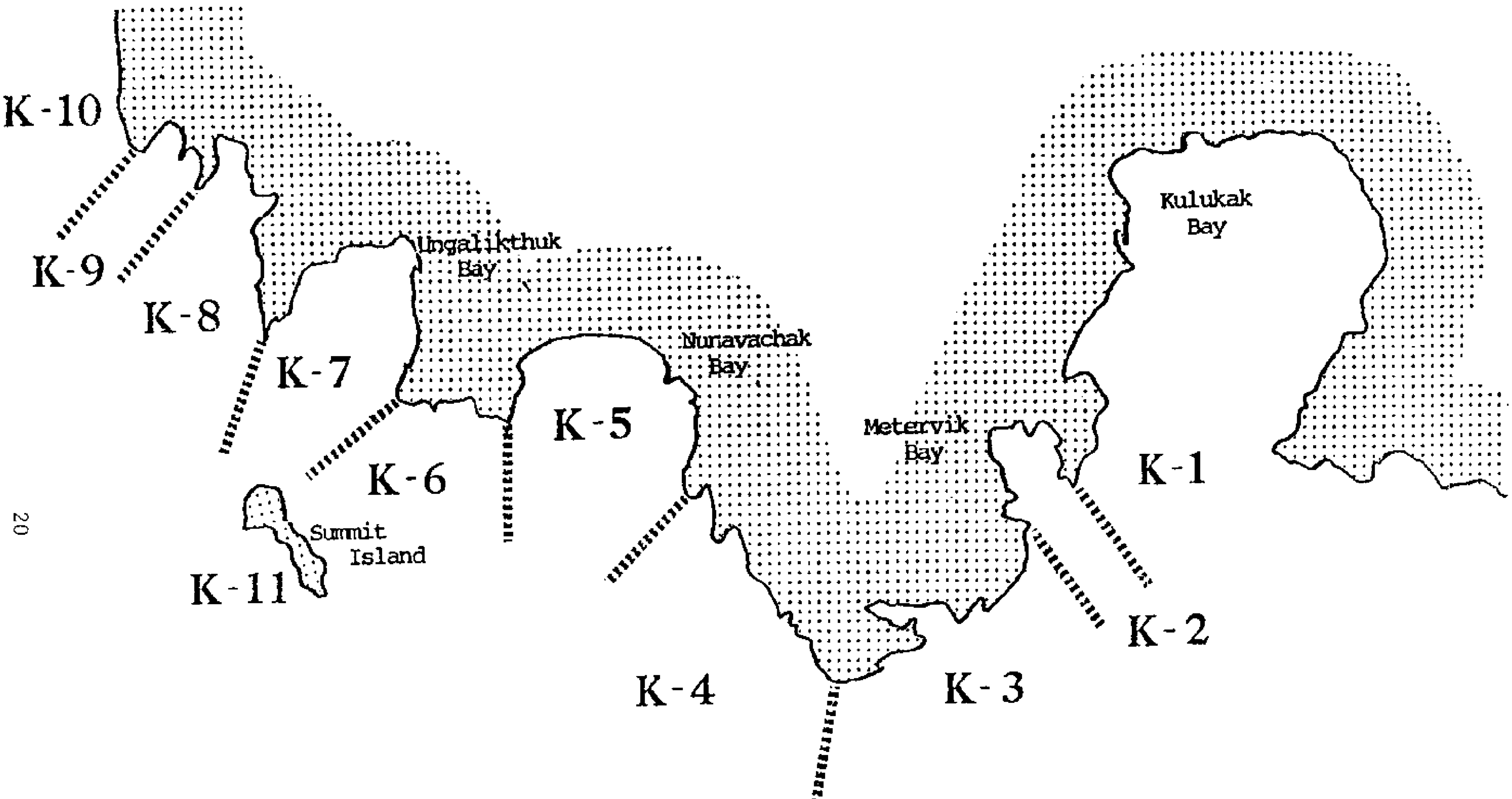

Figure 5. Proposed herring roe-on-kelp management areas (K-1 through K-11), Bristol Bay.

KELP MANAGEMENT PROBLEMS

Little is known of the kelp density in areas north of Bristol Bay, but evidence suggests that the habitat is heavily impacted by wave action and ice scouring, and that there are lesser quantities of commercially marketable product. A continued increase in the harvest will require close monitoring to protect the kelp flora of this region.

Studies of the inter-tidal plant community in Bristol Bay have resulted in a management plan to better distribute the harvest (Appendix B). Further research is needed to define the recovery rate of the affected beds and to monitor overall spawning to allow for sufficient returns of adult herring in subsequent years.

Another management responsibility of the Department of Fish and Game is to provide for the greatest economic return from the resource. To allow the roe-on-kelp harvest to expand to the point of limiting the economically more important sac roe fishery would not be in the best interest of the total resource. The relative value of the two fisheries is expressed in Table 5.

FOOD AND BAIT FISHERY

At the time of this writing, there is a controversy concerning a proposed joint venture between a Soviet processor and a group of American fishermen. A permit allowing a harvest of 5,000 metric tons of herring to be taken north of the Pribilof Islands has been issued by the North Pacific Fishery Management Council. A Native group from the Bethel area has filed suit to block this fishery, maintaining that trawling on a mixed stock on the high seas could unknowingly damage local spawning stocks in areas heavily dependent upon herring for subsistence. The Alaska Board of Fisheries and the North Pacific Council are also in disagreement over this issue.

During the 1979 season, 817 metric tons of bait herring were taken in Bristol Bay; this amounted to over 8 percent of the total harvest. These fish were caught near the end of the fishery in an attempt to utilize processing capacity in excess of the available sac roe herring. Bait herring is less attractive economically and it is likely that future harvests will also be taken after the herring have spawned.

This late season harvest is unfortunate from a biological standpoint because the sampling data indicates that the older age class fish arrive first to spawn and the younger year classes follow later in the run. Ideally, the bait harvest would occur on the earlier older fish that will suffer higher natural mortality during the winter months, rather than younger fish with better potential for subsequent spawnings.

CAPELIN FISHERY

Three times during the brief history of domestic fishing effort on herring in the Togiak area there has also been a harvest of capelin (Mallotus villosus). These catches occurred in 1974, 1977 and 1979 and were all taken by purse seines. The largest catch was made in 1974 when 47 metric tons were taken.

Aerial observations of capelin schools have been recorded on the north side of the Alaska Peninsula, in Bristol Bay, and in some areas north of Cape Newenham (Warner, Barton, 1976). No estimate of biomass has been attempted and this would be difficult due to the close proximity of herring schools and the absence of positive species identification. However, the biomass of capelin in Bristol Bay may even exceed that of herring.

The three small harvests of capelin taken in Bristol Bay were reportedly an attempt by the industry to "test the market." Indications are that this species separates by sex until the time of spawning. If this is verified and a market for capelin roe is established, the potential for a viable fishery does exist. Very large capelin fisheries exist in the Atlantic Ocean and Barents Sea, indicating that under the proper circumstances, capelin are a highly marketable species.

ENFORCEMENT OF REGULATIONS

Because these are new and developing fisheries, enforcement of regulations on domestic operations has not as yet been a serious problem. With the increase of processors in both Bristol Bay and Norton Sound, there has been some difficulty with catch reporting. This issue was addressed by the Alaska Board of Fisheries in 1979 and the resulting new regulation will assist the Department of Public Safety, Fish and Wildlife Protection in their enforcement effort.

Some pollution problems were evident in the small bays near Togiak where large numbers of vessels were present in close proximity to each other. Several minor oil slicks from bilge pumping were noted and large quantities of improperly disposed trash drifted up on the beaches. The Department of Fish and Game has requested the presence of the U.S. Coast Guard on the grounds in 1980; it is hoped that they will be able to more selectively monitor these problems. The largest difficulties facing enforcement officers will be on the high seas. If the domestic fleet moves offshore, distances, surveillance costs, and overlap of federal and state jurisdiction will compound any problems.

Unconfirmed reports of severe under-reporting of herring harvests by the foreign vessels operating within the Fishery Conservation Zone pose further concerns for resource managers and federal enforcement agents.

REFERENCES

Alaska Dept. Fish & Game. 1978. Status of herring stocks and fisheries in the Bering Sea. Rept. to Alaska Bd. Fish.

Alaska Dept. Fish & Game. 1979. Status of herring stocks and fisheries in the eastern Bering Sea. Rept. to Alaska Bd. Fish.

Barton, L. H. 1978. Finfish resource surveys in Norton Sound and Kotzebue Sound. OCSEAP, Final Report (March 1976 - September 1978), ADF&G, Comm. Fish. Div., Anchorage, September.

North Pacific Fishery Management Council. 1979. Bering - Chukchi Sea Herring, Draft Fishery Management Plan. N. Pacific Fish. Mgmt. Coun., P. O. Box 3136 DT, Anchorage, AK 99510.

Hemming, J. E., G. S. Harrison and S. R. Braund. 1978. The social and economic impacts of a commercial herring fishery on the coastal villages of the Arctic/Yukon/ Kuskokwim area. Report prepared under contract for the N. Pacific Fish. Mgmt. Coun. by Dames and Moore. Unpubl.

Marsh, M. C. and J. N. Cobb. 1910. The fisheries of Alaska in 1909. U. S. Bur. Fish., Rep. Comm. Fish. Doc. 730.

Rounsefell, G. A. 1930. Contribution to the biology of the Pacific herring, *Clupea pallasi*, and the condition of the fishery in Alaska. Bull. U. S. Bur. Fish. 45:227-320.

Warner, I. M. 1976. Forage fish spawning surveys, Unimak Pass to Ugashik River. Outer Continental Shelf Energy Assessment Program, Quarterly Report (July-Sept.) pp. 61-96.

Wespestad, V. G.

1978a. A review of Pacific herring studies with special reference to the Bering Sea. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Seattle, WA. Unpubl. 67 pp.

1978b. Exploitation, distribution, and life history features of Pacific herring in the Bering Sea. Natl. Mar. Fish. Serv., Northwest and Alaska Alaska Fish. Center, Seattle, WA., Processed Rpt., 26 pp. (and appendices).

APPENDIX A

BRISTOL BAY HERRING MANAGEMENT PLAN

> The following policy was given to the Department of Fish and Game by the Alaska Board of Fisheries at their December 1979 meeting.

The Bristol Bay herring fishery is still rapidly developing. Harvest trends by gear type are not well established between seine and gillnet gear. Run timing, distribution and magnitude cannot be predicted from past data in this new fishery and most forms of in-season or pre-season regulation to achieve any predetermined gear catch allocation are not feasible.

It is the Board's feeling that resource size and relative gear numbers and efficiency of the two gear types will insure that all users will have ample opportunity to satisfy their economic requirements. Nevertheless, it is desirable to try to insure that neither gear group is totally disadvantaged. The Board therefore directs the staff to take the following actions given the specified circumstances:

> When the total reported harvest reaches 20,000 metric tons, the Department shall determine the reported tonnage for gillnet and seine (purse and hand purse) gear. If the harvest for either gear type has not reached 6,000 metric tons, the fishery on the gear with the higher reported catch shall be closed for 24 hours.

APPENDIX B

MANAGEMENT PLANT TO REGULATE THE HERRING ROE-ON-KELP HARVEST IN THE BRISTOL BAY AREA

> The following policy was given to the Department of Fish and Game by the Alaska Board of Fisheries at their December 1979 meeting.

Management of the Togiak herring roe-on-kelp harvest should center upon a predetermined level of exploitation of *Fucus sp.* The Department recommends the establishment of a conservative exploitation objective of 10 percent of the available *Fucus sp.* biomass.

The Department has estimated the total *Fucus sp.* biomass within nine beach areas studied at 4,135,000 pounds. These areas were chosen on the basis of beach surveys such that individual kelp beds could be described and such that harvest could be monitored by individual area. A 95 percent confidence interval has been calculated for the biomass estimate for each beach area. To be conservative, 10 percent of the lower range estimate for each area will be emphasized as the management objective. Actual harvest quotas of roe-on-kelp product have been derived by assuming that the reported weight of commercial grade roe-onkelp is composed of 25 percent plant weight _Fucus sp._ The 1980 total allowable harvest of roe-on-kelp is calculated at 934,000 pounds.

In the Department's opinion, individual kelp management areas should be kept open to commercial harvest until that harvest reaches the allowable harvest quota. At that time, particular kelp management areas should be closed by emergency order for the remainder of the fishing season.

Realization of this management plan is dependent upon monitoring of effort and harvest levels and upon enforcement of the quota system. The harvest needs to be monitored on a daily basis in-season for each kelp management area as the commercial fleet already has the capability of attaining the proposed quota for several management areas in a single day.

The primary effect of this management strategy is to provide protection to those kelp beda that have historically sustained a large harvest. The Department is not recommending that the kelp harvest be reduced as the 1980 total allowable harvest is roughly double the 1979 harvest of 479,000 pounds. Since 1978, the Department has conducted studies to determine specific regeneration rates of _Fucus sp._ in the Bristol Bay area. Utilization of this management strategy will minimize potential negative effects of the roe-on-kelp harvest on the kelp resource until on-going biological studies of _Fucus sp._ in the Togiak area are completed.

DISTRIBUTION, BIOLOGY AND STOCK ASSESSMENT OF WESTERN ALASKA'S HERRING STOCKS

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ABSTRACT

Herring wintering northwest of the Pribilof Islands migrate to the Alaska coast in spring and spawn from Bristol Bay to the Yukon River. Although some of the stock may spawn in the eastern Aleutian Islands, Alaska Peninsula and Norton Sound, herring in these areas may also winter inshore near spawning grounds. Northward of Norton Sound some herring may winter in brackish lagoons and estuaries. Spawning commences from late April to mid May along the Alaska Peninsula and Bristol Bay and progressively later to the north. Spawning occurs at temperatures of 5° to $12^{\circ}C$ and the time of spawning is related to winter water temperatures with early spawning in warm years and delayed spawning in cold years. Eggs are deposited in intertidal and shallow subtidal zones of rocky headlands or shallow bays and hatch in two to three weeks. Most eastern Bering Sea herring mature at ages three and four coinciding with ages of recruitment to the fishery. Little is known of larval and juvenile stages.

Eastern Bering Sea herring stocks declined in the early 1970s due to a series of weak year classes and high offshore catches. However, abundance has apparently increased in recent years based on spawning stock assessment. The current estimate of spawning biomass ranges from approximately 260,000 to 640,000 mt, which, together with a series of strong year classes since 1972, suggests a favorable outlook for the 1980 herring sac roe season.

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

INTRODUCTION

Pacific herring are an important part of the Bering Sea food web and form the basis of a major commercial fishery. Until recently, Japan and the Soviet Union have been major exploiters of eastern Bering Sea herring stocks. Catches peaked in 1970 at 145,579 mt, and then declined in response to overfishing and poor recruitment. Only within the last three to four years has an apparent increase in herring abundance in the eastern Bering Sea been observed, and the United States has become the dominant exploiter. Most foreign catches of herring now occur as incidental to other species such as pollock.

The domestic herring fishery has developed in response to favorable market conditions and prices created by a worldwide herring shortage. Additional stimulus has been provided through incentives given American fishermen under the Fisheries Conservation and Management Act (FCMA) of 1976 which established a Fisheries Conservation Zone (FCZ) seaward to 200 miles.

Although Cushing (1975) indicates that herring stocks have been extensively investigated in areas where they are commercially important, research on Pacific herring has occurred primarily in southeastern Alaska and British Columbia (Reid, 1972; Taylor, 1964). In contrast, research on herring in the Bering Sea has been limited and most has occurred only very recently. Present knowledge is rudimentary and inferences on many aspects of life history must be drawn from other more thoroughly studied populations.

HISTORY OF RESEARCH

AMERICAN RESEARCH

In the 1880s, exploratory surveys of the Bering Sea and western Alaska were begun by various departments of the federal government. These surveys, which continued into the 20th century, generally included a naturalist or fishery biologist who noted the occurrence of herring in the Bering Sea (Bean, 1887; Cobb, 1907; Gilbert, 1895; Jordon and Gilbert, 1899; Nelson, 1887; Tanner, 1890).

The first biological investigation of herring in the Bering Sea occurred in the late 1920s (Rounsefell, 1930). Rounsefell collected herring samples from Unalaska and Golovin Bay (Norton Sound) in 1928, the year commercial herring fisheries developed at Unalaska. The Bering Sea samples were included with samples from the Gulf of Alaska for investigation of Alaska herring stock relationships. Since 1928, outside of limited sporadic sampling by the Alaska Department of Fish and Game (ADF&G) in the 1960s and early 1970s, no American investigations occurred in the

Bering Sea until the advent of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) in 1975.

Intensive investigations on distribution, relative abundance and history of herring spawning stocks in addition to determination of subsistence use levels were begun by ADF&G in 1975 under OCSEAP in an area from the Alaska Peninsula to Kotzebue Sound. Much of the research in addition to stock identification and spawning biomass estimates is being continued by ADF&G through State of Alaska and North Pacific Fishery Management Council (NPFMC) funding.

The National Marine Fisheries Service (NMFS), under OCSEAP, investigated herring in Norton Sound and the Chukchi Sea and also reported on the occurrence of herring in southeastern Bering Sea demersal fish surveys (Wolotira et al., 1977; Pereyra et al., 1976). Winter hydroacoustic surveys were conducted by NMFS in 1978-79 and 1979-80 northwest of the Pribilof Islands to estimate distribution and abundance of herring on their winter grounds.

In recent years, NMFS has placed observers on foreign vessels fishing within the FCZ to monitor catch rates and collect biological samples. The ADF&G has collected biological data from the domestic herring sac roe fishery in north Bristol Bay since 1977.

FOREIGN RESEARCH

When western Bering Sea herring stocks declined in the late 1950s, the Soviet Union began exploration of the eastern Bering Sea for commercially exploitable stocks. They were successful in locating a major wintering stock northwest of the Pribilof Islands in 1959, and thus initiated investigations to determine the extent and distribution of that stock. Specific investigations dealt with winter abundance and distribution (Shaboneev, 1965), summer abundance, distribution and migration (Rumyantsev and Darda, 1970) and with eastern-western Bering Sea stock relationships (Prokhorov, 1968). The main purpose of these surveys was determination of the extent and potential uses of the resource prior to commercial exploitation by the Soviet fleet. Most of the present knowledge of offshore distribution and behavior of eastern Bering Sea herring is based upon Soviet research.

Japanese research in the eastern Bering Sea began in the mid-1950s with limited exploratory trawl fishing. However, major effort on herring in the eastern Bering Sea did not occur by Japan until 1964. Since that time, they have been collecting catch and effort statistics and occasionally length frequency data from their herring fisheries.

These data have been provided to the United States through the International North Pacific Fisheries Commission (INPFC).

DISTRIBUTION

STOCK DISTRIBUTION

Three major herring wintering grounds have been identified in the Bering Sea: northwest of the Pribilof Islands (Shaboneev, 1965); in the Gulf of Olyutorski (Prokhorov, 1968); and near Cape Navarin (Kachina, 1978; Naumenko, 1979) (Figure 1). Different growth and maturation rates, and dissimilar age structures reported by Prokhorov (1968) occur between herring wintering northwest of the Pribilof Islands and those in the Gulf of Olyutorski (Karaginski herring), suggesting that there is little or no mixing between these stocks. Both Kachina (1978) and Naumenko (1979) indicate that the location of wintering concentrations is directly related to water dynamics in the Bering Sea. They state that herring usually keep within vast anticyclonic eddies where relatively stable conditions of warmer and salty water occur, as apparently form in various years northwest of the Pribilof Islands and near Cape Navarin. However, they suggest that in years when no eddies are formed or where they occupy vast areas in the Bering Sea, the result is a wide and relatively uniform distribution of wintering herring along the continental shelf from 58° N to 62° N latitude. Under such conditions, Kachina states that mixing may occur between the larger wintering stocks of the Pribilof Island area and smaller Cape Navarin stocks, while Naumenko indicates that the bulk of the Pribilof stock may concentrate in areas south of the Pribilof Islands.

Wespestad and Barton (1979) believe that differences in the pattern of migration between the coast and the outer continental shelf have effectively isolated Asian and North American herring in the Bering Sea. They conclude that the bulk of herring which winter near the Pribilof Islands mix very little on the wintering ground with western Bering Sea stocks and spawn in Bristol Bay and in areas between the Yukon and Kuskokwim rivers, based upon Soviet research, similarities in age composition, and the distribution of Japanese trawl catches during the spawning migration.

The relation of spawning herring in Norton Sound and northward to herring further south is unclear. Herring in Norton Sound are genetically similar to those in the south (Grant, 1979) and appear in inshore waters in late May and June (Barton, 1978) which suggests they may winter in offshore regions. Kachina (1978) indicated herring in Norton Sound may mix and winter with those near Cape Navarin. Both Kachina and Barton point out the smaller sizes and lower abundance of these northern stocks in comparison to those in

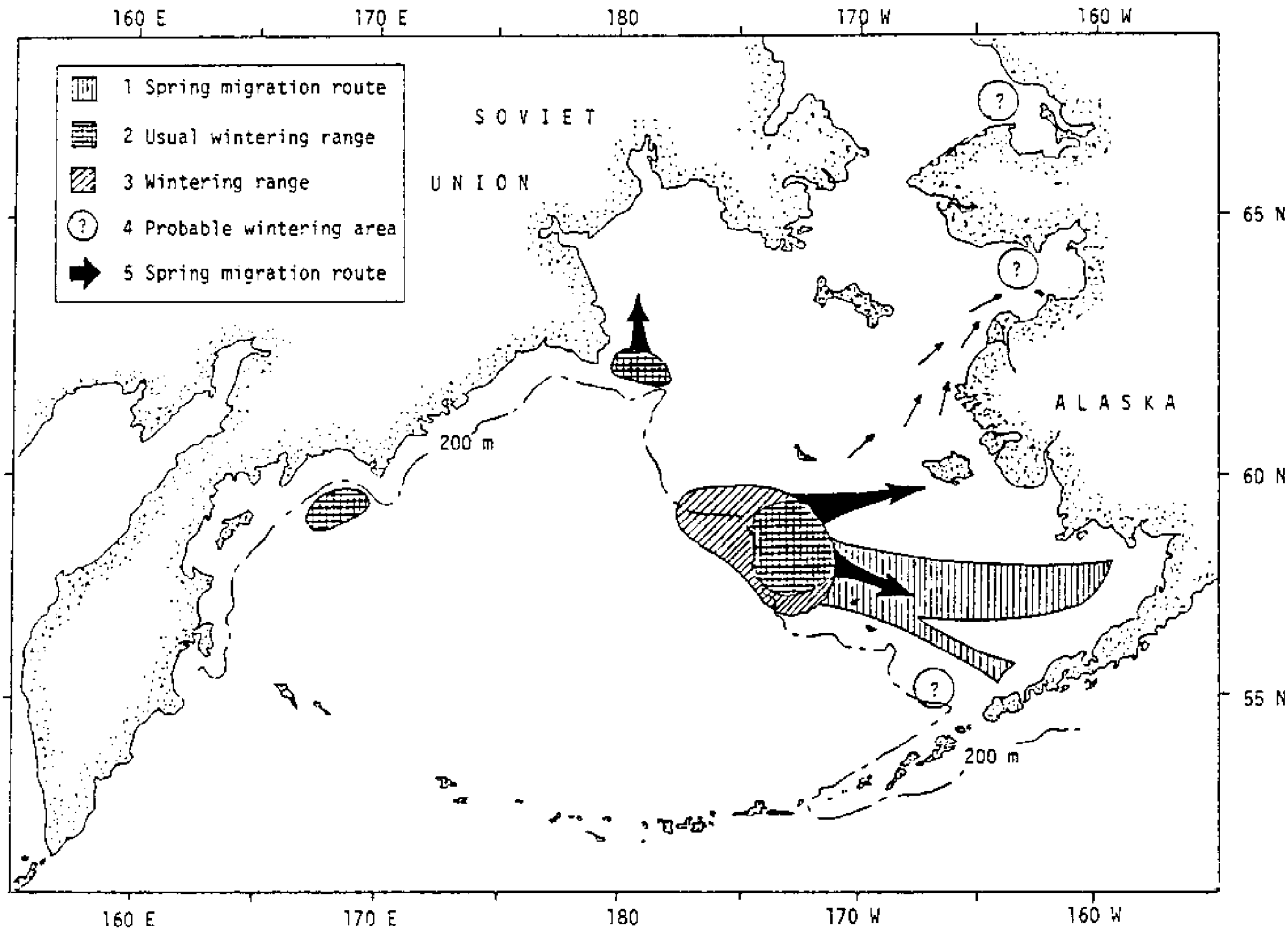

Figure 1. Range of Pacific herring wintering area northwest of Pribilof Islands and average winter location of Pribilof, Gulf of Anadyr and Olyutorski Gulf herring stocks (2 and 3). Possible wintering areas in Norton and Kotzebue Sounds and north of Unalaska Island (4); migration routes to spawning areas: routes reported by Soviet researchers (5); routes shown by Japanese trawl catches during April and May (1); small arrows--possible routes to Norton Sound and Cape Romanzof. (Modified from Wespestad and Barton 1979).

the Pribilof area. However, parts of Norton Sound may be the northern spawning range of the Pribilof Island wintering stocks. Further, it is possible that at least a portion of Norton Sound herring remain in the vicinity all year. Barton (1978) reported that in autumn, a non-spawning run occurs in Golovin Bay in northern Norton Sound, Port Clarence and along the Seward Peninsula into Kotzebue Sound. Also reported was the presence of herring in winter months captured by local residents while jigging for cod through the ice and the presence of winter herring in seal stomachs from Nome northward.

Herring north of Norton Sound are believed to remain in the immediate area year-round and winter in ice-covered coastal lagoons and brackish bays, based upon differences in behavior, growth rates and maturity (Barton, 1978; Barton and Steinhoff, 1980). Further supportive evidence that herring differ north of the Yukon River from those to the south is suggested from preliminary findings in scale growth characteristics (K. Rowell, ADF&G, personal communication).

Herring may also occur along the Alaska Peninsula and throughout the Aleutian Islands. Marsh and Cobb (1911) reported that a large spawning occurred at Atka Island in 1910, and that spring and autumn runs (the latter presumably non-spawning) occurred at Unalaska and Port Heiden. The fishery which operated at Unalaska in the 1930s and 1940s harvested herring in summer and early autumn, averaging 1,337 mt between 1929 and 1937. The current status of these stocks or their relationship to other eastern Bering Sea stocks is unknown. Recent aerial surveys by ADF&G have found small spawning concentrations on the north shore of Unimak Island, in Heredeen Bay, and in Port Heiden (Warner and Shafford, 1977). Catches by Japanese trawlers just north of Unimak Pass in winter indicate that this may be the wintering area of herring spawning on the Alaska Peninsula (Wespestad, 1978a).

SEASONAL DISTRIBUTION-PRIBILOF STOCK

Temperature may be the major factor influencing seasonal distribution. Soviet scientists found herring moving through sub-zero water temperatures in the spring on the way to spawning grounds, but during summer months they were found on the shelf in warmer, upper layers of the water column (Figure 2). Svetovidov (1952) believes that migrations to the coast for spawning developed because of the lack of sufficiently warm water in spring and summer in the North Pacific Ocean. Also, earlier warming of coastal waters provides an earlier development of phytoplankton and zooplankton and better feeding conditions.

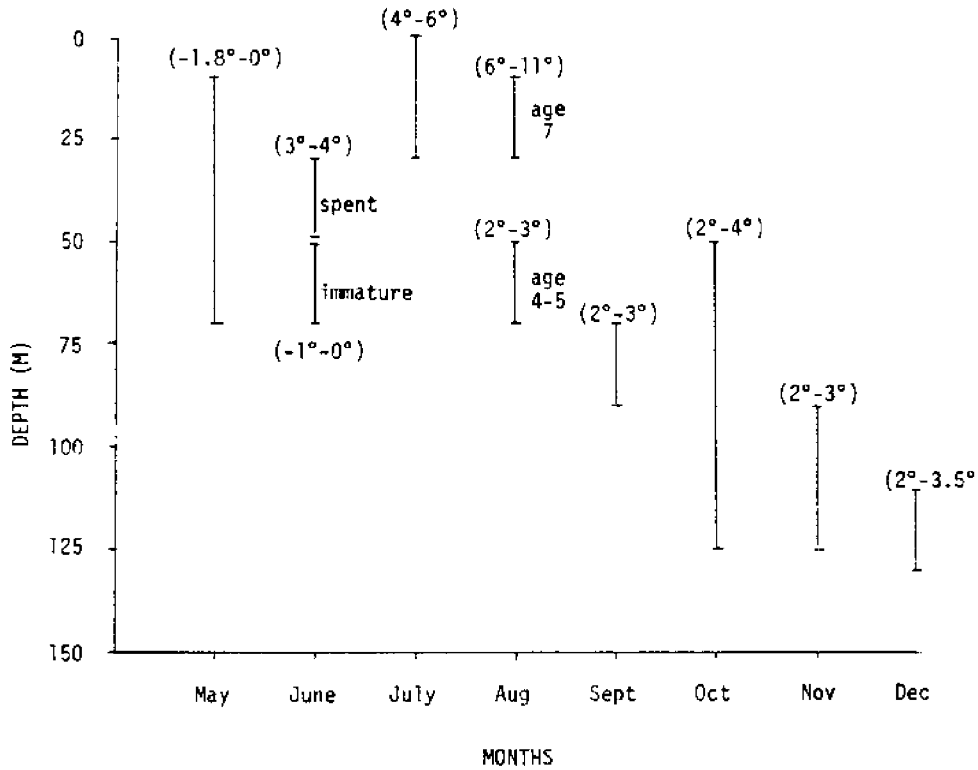

Figure 2. Monthly distribution of Pacific herring by temperature and depth in the eastern Bering Sea. May-November data from Rumyant'sev and Darda (1970), December data from Shaboneev (1965).

WINTER

The major wintering grounds of eastern Bering Sea herring are located northwest of the Pribilof Islands, approximately between 57 and 59° N latitude representing an area of between 1,600 and 3,000 square kilometers (Shaboneev, 1965) that shifts in relation to the severity of winter. In mild winters herring concentrate farther north and west, and in severe winters they move south and east (Figure 1).

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

SPRING

Soviet scientists investigating herring distribution in the mid-1960s found that herring left the wintering grounds in late March and believed that herring followed two routes to the coast; Japanese trawl catches in April and May indicate one major and one minor path (see Figure 1). The past two years (1977-78 and 1978-79) have been mild winters and 1978-79 especially so. In these years, herring arrived on spawning grounds along the coast several days to two weeks earlier than average.

SUMMER

Failure of Soviet surveys in the mid-1960s using gillnets and trawls to locate herring concentrations on the Bering Sea slope or shelf in the summer suggested that most herring apparently remain termporarily in coastal waters after spawning. Annual NMFS summer trawl surveys covering much of the continental shelf of the eastern Bering Sea support this conclusion, as very few herring have been taken in summer surveys (Pereyra et al., 1976; Bakkala and Smith, 1978). A pollock hydroacoustic survey conducted along the outer shelf between Unimak Pass and the U.S.-U.S.S.R. convention line in June and July 1979 found only one herring in 2,558 nm and 35 midwater trawl hauls. These results indicate that only a small amount of herring may remain or return offshore in summer and the bulk remains in coastal waters.

Summer distribution may be influenced by the availability of food and heavy phytoplankton blooms. Rumyantsev and Darda (1970) concluded that herring remained in coastal waters during the summer because heavy phytoplankton blooms (1-3 g/m^3) occurred on the outer shelf. Those captured on the outer shelf during the summer were in poor condition and had been feeding on items of low nutritional value--items other than their preferred zooplankton diet. Herring are believed to avoid areas of heavy phytoplankton blooms because of low nutritional value and gill clogging properties of certain phytoplankton species which interfere with respiration (Henderson et al., 1936).

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

Distribution of herring between the time they leave the spawning grounds and the time they reappear in offshore waters is unknown. Salmon fishermen report catching large herring frequently in salmon gillnets in coastal areas of Bristol Bay in late June and July. Also, Dudnik and Usol'tsev (1964), using drift nets, found commercial quantities of herring only in littoral areas along the northern portion of the Alaska Peninsula. Reappearance of seaward migrants in late summer in two locations suggests a summer migration along the coast (Figure 3). Migration to winter grounds continues through September with herring moving progressively to deeper water and concentrating in the 2 to 4° C temperature stratum.

FALL

Concentration on the winter grounds begins in October and continues into winter. Mature fish were found to arrive on the wintering grounds prior to the arrival of immature fish (Ramyantsev and Darda, 1970). It was also found that immature fish had a preference or tolerance for the lower temperature and saline waters of the shelf than did adult fish (Figure 4).

GENERAL BIOLOGY

SPAWNING

Herring spawn along the western Alaska coast in late spring to midsummer (Figure 5). Time of spawning is generally associated with climitological conditions, particularly ice breakup, and in most years commences along the Alaska Peninsula and in Bristol Bay from late April to late May and progressively later to the north (Barton, 1978). It has been recorded over a range of 6 to 10° C in Bristol Bay

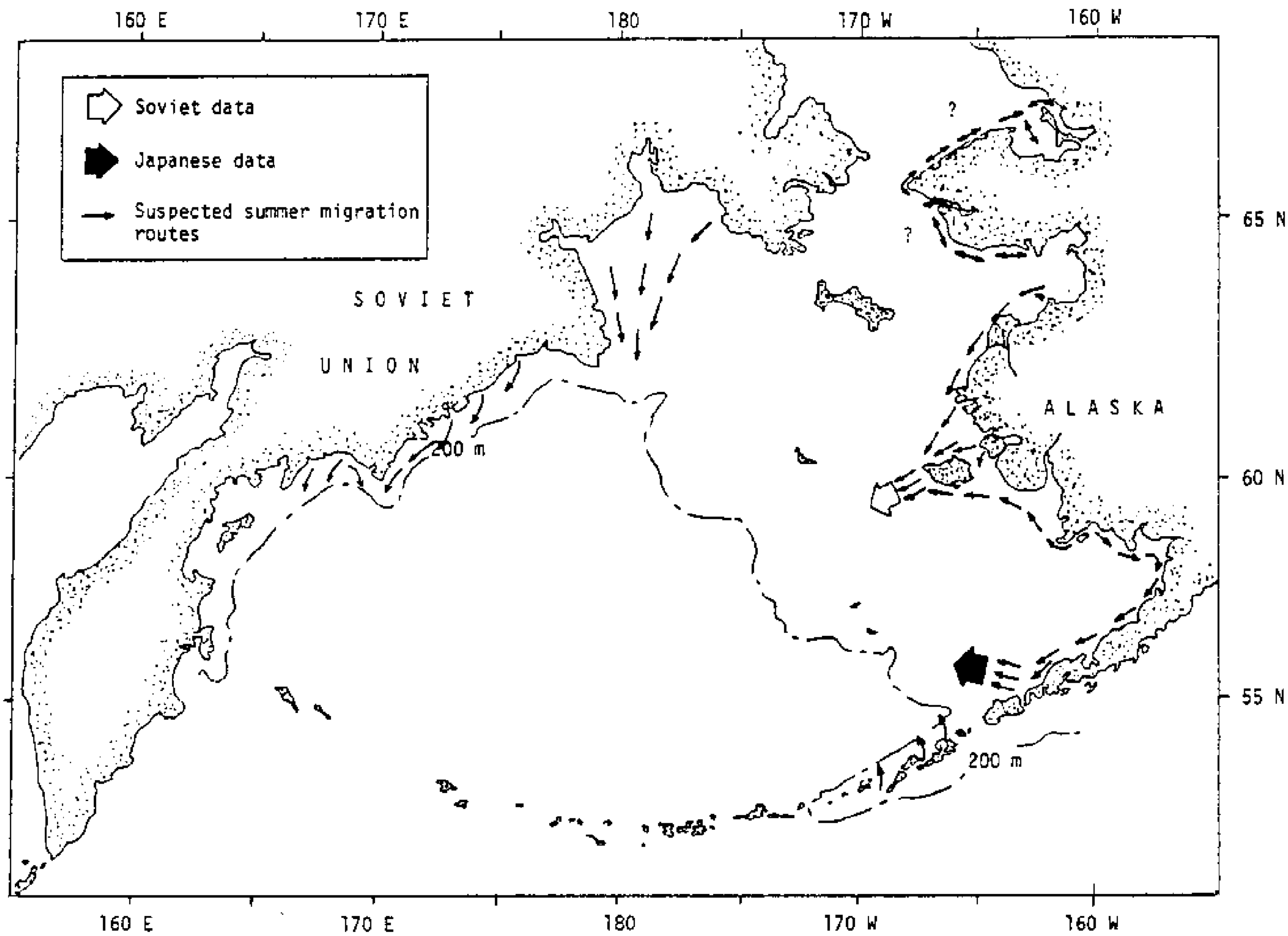

Figure 3. Summer and autumn migration routes to winter grounds. Large solid arrow--area of reappearance in offshore waters as determined by Soviet research and Japanese catches; large white arrow--area of autumn reappearance in offshore waters reported from Soviet research; small arrows--possible summer feeding routes and autumn migration routes. (Modified from Wespestad and Barton 1979).

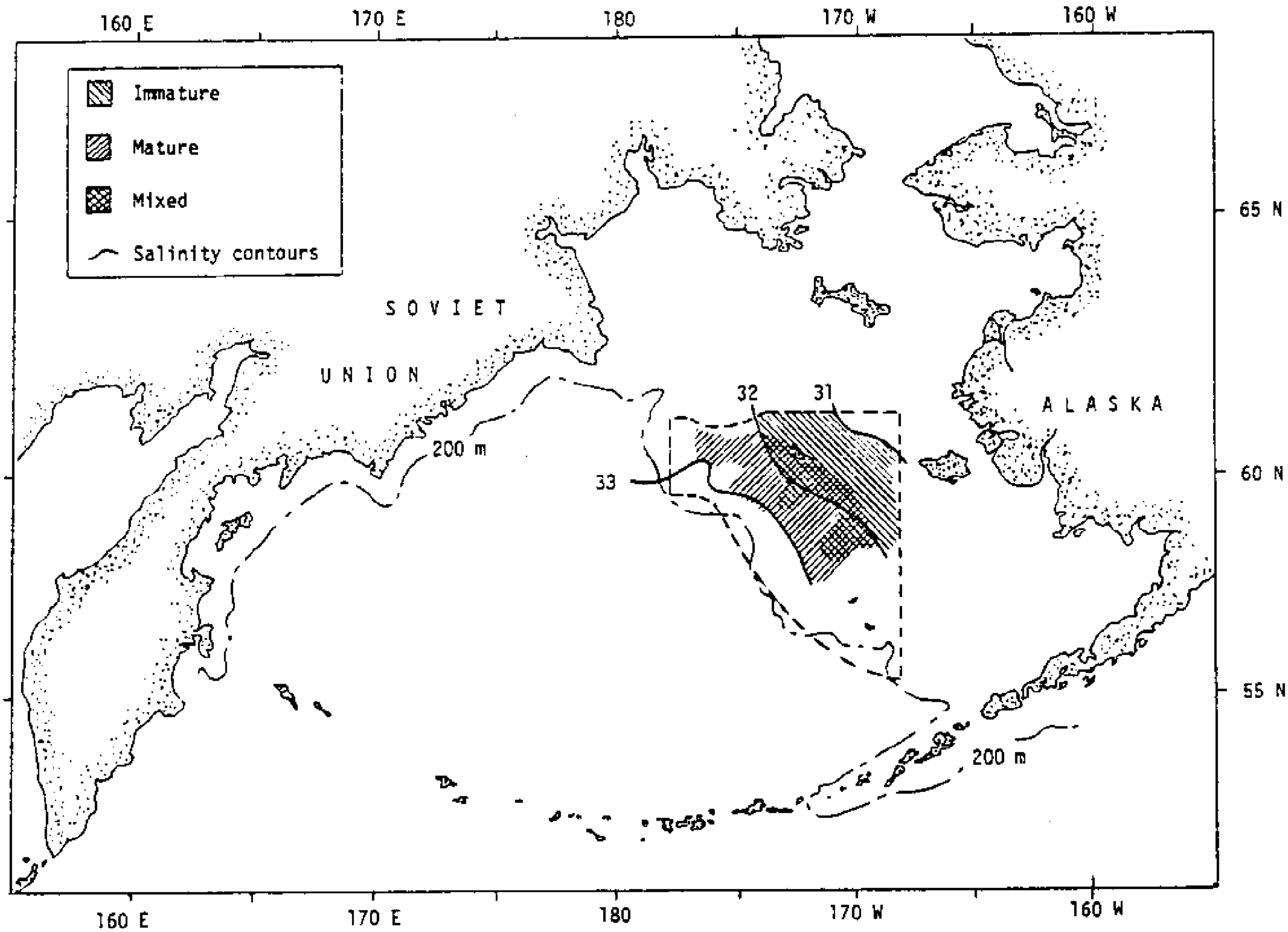

Figure 4. Distribution of Pacific herring in October and the relationship of adults (mature) and juveniles (immature) to salinity (parts per thousand) gradients. (Modified from Rumyantsev and Darda 1970).

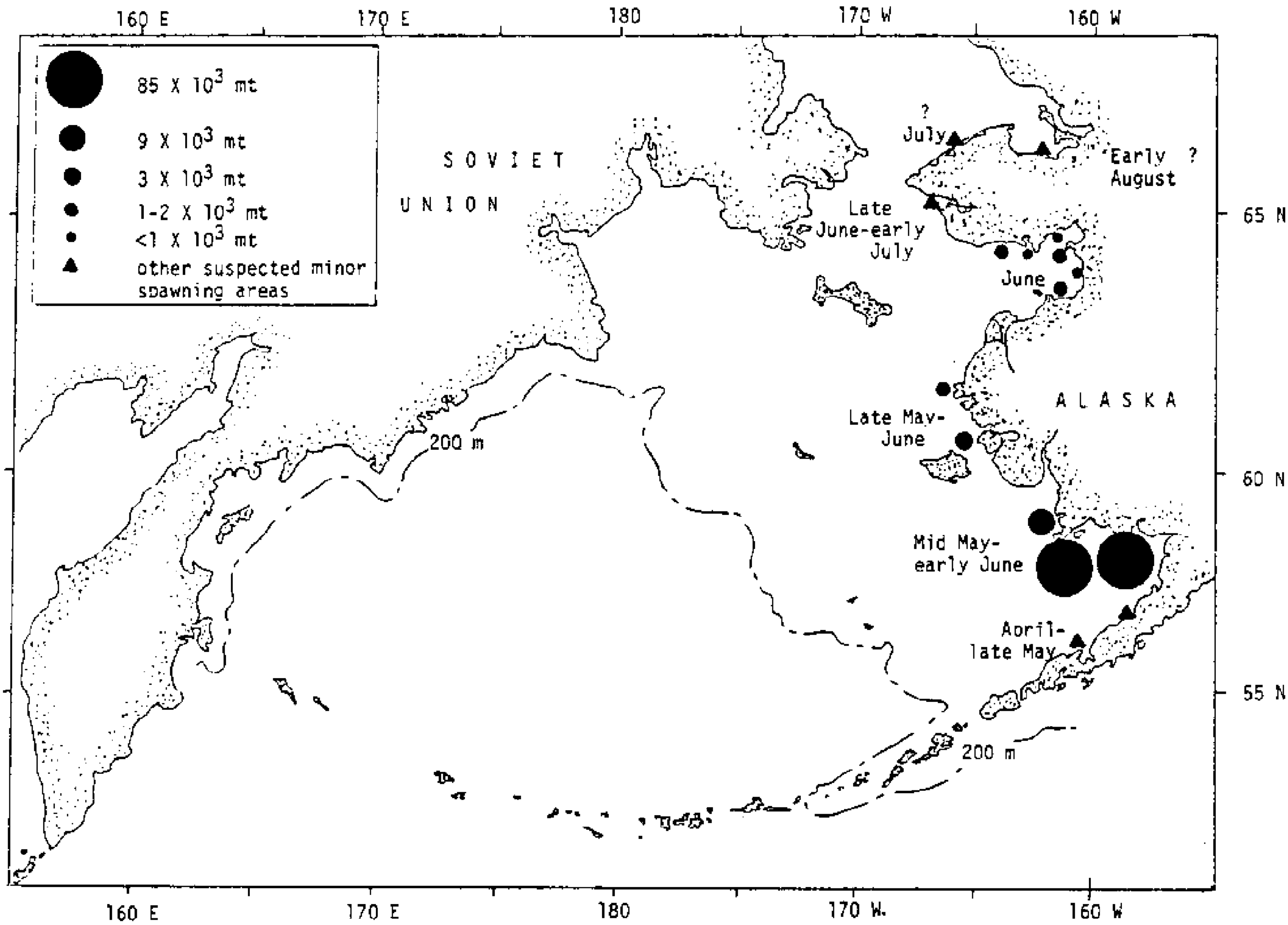

Figure 5. Distribution, average time of spawning and relative abundance of Pacific herring on coastal spawning grounds in the eastern Bering Sea. Relative abundance is based upon aerial survey observations in 1978-79.

(Warner and Shafford, 1977) and in a range of 5.6 to 11.7° C at spawning areas between Norton Sound and Bristol Bay (Barton, 1979).

Prokhorov (1968) found that approximate time of spawning in the western Bering Sea is related to winter and spring water temperatures with early maturation and migration to the spawning grounds in warm years and delayed development and timing in cold years. Barton and Steinhoff (1980) documented that essentially the same phenomenon applies to eastern Bering Sea stocks from maturation and timing results observed in spawning stocks from Bristol Bay to Norton Sound in 1978 and 1979.

Duration of spawning may range from a few days to several weeks. Generally, older herring are the first to spawn followed successively by younger fish. There are two types of spawning habitats: exposed rocky headlands and shallow lagoons and bays (Barton, 1978). Eggs are deposited on vegetation in intertidal and shallow subtidal waters, predominantly on rockweed (Fucus sp.) and eelgrass (Zostera sp.) (Barton, 1978; Barton and Steinhoff, 1980). South of Port Clarence most spawning occurs in intertidal zones on rockweeds while north of Norton Sound spawning in shallow subtidal embayments appears to predominate. Barton points out that herring in the latter area are apparently more euryhaline and he believes that less available suitable spawning habitat in areas north of the Yukon River may be a major factor limiting the biomass of herring in these areas.

Eggs take from 10 to 21 days to hatch depending on water temperature. In northern Bristol Bay hatching has been observed in 13 to 14 days at 8 to 11° C (Barton, 1979) and 18 days at 5 to 8.9° C (Barton and Steinhoff, 1980). Alderdice and Velson (1971) have suggested that optimum temperatures for Pacific herring egg development are 5 to 9° C and that below 5° C egg mortality occurs.

Although offshore subtidal spawning has been documented on occasion from the presence of milt, its extent and significance to egg deposition in intertidal zones is not known. Barton and Steinhoff (1980) revealed that loss of intertidal spawn through disruption of habitats from spring storms is significant in most areas along the west coast. They also noted heavy losses in the Yukon/Kuskokwim Delta region from desiccation of eggs and rockweed left exposed to excessive sunlight and wind during periods of low tide. Predation was also noted as an important source of mortality. Yellowfin sole, other flounder species and Dolly Varden were among the primary fish species observed feeding on eggs. Sea birds, snails and crabs were also noted as predators of herring spawn.

LARVAL AND JUVENILE DEVELOPMENT

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

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). More than 50 percent of the juveniles were captured in Imuruk Basin, the brackish forebay of the Port Clarence-Grantley Harbor complex in water of $4^{0}/_{00}$ salinity. Although juveniles were present in the spring spawning period (late June-early July), significant numbers were not captured until mid-August. Their presence in Hotham Inlet in November was indicated by stomach analysis of sheefish (*Stenodus leucichthus*). Further, substantive numbers of age 1 herring were captured in June 1978 in Hagemeister Strait of northern Bristol Bay (Barton, 1979).

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

MATURATION

Sexual maturity of eastern Bering Sea herring coincides with recruitment into the fishery, primarily at ages 3 and 4. Rumyantsev and Darda (1970) found that eastern Bering Sea stocks mature primarily at ages 3 (50% mature) and 4 (78% mature). They reported by age 5, 95 percent of the population is mature. Although Barton (1978) found essentially the same for stocks spawning in Port Clarence and Norton Sound in 1977, Barton and Steinhoff (1980) indicate that when mild winter and spring conditions persist in the Bering Sea, attainment of sexual maturity may be advanced. In the spring spawning season of 1979 (following an exceptionally mild winter), 74, 97 and 100 percent of age 2, 3 and 4 herring, respectively, from Bristol Bay to Bering Strait were found to be sexually mature. Further, they report that herring stocks north of Bering Strait may mature and spawn for the first time at older ages than those in the eastern

Bering Sea. This was based on limited sampling in the spring of 1977 and 1979. The onset of sexual maturity occurs earlier in the herring's southern range (stocks mature between ages 3 and 4 in British Columbia and ages 2 and 3 in California--Hart, 1973; Rabin, 1977).

ABUNDANCE TRENDS AND STOCK STATUS

RELATIVE ABUNDANCE

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

In 1963, three years after the fishery began, the eastern Bering Sea herring biomass was estimated to be 2.16 million mt based on a Soviet hydroacoustic survey of the wintering grounds (Shaboneev, 1965). 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 oringinal density (3.38 fish/m^3) was determined by comparing acoustic echograms from the eastern Bering Sea to echograms of schools sampled by purse seines in western Bering Sea coastal water. The revised estimate of 0.5 fish/m^3 is based on densities observed in subsequent surveys of herring concentrations on the winter grounds northwest of the Pribilof Islands during the period 1969 to 1971. Densities derived are questionable but cannot be fully evaluated because few specific details are available regarding Soviet survey methods and accuracy. However, data reported in the literature and from individuals involved with herring hydroacoustic surveys indicate that the range of densities used by the Soviets may be extreme and an intermediate value may be more realistic.

Recently, a numerical ecosystem model was applied to estimate biomass of eastern Bering Sea herring (Laevastu and Favorite, 1978). This model simulated herring abundance based on the amount of herring needed to sustain the diet of herring predators at reported rates of consumption. Although the accuracy of input parameters, such as predator population size and consumption rates, has not been sufficiently evaluated, model results show that a minimum stock size of 2.49 million mt of herring is required to maintain components of the ecosystem, including predators, at a level observed in the mid-1960s prior to the start of intensive fishing.

Aerial surveys have been flown by ADF&G in the past several years along the western Alaska coast during the spawning period and the number of fish schools recorded by surface area (Barton and Steinhoff, 1980). Daily counts at selected coastal index areas are weighted by surface area ($50m^2$) and an adjusted count derived, which is termed the relative abundance index (RAI). Daily RAIs are evaluated by index area(s) to determine peak fish abundance after equating each to biomass using density ranges of 0.02 to 0.10 mt/m^2. The range of conversions is based upon commercial purse seine catches in the Bristol Bay fishery, while the actual conversion applied varies among index areas reflecting differences in water depth.

Barton and Steinhoff (1980) discuss at least three areas where more research is needed to provide information which will increase a precision of spawning biomass estimates through aerial assessment. First, methods of determining peak abundance vary among index areas based upon present, limited knowledge of the movement and mixing of spawners and post spawners. Second, biomass estimates are reduced 25 percent to compensate for the presence of other schooling fish species which can be observed from the air. These species include capelin and smelt (Osmaridae) and cod (Cottidae). They found these species constituted 25 and 26 percent of inshore test net catches during the spawning season from Bristol Bay to Port Clarence in 1978 and 1979, respectively. Lastly, conversion factors for estimating biomass are based on very limited purse seine samples and the absence of large scale bathymetry charts.

In the late 1960s and early 1970s herring abundance in the eastern Bering Sea declined significantly as indicated by the catch and catch per unit effort (CPUE) of Japanese stern trawlers fishing on the Pribilof wintering stocks. The CPUE (mt/hr) for large stern trawlers decreased from a high of 6.80 in 1969-70 to 0.77 in 1973-74 (Figure 6). The catch and CPUE of foreign trawlers are no longer useful as indicators of herring abundance, since herring are now largely captured incidental to other fisheries. This change was attributed to a decrease in herring abundance, increased targeting on pollock and low allowable catches in recent years (Wespestad, 1978a).

Abundance of herring in the eastern Bering Sea appears to have increased since 1978 in all major spawning 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 percent increase at the low range (Barton and Steinhoff 1980). Analysis of the distribution of the spawning biomass in 1979 shows that 84 percent of the total biomass spawned in the Togiak District, 13 percent in the Yukon-Kuskokwim area and 3 percent in Norton Sound. Biomass distribution in 1978 was 95 percent, 5 percent and 3 percent, respectively.

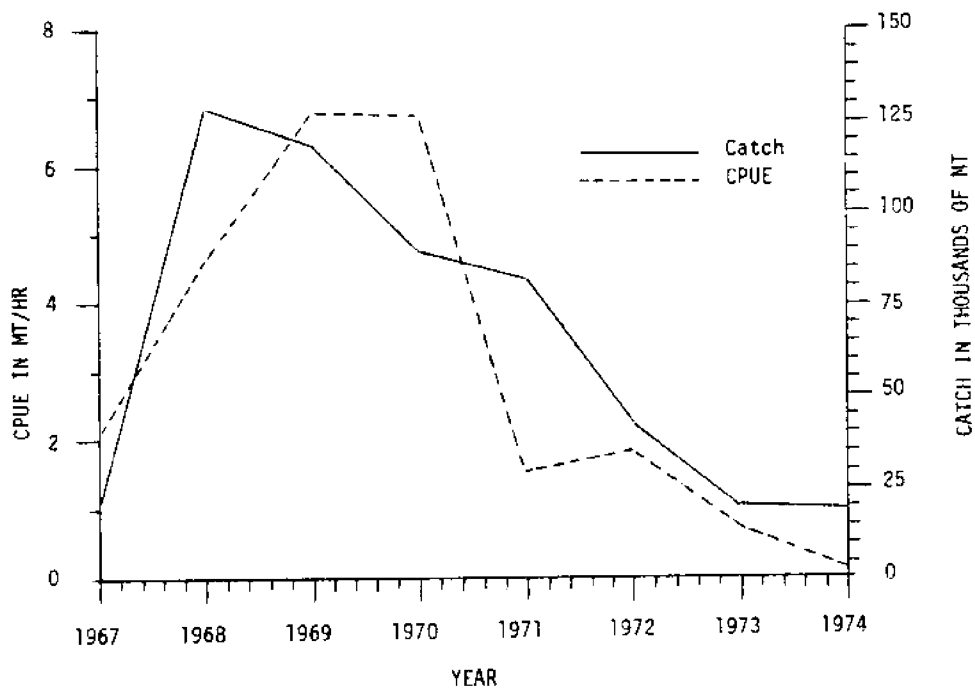

Figure 6. Catch and catch per unit effort (CPUE) relationship for large Japanese stern trawlers in the eastern Bering Sea, 1967-1974.

Although Barton and Steinhoff (1980) point out that present biomass levels cannot be precisely related to those which existed from 1968-1971, they state that available evidence indicates that herring biomass in the eastern Bering Sea are at their highest levels since that period. They concluded, in view of the rapid development of Bering Sea herring fisheries, inadequate knowledge of present stock status compared to earlier periods of history and the variables associated with determining herring biomass from aerial surveillance, that the low range of biomass be considered as the best estimate of spawning biomass.

AGE COMPOSITION AND RECRUITMENT

Wespestad (1978b) points out that herring length and age frequency data, available from foreign trawl fisheries from the late 1960s to early 1970s, indicate that herring catches were composed of larger and older fish than the past few years. Available data suggests that recruitment was poor until recently and may have been a major contributing factor to a lower herring abundance in the early 1970s. Year-class strength data presented recently by Naumenko (1979) show several years of relatively weak year classes in the 1960s and early 1970s (Figure 7). These data suggest that the peak catches of the fishery were sustained by a few strong year classes and that future yields of this magnitude are likely only in the event of a series of much above average year classes or change in the ecosystem. In recent years recruitment appears to have increased as evidenced by the relatively strong recruitment of 1972, 1973 and 1974 year classes at age 4 (Figure 8). The frequency of age 4 herring in 1979 (year class 1975) was decreased from that observed in the 1976-78 fisheries but ADF&G test net records suggested a fair return of age 3 herring (Barton and Steinhoff, 1980).

While recognizing the inherent limitations with interpretation of variable mesh gillnet age composition data, Barton and Steinhoff (1980) feel results are sufficiently sensitive to detect major changes in year class strength, especially in fully recruited age classes. Their results with this gear type in 1979 from Bristol Bay to Bering Strait, inferred strongly that relatively strong year classes existed from 1974 and 1972 (Figure 4). The 1976 year class appeared strong in both Bristol Bay and Norton Sound while the 1972 year class appeared strongest in areas north of Bristol Bay. A relatively strong return from the 1973 year class was also observed in Bristol Bay. That the 1972 year class contributed more to northern stocks is possibly a function of less intense domestic commercial fishing pressure on those spawning stocks. Also, the increase in spawning stocks from 1978 to 1979 can possibly

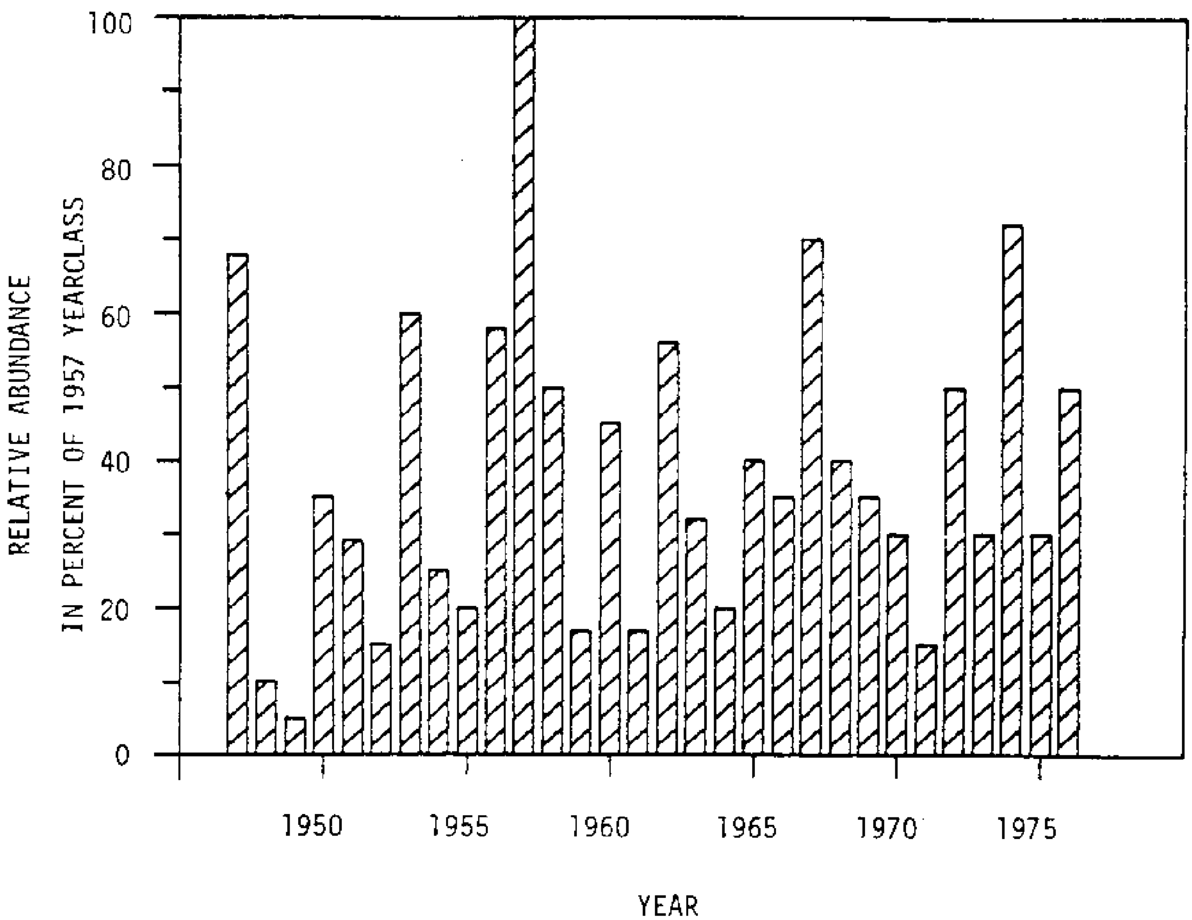

Figure 7. Abundance of Pacific herring year classes in the eastern Bering Sea relative to the 1957 year class. (From Naumenko 1979).

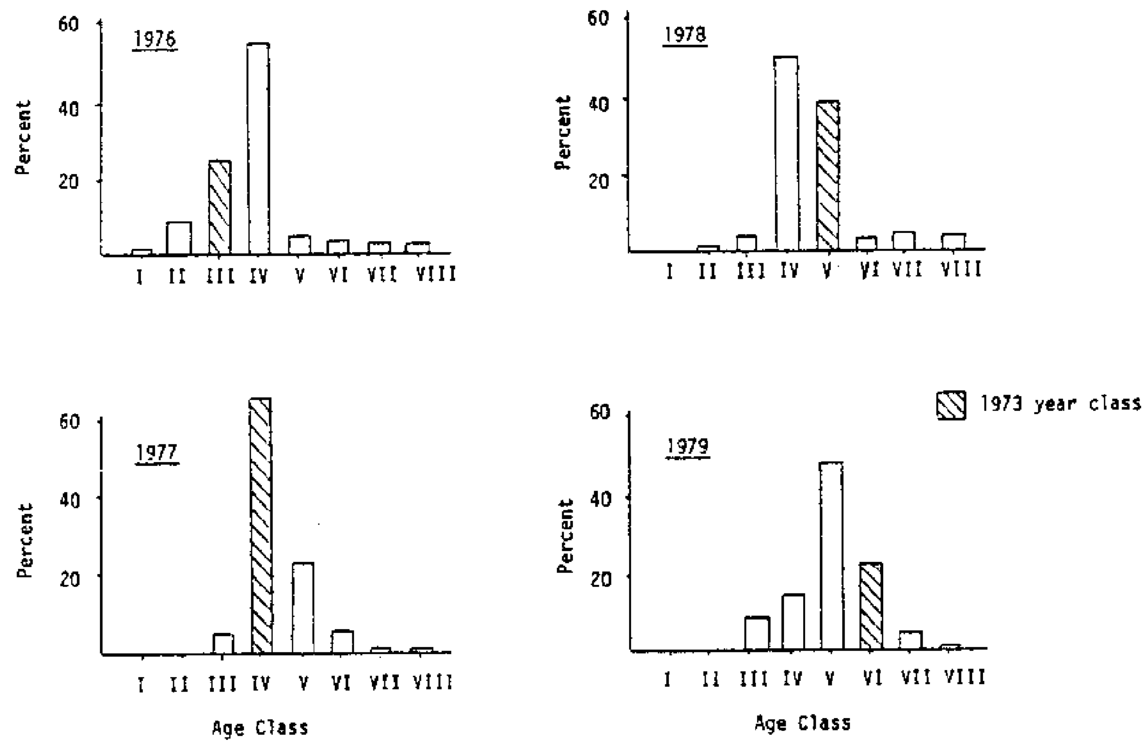

Figure 8. Annual variations observed in Pacific herring year class strength of domestic commercial harvests in the eastern Bering Sea (Togiak District), 1977-1979. The 1976 data is from test netting.

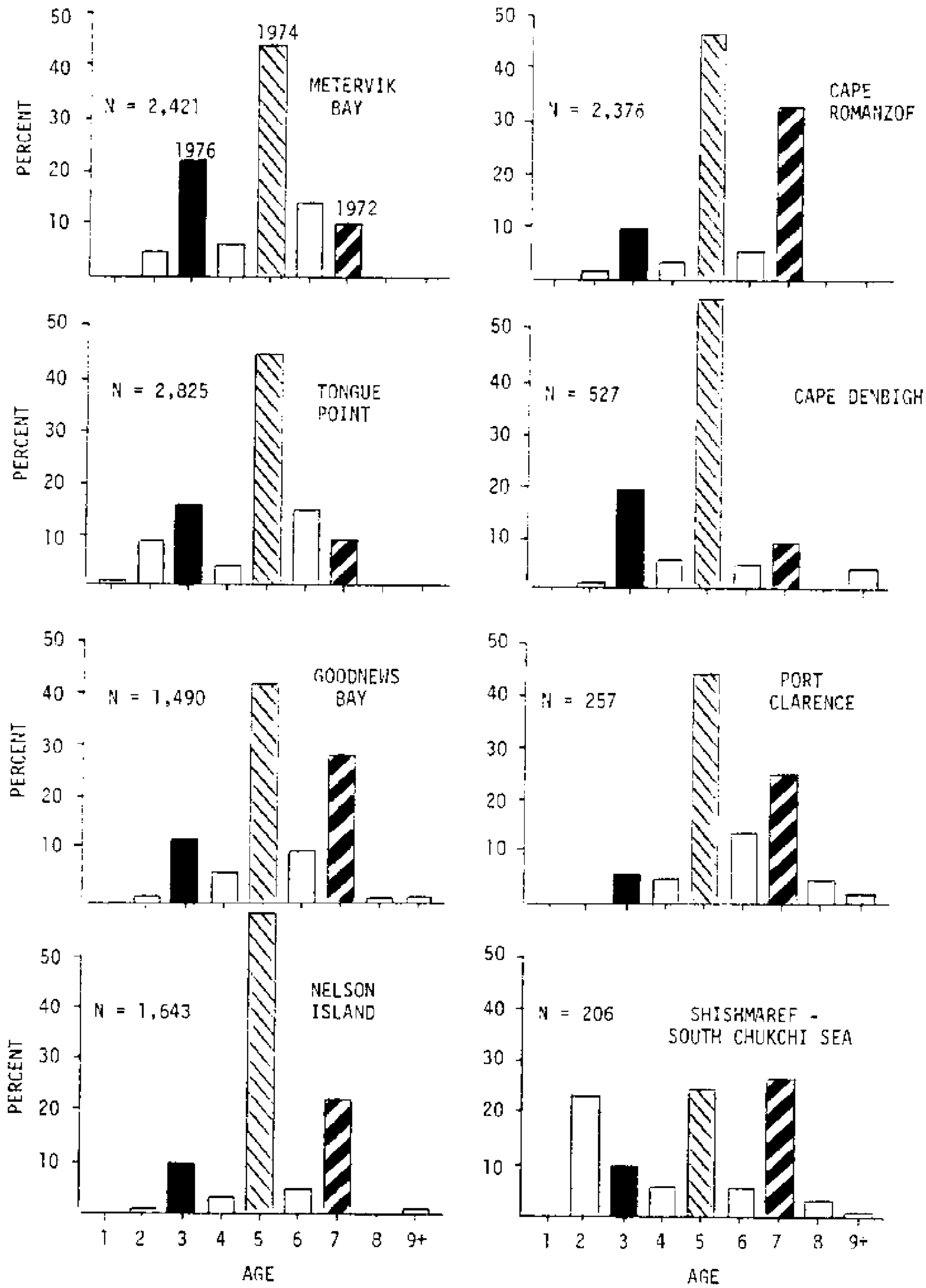

Figure 9. Percent age composition of Pacific herring captured in variable mesh test nets at eight spawning areas from Bristol Bay to Kotzebue Sound, spring 1979.

be attributed not only to strong recruitment of the 1972, 1974 and possibly 1976 year classes but also to reduced fishing by foreign fleets on mixed wintering stocks in recent years.

These data would suggest a favorable outlook for the 1980 domestic sac roe season with the fisheries concentrating primarily on herring from the 1974 and 1976 year classes; i.e. returning as ages 6 and 4. Mild winter conditions which persisted in the Bering Sea in 1977-78 may have been favorable to survival and thus contribute to a healthy recruitment of age 3 herring (1977 year class) in 1980. It is not known how strong the 1973 year class will be, but it is unlikely that the 1972 year class will contribute significantly to any spawning stock in 1980.

RESEARCH NEEDS

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

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

In spite of limitations due to weather and narrow time area coverage, aerial surveys may be one of the more cost-effective ways of measuring the abundance of spawning herring. Improvement in aerial biomass estimation procedures needs to be made specifically with the relationship of herring density and water depth. Intensive coastal test fishing should be conducted to determine the occurrence of other schooling species vital to accurate assessment of aerial survey results. Such a program should be designed to more accurately define entry-exit patterns and extent of mixing of various spawning units on the spawning grounds. Satellite technology may be a means of augmenting aerial surveys in that large schools may be observable at distances from the coast or spawning (milt) observable nearshore. A combination of low level aircraft and satellite observations may provide answers to the effective coverage of tracklines and time-space distribution of schools. On the other hand, use of high altitude surveillance may be limited due to such factors as degree of resolution, cloud cover, and frequency of coverage made of the Bering Sea.

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

The occurrence and extent of subtidal spawning is not understood and needs further investigation. Particular attention should be given to its importance compared to intertidal spawning. The necessity of such a study is clearly evident considering the vulnerability of intertidal spawn to mortality directly from snow runoff, pollution, storm action and commercial harvest. Success of intertidal spawning may be indirectly affected by destruction of vegetation from severe ice scouring, winter storms or pollution from petroleum related activities. The ADF&G is at present examining revegation rates of *Fucus sp.* beds which are affected by some of the above factors.

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

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

Lastly, stock distribution needs to be investigated so that individual stocks within the eastern Bering Sea can be monitored with regard to relationship to other stocks and occurrence in fisheries. Also, very little is known about timeing, distribution and abundance of herring spawning stocks in the southern Chukchi Sea.

REFERENCES

Alderdice, D. F. and F. P. J. Velson
1971 Some effects of salinity and temperature on early development of Pacific herring (*Clupea pallasi*). J. Fish Res. Board Can. 18(10): 1545-1562

Bakkala, R. G. and G. B. Smith
1978 Demersal fish resources of the eastern Bering Sea: spring 1976. U.S. Dept. Commerce, Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Seattle, WA., Processed Rpt., 233 pp.

Barton, L. H.
1978 Finfish resource surveys in Norton Sound and Kotzebue Sound. OCSEAP, Final Report (March 1976-September 1978), ADF&G, Comm. Fish. Div., Anchorage, September.

1979 Assessment of spawning herring and capelin stocks at selected coastal areas in the eastern Bering Sea. Annual report to North Pacific Fishery Mgt. Council, Contract 78-5, Alaska Dept. of Fish and Game, Comm. Fish. Div., Anchorage, March.

Barton, L. H. and D. L. Steinhoff
1980 Assessment of spawning herring and capelin stocks at selected coastal areas in the eastern Bering Sea. Final report to North Pacific Fisheries Mgt. Council, Contract 78-5, Alaska Dept. of Fish and Game, Comm. Fish. Div., Anchorage, in print.

Bean, T. H.
1887 The fishery resources and fishing grounds of Alaska. *In* George Brown Goode et al. The fisheries and fishery industries of the United States, pp. 81-115. Gov. print. off., Washington, D.C.

Cobb, J. N.
1907 The fisheries of Alaska in 1906. U.S. Bur. Fish., Rep. Comm. Fish. 1906 (1908). 70 pp. (Doc. 618, issued May 16, 1907).

Cushing, D. H.
1975 Marine ecology and fisheries. Cambridge Univ. Press. Cambridge, 278 pp.

Dudnik, Y. I. and E. A. Usol'tsev
1964 The herring of the eastern part of the Bering Sea. In P.A. Moiseev (ed.). Soviet fisheries investigations in the northeast Pacific. Part

II: 225-229. (In Russian. Transl. 1968. Israel program sci., Transl., avail. U.S. Dept. Commer., Natl. Tech. Inf. Serv., Springfield, VA.

Gilbert, C. H.
1895 The ichthylogical collection of the steamer Albatross during the years 1890 and 1891. U.S. Comm. Fish and Fish.; Part 19, Rep. Comm. 1893: 393-476.

Grant, S.
1979 Biochemical genetic variation among populations of Bering Sea and North Pacific herring. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Seattle, WA., Processed Rpt., 22 pp.

Hart, J. L.
1973 Pacific fishes of Canada. Fish. Res. Board Can. Bull. 180, 740 pp.

Henderson, G. T. D., C. E. Lucas and J. H. Fraser
1936 Ecological relations between the herring and the plankton investigated with the plankton indicator. J. Mar. Biol. Assoc. U. K. 21(1): 277-291.

Jordan, D. S. and C. H. Gilbert
1899 The fishes of the Bering Sea. In David Starr Jordan (ed.). The fur seals and fur seal islands of the North Pacific Ocean, Part 3, p. 433-492. Gov. print. off., Washington, D.C.

Kachina, T.
1978 The status of the eastern Bering Sea herring stocks. Pac. Sci. Inst. Fish. Ocean. (TINRO) Vladivostok, U.S.S.R. Rep. submitted at U.S.-U.S.S.R. scientific meetings, Dec. 20-24, Northwest and Alaska Fisheries Center, Seattle, WA., 6 pp.

Laevastu, T. and F. Favorite
1978 Fluctuations in Pacific herring stock in the eastern Bering Sea as revealed by ecosystem model (DYNUMES III). I.C.E.S. Symposium on Biological Basis of Pelagic Fish Stock Management No. 31, 26 pp.

Marsh, M. C. and J. N. Cobb
1910 The fisheries of Alaska in 1909. U.S. Bur. Fish., Rep. Comm. Fish. Doc. 730.

Naumenko, N. I.
1979 The state of stocks of the eastern Bering Sea herring. Pacific Research Institute of Fisheries

and Oceanography (TINRO), Vladivostok, U.S.S.R. Unpubl. 15 pp.

Nelson, E. M.
1887 Report upon natural history collections made in Alaska between the years 1887 and 1881. Field notes on Alaskan fishes. pp. 295.

Pereyra, W., J. Reeves and R. Bakkala
1976 Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Data appendices. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Cent., Seattle, WA., Processed Rpt., 619 pp.

Prokhorov, V. G.
1968 Winter period of life of herring in the Bering Sea. Proceedings of the Pacific Scientific Research Institute of Fisheries and Oceanography 64: 329-338. (In Russian. Transl. 1970, Fish. Res. Board Can., Transl. Ser. 1433).

Rabin, D.
1977 Status of fisheries of California. In D. Blankenbeckler (3d.), Proceedings of third Pacific Coast Herring Workshop, June 22-23, 1976. Fish. Res. Board Can. Manu. Rep. Ser. No. 1421.

Reid, G. M.
1972 Alaska fishery resources--the Pacific herring. U.S. Dept. Comm., NOAA, NMFS, Fish facts - 2, 20 pp.

Rounsefell, G. A.
1930 Contribution to the biology of the Pacific herring Clupea pallasi, and the condition of the fishery in Alaska. Bull. U.S. Bur. Fish. 45: 227-320.

Rumyantsev, A. I. and M. A. Darda
1970 Summer herring in the eastern Bering Sea. In P.A. Moiseev (ed.), Soviet fisheries investigations in the northeastern Pacific, Part V: 409-441. (In Russian. Transl. 1972, Israel Program Sci. Transl. avail. U.S. Dept. Commer., Natl. Tech. Inf. Serv., Springfield, VA.).

Shaboneev, I. E.
1965 Biology and fishing of herring in the eastern part of the Bering Sea. In P.A. Moiseev (ed.), Soviet fisheries investigations in the northeastern Pacific, Part IV: 130-154. (In Russian. Transl. 1968. Israel Program Sci. Transl., avail. U.S. Dept. Commer. Natl. Tech. Inf. Serv., Springfield, VA.).

Tanner, Z. L.
1890 Explorations of the fishing grounds of Alaska, Washington Territory, and Oregon, during 1888, by the U.S. Fish Comm. steamer Albatross, Lieut. Comdr. Z. L. Tanner, U.S. Navy, Commanding. Bull. U.S. Fish. Comm. 8: 1-95.

Svetovidov, A. N.
1952 Clupeidae, Fauna of U.S.S.R., Fishes Vol. II No. 1. Academy of Sciences, U.S.S.R., Moscow. 428 pp. Avail. Natl. Tech. Inf. Serv., Springfield, VA.

Taylor, F. H. C.
1964 Life history and present status of British Columbia herring stocks. Fish. Res. Board Can., Bull. 143. 81 pp.

Warner, I. M. and P. Shafford
1977 Forage fish spawning surveys--southern Bering Sea. Alaska Marine Environmental Assessment Project, Project Completion Report.

Wespestad, V. G.
1978a Exploitation, distribution, and life history features of Pacific herring in the Bering Sea. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Center, Seattle, WA., Processed Rpt., 26 pp. (and appendices).

1978b A review of Pacific herring studies with special reference to the Bering Sea. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Center, Seattle, WA. Unpubl. 67 pp.

Wespestad, V. G. and L. H. Barton
1979 Distribution and migration and status of Pacific herring. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Center, Seattle, WA., December.

Wolotira, R. J., T. M. Sample, and M. Morin
1977 Demersal fish and shellfish resources of Norton Sound the southeastern Chukchi Sea and adjacent waters in the baseline year 1976. Natl. Mar. Fish. Serv., Northwest and Alaska Fish. Center, Seattle, WA., Processed Rpt., 292 pp.

GULF OF ALASKA HERRING MANAGEMENT

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The following presentation will discuss the herring fisheries associated with the Gulf of Alaska. Emphasis will be placed on management of the southeastern Alaska stocks where I am responsible for the collection and analysis of data.

The Gulf of Alaska herring fisheries can be divided into three distinct fisheries based on the type of commercial product: a winter bait and food fishery, a spring sac roe fishery, and a spring spawn on kelp fishery. Each fishery has its own set of management complexities based on the product desired and the fishery gear used for harvest. For example, sac roe fisheries are complicated by the physiology and behavior of herring. The timing of the commercial fishery opening is critical. Technicians are required to sample herring prior to the fishery, determining roe percentages to insure a quality product.

Management tools include catch sampling for age and growth analysis, aerial surveys of herring distribution and occurrence of beaches receiving spawn, and acoustical assessment of herring biomass and distribution.

The Gulf of Alaska is broken down into the following areas of responsibility by the Alaska Department of Fish and Game: Cook Inlet, Kodiak, Prince William Sound, and southeastern Alaska.

The majority of the bait product comes from southeastern Alaska. Prince William Sound provides the only roe on kelp product. The increased price and demand for sac roe herring is reflected in the harvest of all areas. Herring harvest for the past five years, including prices paid to fishermen, is summarized in Tables 1 through 4.

The herring fishery in the Gulf of Alaska in 1979 was represented by a harvest of 26.3 million pounds valued at $15.8 million. Roe on kelp harvest was 472,200 pounds valued at $633,000. To further evaluate the value of the fishery, a range of prices paid to fishermen for 1979 is summarized in Table 5.

The remainder of this paper will describe the management tools utilized, management strategies, and management

TABLE 1. Cook Inlet herring harvest in pounds and value per pound in dollars 1975 - 1979.

YEAR	FOOD & BAIT	VALUE	ROE HERRING	VALUE	ROE ON KELP	VALUE
1975	12,483	624	8,237,100	411,855	0	0
1976	11,625	1,163	9,684,436	968,444	0	0
1977	42,566	5,959	6,397.053	895,587	0	0
1978	297,840	62,546	803,886	200,967	0	0
1979	129,541	25,908	1,068,016	801,012	0	0

TABLE 2. Kodiak herring harvest in pounds and value per pound in dollars 1975-1979.

YEAR	FOOD & BAIT	VALUE	ROE HERRING	VALUE	ROE ON KELP	VALUE
1975	0	0	15,996	not available	0	0
1976	0	0	9,148	1,006	0	0
1977	0	0	676,880	155,682	0	0
1978	566,816	79,354	1,242,335	323,007	0	0
1979	213,200	42,640	3,470,800	2,429,560	0	0

TABLE 3. Prince William Sound herring harvest in pounds and value per pound in dollars 1975 -1979.

YEAR	FOOD & BAIT	VALUE	ROE HERRING	VALUE	ROE ON KELP	VALUE
1975	533,400	24,003	11,708,000	526,860	917,000	605,220
1976	0	0	5,168,000	452,000	485,000	247,350
1977	34,000	4,760	4,568,000	639,520	417,000	287,730
1978	2,087,000	394,443	2,713,000	984,520	141,000	175,827
1979	not available	N/A	8,272,000	5,583,600	472,200	632,748

TABLE 4. Southeastern Alaska herring harvest in pounds and value per pound in dollars 1975 - 1979.

YEAR	FOOD & BAIT	VALUE	ROE HERRING	VALUE	ROE ON KELP	VALUE
1975	11,820,800	472,832	4,100,000	820,000	0	0
1976	11,376,200	682,572	4,970,000	994,000	0	0
1977	12,818,800	769,128	5,315,000	1,594,500	0	0
1978	8,084,600	485,076	6,124,800	3,674,880	0	0
1979	6,970,000	697,000	6,174,200	6,174,200	0	0

TABLE 5. Range of prices paid to fishermen by product for 1979.

PRODUCT	RANGE IN DOLLARS PER POUND	$ / SHORT TON
Food & Bait	$ .10 - .20	$200 - 400
Sac Roe	$ .33 - 1.00	$660 - 2,000
Roe on Kelp	$1.34	

problems encountered in southeastern Alaska by the Alaska Department of Fish and Game.

Information collected to manage herring stocks includes estimating biomass available, determining age and growth, and evaluating spawning ground success.

Development of hydroacoustics in southeastern Alaska was initiated in 1969 as a research program. Success in the program resulted in using acoustical estimates as a basis for management primarily establishing harvest quotas.

Acoustical systems capable of assessing biomass are installed on four ADF&G support vessels in southeast Alaska. A state vessel in Cordova is also equipped. The National Marine Fisheries Service at Auke Bay also utilizes similar systems. The acoustic systems consist of a Ross 200A echo sounder modified for collection of data on magnetic tape. These systems operate at 105 KH_z with 7^{o} circular transducers. These systems are fully claibrated. Parameters calibrated include source level, transducer receiving response, receiver gain, receiver linearity, time varied gain, and pulse length. Parameters, except receiver time varied gain, are reasonably stable and are calibrated once each year. These measurements are conducted with a specialized field calibration system developed and built under contract by the Applied Physics Laboratory, University of Washington. The calibration system includes a calibrated standard hydrophone on a frame which is attached by a diver to a special mounting plate to the transducer on the ship's hull.

The unstable receiver gain characteristics are monitored prior to every survey using an internal calibration signal in the system.

To provide insight into the application of this system, the following will illustrate ADF&G survey methods for the 1978-1979 season.

Hydroacoustical surveys are conducted in known herring concentration areas on a monthly time interval from October through May. September, prior to the field season, calibration of all acoustical systems is accomplished. Service contracts are set up at this time with the University of Washington for computer data analysis and technical, calibration, and maintenance services during the field season. Three biologists working full time, plus support from Area Management Biologists, are required to conduct the surveys.

Surveys include defining an area encompassing a herring concentration. This is accomplished by previous experience, or searching with sonar. All vessels are equipped with Wesmar side scanning sonars. Sea Tec Omni sonars are going to replace two of the existing Wesmars in the near future. A series of assessment surveys are then conducted on the area of herring concentration. A series of transects spaced evenly over the area is conducted to determine the density. During surveys, midwater trawl samples are also conducted to determine species composition of acoustical targets observed. ADF&G presently has one midwater trawl with a 20 x 20 foot spread equipped with a Furuno Model FNR-200 Mark II net recorder. After the surveys are completed, the magnetic tapes are sent to the University of Washington. The magnetic tapes are analyzed and results submitted to ADF&G. It is possible to have complete analysis in one to two days after the survey. Data analysis is by echo integration. Using University of Washington's data analysis system, a PDP 11/45 computer with special software and hardware modifications.

A total of 141 computer analyzed surveys were conducted during the 1978-1979 season. A total of 91 hours of acoustical data was computer analyzed. Surveyed areas in 1979 accounted for 219 million pounds (99,320 mt) used as a biomass index.

Prerequisites to a successful acoustical program are as follows:

1) Herring are distributed in large concentrations over a relatively long period of time.

2) Herring are distributed in depths greater than 20 fathoms and above the bottom.

3) Possess seaworthy vessels with high quality electrical systems.

4) Require provisions for maintenance, calibration, and repair of acoustical system by competent electrical engineer.

5) Provide provisions for competent computer operators with experience relating to fish assessment.

6) Possess trawling capabilities to determine species, composition, and size of acoustical targets.

7) Possess experienced biologists familiar with acoustical systems and herring behavior.

Estimated costs, above vessel support, for acoustical systems are as follows:

1) Modified Ross system including sounder, oscilliscope, interface amplifier, and tape recorder..............................$15,000

2) Side scanning sonar (Wesmar) or............. 7,000

3) Omni sonar.................................. 40,000

4) Midwater trawl (net only)................... 3,000

5) Trawl net sounder - Furuno FNR-200.......... 12,000

6) Computer analysis - 100 hours............... 12,000

7) Maintenance repair, and calibration......... 10,000

Age and growth data is collected from scale samples taken from the commercial harvest and ADF&G project sampling. Two to five thousand samples are aged annually in southeastern Alaska.

This information is valuable in showing year class strengths. Growth difference from various areas also aids in stock separation. The commercial fishery selectively fishes for large herring for market reasons, but the data are considered comparable in showing relative strengths of various aged fish.

Since 1960, the Alaska Department of Fish and Game has conducted annual aerial surveys to monitor herring spawn in terms of linear miles. Effort and intensity of surveys has varied considerably over the years. Recognizing the commercial interest in herring sac roe, ADF&G initiated comprehensive spawning ground studies in 1976.

These comprehensive surveys are conducted by divers collecting samples documenting certain biological and physical parameters on established transect lines. Spawning areas are delineated by systematic aerial surveys. Once the spawning area is known, transects are established at selected intervals. Transect lines are set perpendicular to the shore and marked at 5 meter intervals. Divers follow the transect line until spawn or vegetation disappear. The transect line is then followed back to the beach documenting parameters such as depth, temperature, egg density, and substrate type. In areas where spawn occurs, all vegetation and spawn is collected in a 0.1 square meter sample every 10 meters. Where egg deposition occurs on rock or where unattached eggs occur, visual estimates of numbers are made in the sample frame. Visual egg estimates have been made and compared to actual laboratory counts of samples to develop a rapid acceptable method to assess larger areas. In the laboratory, eggs are separated from kelp by manual scraping, and/or by using a chemical digestive process for separation.

In the Kah Shakes gillnet sac roe fishery near Ketchikan, egg densities are back calculated to the number of spawners. This biomass number is used to establish harvest quotas. Herring distribution, in this area, does not allow for reliable acoustical assessments.

Prerequisites to a successful comprehensive spawning dive survey are as follows:

1) A relatively small spawning area since any form of diving activity is very time consuming.

2) The spawning area is protected from outside weather to allow divers to work.

3) Spawning takes place over a short period eliminating survey problems associated with multiple spawnings over time.

The management strategies for southeastern Alaska herring fisheries are as follows:

1) Determine harvest rates based on all information available, including acoustical estimates, spawning ground analysis, and age and growth information.

2) Establish threshold or escapement levels for various stocks and allow 10 to 20 percent harvest of acoustical estimates which meet this level. The 20 percent level will be applied only when stocks reveal strong building tendencies.

3) Minimize the harvest of immature herring.

4) Promote accurate reporting of catch.

5) Avoid the harvest of mixed stocks.

6) Provide for an orderly harvest.

7) Provide for a high quality roe product of at least 10 percent recovery.

These strategies in 1978-1979 resulted in shorter seasons, restricted or no harvest to meet escapement levels established, and restrictions to minimize harvest of immatrue herring.

Management problems for southeast Alaska herring are as follows:

1) Determineation of the degree to which the harvest of small herring should be minimized.

2) Splitting of the winter bait fleet to provide for an orderly harvest.

3) Manpower to assess and manage an increasingly complex fishery.

HERRING RESEARCH IN THE GULF OF ALASKA--A HISTORIC OVERVIEW

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INTRODUCTION

The themes have predominated in research on Pacific herring in Alaska: their basic biology and separation of the different stocks. Other research on herring has focused on their age, growth, longevity, mortality, behavior, population dynamics, and seasonal distribution.

BIOLOGY

In what is still probably the most comprehensive study of Pacific herring in Alaska, George Rounsefell (1930a) described many aspects of their biology. His studies, primarily in the 1910s and 1920s, described the morphology and meristics of Pacific herring in southeastern Alaska and Cook Inlet. At the same age, Pacific herring in the northern and western parts of his study area were larger than in the southern and eastern parts of the study area. Spawning, which takes place in spring in tidal shallows, was later in the northern and western parts of his study area than in other parts. Spawning in Alaska typically begins in March near Dixon Entrance and extends into July in the Bering Sea. A mature 3-year-old female produces about 10,000 eggs, and an 8-year-old produces about 59,000 eggs (Reid, 1972). Rounsefell (1930a) also found that half of the herring matured at age 3 and nearly all of the remainder matured by age 4.

Later studies show that the maximum age of Pacific herring is 15 to 16 years, but few rarely exceeds 9 years, of age (Reid, 1972). Dominant year classes do not contribute much to a fishery beyond age 7 (Reid, 1972).

Rounsefell (1930a) described dominant year classes that typify the structure of Pacific herring populations in Alaska. He also analyzed the effects of commercial fisheries on herring during the 1920s in Price William Sound, Cook

Inlet, Kodiak, and southeastern Alaska, and found evidence of depletion of the herring stocks in most areas.

STOCK SEPARATION

Rounsefell (1930a) and Rounsefell and Dahlgren (1935) were the first researcher to separate stocks of Pacific herring in Alaska. They initially used vertebral counts and growth rates to define the stocks. Vertebral counts increased significantly from south to north and from east to west, and growth rates varied substantially between stocks in summer feeding areas in southeastern Alaska. Rounsefell and Dahlgren (1935) interpreted their findings to mean that separate stocks existed, but at the time they did not know the extent of intermingling on summer feeding grounds of herring stocks that overwintered in different locales.

In the early 1930s, Rounsefell and Dahlgren began tagging herring in southeastern Alaska to separate stocks. Some of the earliest tags were small, magnetic tags implanted in the body cavity of the fish. Because the herring were tagged on spawning grounds, they were initially defined as "spawning stocks." The tagged herring were recovered in the summer reduction fishery that operated on the summer feeding grounds in southeastern Alaska. These early tagging studies showed that Pacific herring which spawned near Sitka migrated to summer feeding grounds near Cape Ommaney and lower Chatham Strait and that Pacific herring spawned at Auke Bay (near Juneau) did not make a simliar migration (Rounsefell and Dahlgren, 1935). Later work of Dahlgren (1936) showed that Pacific herring which spawned near Craig also migrated to Cape Ommaney in the summer and mixed with herring from the Sitka stock. From tag return rates, Dahlgren found that the fishery took an "appreciable toll" from the Sitka stock and less from the Craig stock. Skud (1963) summarized results of these tagging studies and estimated total mortality rates for four different year classes: total mortalities ranged from 60 percent between ages 4 and 5 to 95 percent between ages 8 and 9.

During the early 1960s, a tagging study using radioactive internal body-cavity tags (described by Wilimovsky, 1963) was begun in southeastern Alaska (Carlson, 1977). This work reaffirmed previous findings from the 1930s and provided evidence that a third spawning stock, the stock in Seymour Canal, migrated to Cape Ommaney and Chatham Strait in the summer and mixed with the Sitka and Craig stocks on common feeding grounds. The study also generated evidence that the Ketchikan spawning stock was isolated and did not migrate to mix with the other stocks.

In the 1970s, Grant (1979) used electrophoretic starch-gel tests to separate races of herring on the basis of allele frequency. Two distinct groups of Pacific herring in the Gulf of Alaska were identified--an eastern group extending from Kodiak southward, and a western group that extended into the Bering Sea.

In the late 1970s, Krieger (unpublished manuscript) showed that tiny coded microwire tags designed for tagging young salmon could be used to tag adult herring. The tags were implanted in a muscle under the lower jaw.

POPULATION DYNAMICS

Population dynamics and relative abundance of herring stocks around the Gulf of Alaska have historically received much attention. Rounsefell (1930b) demonstrated that Pacific herring in southeastern Alaska typically had strong and weak year classes, and he speculated on possible causes of year-class strength, such as the relationship of spawning success to water temperatures. After analyzing the variation in commercial catches in southeastern Alaska during the 1920s and 1930s, Dahlgren and Kolloen (1943) concluded that nine out of every 15 spawnings failed to produce enough recruits to replace the adult spawners.

Various methods have been used to estimate abundance of herring stocks. Aerial surveys of spawning herring and the length of beach area in which they spawn have been used to estimate the size of stocks that would be available to the summer fishery. No correlation has been found between spawning intensity and resultant year-class strength (Skud, 1959; and others). Presently, biologists from the state of Alaska use hydroacoustic surveys of Pacific herring on wintering grounds to estimate the herring biomass (in millions of pounds) and set quotas for the spring roe fishery.

For many years, fishermen and other resident Alaskans have speculated about the existence of a high-seas herring stock over oceanic depths in the Gulf of Alaska, but no evidence supports its existence. Attempts were made to locate this "stock" in the open ocean in the Gulf of Alaska during the 1920s by using the European method of drift-net fishing with long gillnets, but this was unsuccessful (Huizer, 1952).

A survey of offshore waters of the Gulf of Alaska was made during the summer of 1957 to locate herring. The two-month survey covered an extensive part of the Gulf between southeastern Alaska and Prince William Sound and into the center of the Gulf, but little echosign was seen and none was identified as herring (Powell, 1957). Powell (1957) attributed not finding herring to the searching techniques (sonar and echosounder) and sampling methods (mid-water trawl and gillnets), but the results could be interpreted as evidence that herring do not occur in oceanic waters in the Gulf of Alaska.

SEASONAL DISTRIBUTION

Seasonal distribution of herring has received some attention since Rounsefell's (1930) early work, which defined major spawning grounds in southeastern Alaska and Cook Inlet. Further exploratory fishing in southeastern Alaska during the winter of 1952-53 demonstrated that herring were not in locations frequented in summer but were wintering in areas usually distant from summer locations (Kolloen and Smith, 1953).

The annual surveys of winter herring biomass in southeastern Alaska conducted by the state of Alaska have identified wintering areas of major stocks, which are usually located close to traditional spawning beaches (Blankenbeckler, 1977). The aerial spawning surveys begun in the 1950s by the federal government (Skud, 1959) and continued through the 1960s and 1970s by the state of Alaska have documented spawning distribution on a comparable year-to-year basis.

During the period 1973 to 1975, the author followed the month-to-month horizontal and vertical distribution and environment of adult herring schools of the Auke Bay-Lynn Canal stock for 24 consecutive months during all hours of the day and night. Geographic and depth distribution of the same schools were then monitored each season for the next from 1975 to 1978 (Carlson, 1980). The Auke Bay-Lynn Canal herring concentrated along open straits on summer feeding grounds with moderate currents and abundant copepod concentrations. During warmer months, the schools ranged through the upper part of a stratified water column. In October each year for five consecutive years, the herring moved from open straits into the wintering grounds when windstorms and sinking of cooling surface waters broke up stratification of the water column. By this time, copepod abundance had declined sharply, and day length had shortened.

During winter days, the schools remained near bottom but continued diurnal migrations at night. The herring left the wintering grounds in late winter, moved out into the open straits off spawning beaches to the north, and remained over deep trenches until late April and early May when herring moved into tidal shallows, where phytoplankton blooms obscured surface visibility, to spawn. After spawning, the herring gradually concentrated on the same summer feeding grounds as copepod abundance and day length reached a peak and the water column again became sharply stratified.

SUMMARY

Some form of research on Pacific herring around the Gulf of Alaska has been conducted for nearly 70 years. During that time, many aspects of their biology have been worked out, including spawning habits, larval and juvenile development, age of maturity, fecundity, longevity, growth rates, feeding habits, and seasonal distribution and migrations. The major stocks of Pacific herring in southeastern Alaska have been identified and their population dynamics, fluctuations in abundance, and mortality rates have been documented.

Future research might do well to aim at gaining a better understanding of such things as density-dependent behavior of herring as it relates to survival, distribution, and the great flux of interrelated environmental factors.

REFERENCES

Blankenbeckler, D. (Ed.) 1977. Pages 91-93 *in* Proceedings of the Third Pacific Coast Herring Workshop, June 22-23, 1976. Fish. Res. Board Can., Ms. Rep. Ser. No. 1421.

Carlson, H. R. 1977. Results of a tagging study of Pacific herring in southeastern Alaska in 1960-62 using radioactive body cavity tags. Northwest and Alaska Fisheries Center Processed Rpt., Auke Bay Laboratory, Auke Bay, Alaska, USA.

Carlson, H. R. 1980. Seasonal distribution and environment of Pacific herring near Auke Bay, Lynn Canal, southeastern Alaska. Trans. Am. Fish. Soc. 109:71-78.

Dahlgren, E. H. 1936. Further developments in the tagging of the Pacific herring, *Clupea pallasii*. J. Cons., Cons. Int. Explor. Mer. 11:229-246.

Dahlgren, E. H., and L. N. Kolloen. 1943. Fluctuations in the abundance of the Alaska herring. Sci. Mon. 55:538-543.

Grant, S. 1979. Biochemical genetic variation among populations of Bering Sea and North Pacific herring. Final Rpt. to Natl. Mar. Fish. Serv., 2725 Montlake Blvd. E., Seattle, Wash., 98112. 22 p.

Huizer, E. J. 1952. History of the Alaska herring fishery. Pages 65-76 *in* Alaska Dep. Fish., Juneau, Alaska, Annu. Rep. for 1952.

Krieger, K. J. (unpublished manuscript). A method for tagging herring with binary-coded microwave. Natl. Mar. Fish. Serv. Auke Bay Laboratory, P. O. Box 155, Auke Bay, AK 99821.

Kolloen, L. N., and K. A. Smith. 1953. Southeastern Alaska exploratory herring fishing operations, winter 1952/53. Comm. Fish. Rev. 15(11):1-24.

Powell, D. E. 1957. Alaska offshore herring exploration by the R/V John N. Cobb--July-August 1957. U.S. Fish Wildl. Serv., Bur. Comm. Fish., Mar. Fish. Inv., Operations Rep., 1957.

Reid, G. M. 1972. Alaska's fishery resources--the Pacific herring. Natl. Mar. Fish. Serv., extension publ., Fishery Facts-2. Seattle, Wash.

Rounsefell, G. A. 1930a. Contribution to the biology of the Pacific herring Clupea pallasii, and the condition of the fishery in Alaska. U.S. Bur. Fish., Bull. 45:227-320.

Rounsefell, G. A. 1930b. The existence and causes of dominant year classes in the Alaska herring. Pages 260-270 in Contributions to Marine Biology. Stanford Univ. Press.

Rounsefell, G. A., and E. H. Dahlgren. 1935. Races of herring, Clupea pallasii, in southeastern Alaska. U.S. Bur. Fish., Bull. 48:119-141.

Skud, B. E. 1959. Herring spawning surveys in southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 321. 16 p.

Skud, B. E. 1963. Herring tagging experiments in southeastern Alaska. Fish. Bull., U.S. 63: 19-32.

Wilimovsky, KY, N. J. 1963. A radioactive internal tag for herring. Pages 359-361 in Spec. Publ. 4. North Atlantic Fish Marking Symposium at Woods Hole, Mass., USA, May 1961. Issued from Commission Headquarters, Dartmouth, N.S., Canada.

THE BIOLOGICAL ASPECTS OF MANAGEMENT OF CANADA'S WEST COAST HERRING RESOURCE

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ABSTRACT

Pacific herring spawn in March and April in the intertidal and subtidal zones in several hundred localities scattered along the entire coast of British Columbia. It is during the migration of adult fish from their feeding grounds on the continental shelf to their inshore spawning grounds that a seine fishery has traditionally exploited the run.

The commercial fishery began at the turn of the century. It developed initially for the dry salted market in the Orient, peaking with a catch of 85,000 tons in 1927. In 1934, the fishery switched to the meal and oil market and catches averaged about 100,000 tons until 1946. Catches then increased sharply, averaging about 200,000 tons until 1965, after which the stocks collapsed. As the stocks recovered, a seine and gillnet fishery for roe was introduced in 1971 which has produced a relatively modest catch of between 50,000 and 100,000 tons since 1972. The landed value of the roe catch has climbed steadily from $2 million in 1972 to $122 million in 1979, usually accounting for over 90 percent of the landed value for all herring fisheries.

Management measures were initially confined largely to closed periods and mesh restrictions to protect spawning and young fish. The introduction of catch quotas around 1940 for five of the seven major populations (identified by meristic and tagging studies) failed to curb overfishing in the 1960s and stock assessment procedures in use at the time failed to detect the critical extent of the decline in stocks until it was well advanced.

Building on this experience, the management policy for the present roe fishery places overriding priority on preservation of the resource and aims to maximize the economic benefits to society as a whole rather than maximizing the tonnage caught. Current management strategy calls for managers in the field to regulate roe fisheries off individual spawning grounds (management units) to provide the desired escapement to that spawning ground. The abundance of fish present is estimated from pre-season forecasts updated by sounder surveys and the sampling of fish on the grounds. The surplus above spawning requirements is split between the two gear types according to a predetermined ratio (currently 55 percent seine and 45 percent gillnet for the coast as a whole) by regulating the duration of separate openings for each gear type. Other minor fisheries, all of which preceed the roe fishery, are regulated by permits to individual operations for set amounts of fish.

Annual monitoring data on catch, spawn depositions and sampling for age, length, weight, sex and maturity are entered into a stock assessment analysis used to determine the abundance of each cohort in the catch and spawning escapement for each management unit. These data form the basis for pre-season forecasts of abundance by stock. The desired spawning escapement is also estimated annually on the basis of estimates of the egg deposition most likely to maximize the production of that cohort. Research continues on improving both the data base and the analytical procedures for the above. Other current biological research projects include stock identification (mainly by tagging), distribution and abundance on feeding grounds (mainly hydroacoustic surveys), gear impact studies (mainly effects on spawning success) and small scale studies of various aspects of life history and ecology conducted in conjunction with more specifically management oriented projects.

HISTORICAL BACKGROUND

LIFE HISTORY

Pacific herring (<u>Clupea harengus pallasi</u>) spawn on vegetation in and immediately below the intertidal zone in several hundred localities scattered along the entire coast of British Columbia (Figures 1A and 1B). Spawning usually involves specific behaviour patterns with individual fish interacting with the vegetation on which they spawn (Hourston

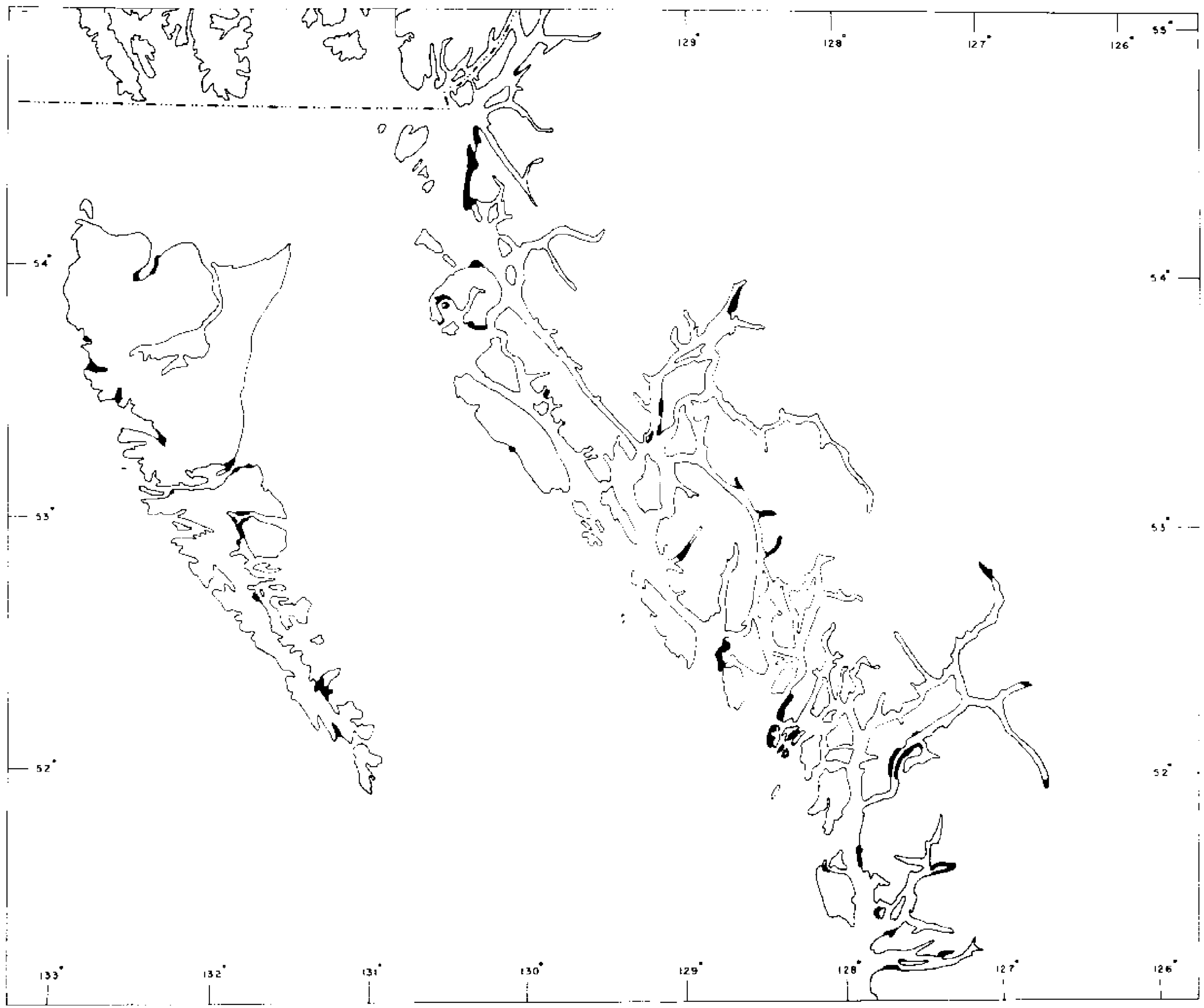

Figure 1a. Herring spawning grounds in the northern and southern parts.

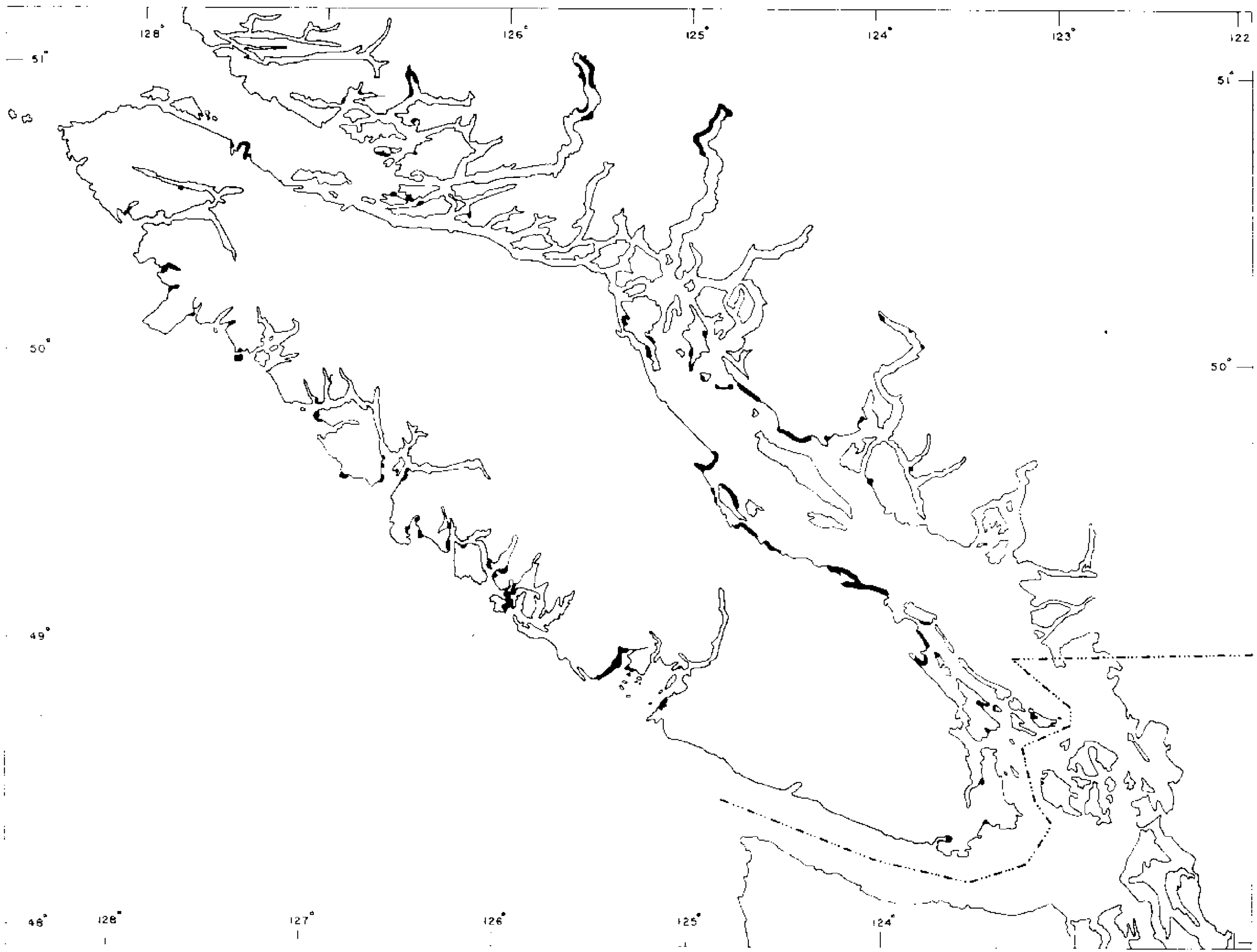

Figure 1b. Herring spawning grounds on Canada's Pacific coast during 1970s.

et al., 1977; Stacey and Hourston MS, 1980). The adhesive eggs are usually attached to vegetation such as red and brown algae, eelgrass, rockweed or kelp (Humphreys and Hourston, 1978a). After an incubation period of 2 to 3 weeks depending mainly on temperature (Alderdice and Velson, 1971), the eggs hatch into thread-like transparent larvae about 9 mm in length. Over the next six days or so, the yolk sac provides a source of nourishment as the larvae learn to feed. The larvae are gradually dispersed from the spawning grounds by the prevailing currents (Stevenson, 1962). Since mortality is high during this stage (99 percent), differences in the extent and direction of this dispersal from year to year may be the major factor in determining year-class strength. The larval stage lasts about 6 to 10 weeks, after which the herring metamorphose into miniatures of their adult form at a standard length of about 35 mm (Hourston, 1951). These juveniles school up into increasingly larger aggregations, and migrate offshore in the early fall (Hourston, 1958). They appear to remain on offshore feeding grounds, mainly on the edges of banks in depths of 100 to 200 m, until they mature, usually at the end of their third growth season. They then join schools of maturing adult fish for their annual inshore migration to the spawning grounds. It is during the later stages of this migration, when large schools are confined in relatively small channels and inlets, that the major herring fisheries have traditionally taken place (Taylor, 1964).

THE FISHERY

Commercial fishing for herring began in 1877 and was almost exclusively conducted by seine until the 1970s. The annual catch remained below 700 short tons until 1902. By 1908, the catch had climbed to 10,000 tons (Figure 2). The development of a dry salted market in the Orient brought catch levels up to about 25,000 tons between 1909 and 1920. Between 1920 and 1928, catches continually increased to 85,000 tons and then fell to 30,000 tons by 1934 with the rise and decline of the dry salted herring market. The introduction of a meal and oil reduction industry in 1935 almost doubled the catch in each of the succeeding two years and catches averaged about 100,000 tons until 1946. The catch then jumped to 170,000 tons in 1947 and averaged about 200,000 tons until 1965 (except for 1953 and 1958 when industrial disputes tied up most of the fleet). A sharp decline in abundance over the next three years led to a closure of the reduction fishery in 1968. Small catches by the traditional food and bait fisheries continued and, as the stocks recovered, a fishery for roe was begun in 1972 when demand arose for this product in Japan. The catch again rose to about 100,000 tons in a period of peak abundance in 1976 and has remained between 50,000 and 100,000

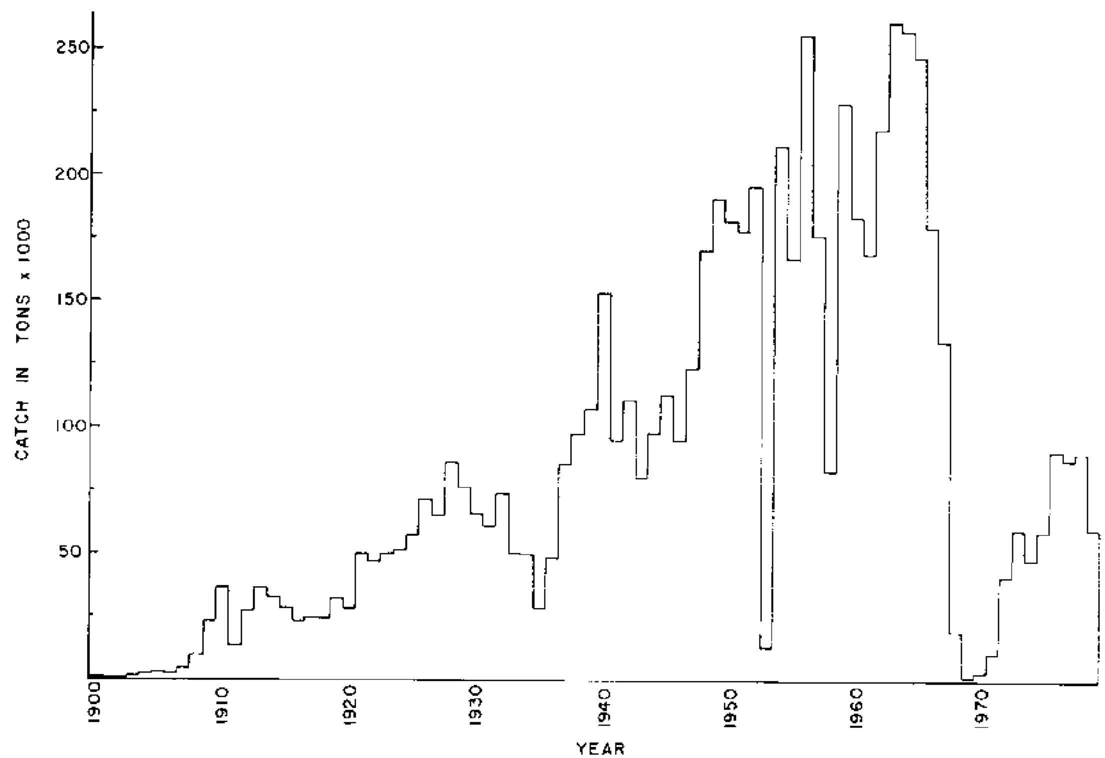

Figure 2. Herring catches on Canada's west coast since 1900.

tons since that time. The early history of the fishery was reported in detail by Tester (1935, 1945) and Taylor (1964). The decline and recovery of the stocks in the mid 1960s and early 1970s was analysed by Hourston (1978).

MANAGEMENT OF THE RESOURCE

Up to the late 1930s, this was a developing fishery which expanded outward from the processing centers as demand for the product increased. Management measures during this period were largely limited to seasonal closures to protect spawning and immature fish. Concern for conservation of the stocks led to the establishment of catch quotas on the lower east coast and the west coast of Vancouver Island (1936-1937 season), the middle east coast of Vancouver Island (1940-1941 season), and the northern and central coasts (1941-1942 season). Biologically distinct populations had been identified in these areas (Tester, 1949). However, these quotas had a limited effect on the catch as extensions were frequently granted (but not always taken). In 1946-1947, the quota for the west coast of Vancouver Island was removed to compare the effects of unlimited fishing on this stock with those of fishing under quota on the lower east coast stock (the "West Coast Experiment"). No detectable differences were noted in the response of the two stocks. Consequently, there was a relunctance to accept the possibility of overfishing these stocks in the 1960s in spite of major advances in fishing efficiency resulting from the use of larger and faster boats, and the introduction of the puretic block, drum seining and sonar. Moreover, stock assessment procedures in use at the time (age composition and linear miles of spawn roughly adjusted for density differences) failed to detect the drastic extent of the decline in abundance until it was well advanced and the reduction fishery was finally closed in 1968 (Hourston, 1978).

CURRENT RESOURCE MANAGEMENT

POLICY

Following the drastic decline of all the major herring stocks in the 1960s, the policy for management of the resource was revised from maintaining the catch to preservation of the resource, and from maximizing the tonnage caught to maximizing the benefits from the catch to the country as a whole. The latter is seen as involving a diversification of markets (to avoid the "boom or bust" type of situation); maximizing the processing done in Canada (to avoid the export of jobs); improving the quality of the product (to maximize the total economic return from the resource); and the return to the country from industry in the form of payments for access to the resource, which would at least cover the cost of management and research. The role of the research sector is to provide the biological, technological, and economic basis for implementation of this policy.

STRATEGY

Implementation of this policy required a major overhaul in the strategy for management of the resource. The basis for management of the fishery was changed from setting quotas on catch to setting quotas on spawning escapements, with the surplus being made available to the fishery. The available catch would then be allocated to the various fisheries on the basis of balancing the benefits of maintaining diversified markets and maximizing economic return. Within fisheries, catches were to be allocated proportionately to the various gear types on the basis of equalizing returns to labour and investment in order to provide access to the resource by various segments of the fleet. Quality was to be improved by testing and improving methods of handling and storing the fish at sea (Tomlinson et al, 1975), and in the processing plants (Boyd et al, 1972, 1980; Bilinski et al., 1975; Tsuyuki et al., 1975, 1978). Also, fish inspection standards would be tightened and more strictly enforced, and the timing of catches regulated to avoid having to hold landings in excess of plant capacities for later processing. Finally, fishing capacity had to be limited to manageable levels. The measures employed for this purpose include license limitation (introduced in 1974), boat quotas (for minor fisheries), finely controlled openings and closures (with some seine fisheries as short as 15 minutes) and limitations on net size. (Seines are now limited in length to 275 fm. Gillnets are restricted to one piece of net no longer than 75 fm and no more than 100 meshes deep, with a mesh size no smaller than 2-1/4 in).

FISHERIES

Following a catch of 33,043 tons during the 1971-1972 season (July 1971 to June 1972), the total catch of herring in British Columbia waters has fluctuated between about 50,000 to 100,000 tons (Figure 3). The major fishery is for roe. Roe catches have ranged between 38,000 and 87,000 tons since 1973 accounting for 73 to 92 percent of the total catch. The landed value has increased steadily from $2 million in 1972 to $122 million in 1979, usually accounting for well over 90 percent of the landed value for the catches from all herring fisheries.

The roe fishery is conducted close to the spawning grounds by seine and gillnet (Figures 4, 5, and 6) with a coastwide allocation of 55 to 45 percent, respectively, of the catch. As many as 200 seiners and/or 1,000 gillnet skiffs may participate on a single fishing ground, giving

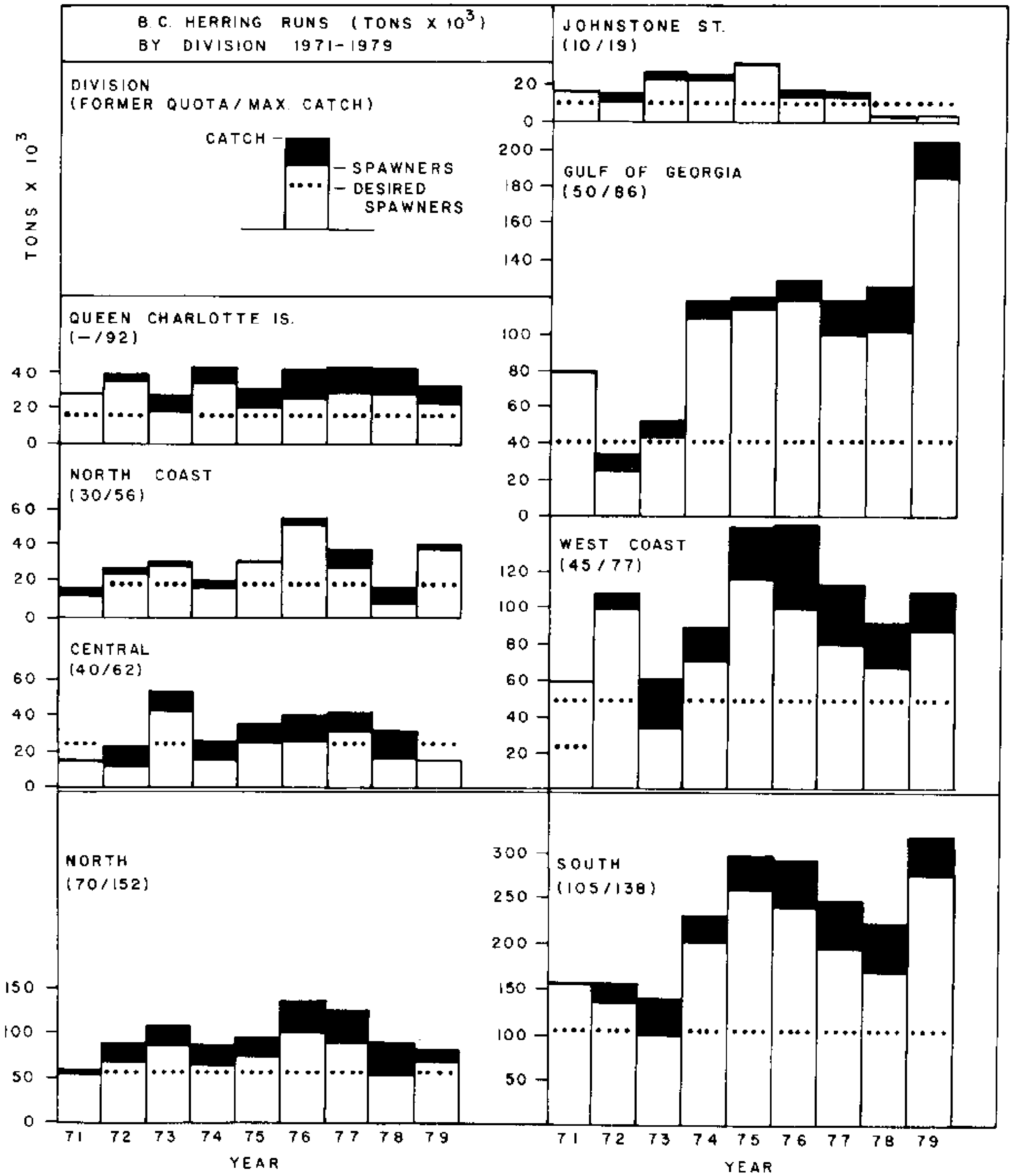

Figure 3. Catches and spawning escapements by district, 1971-1979.

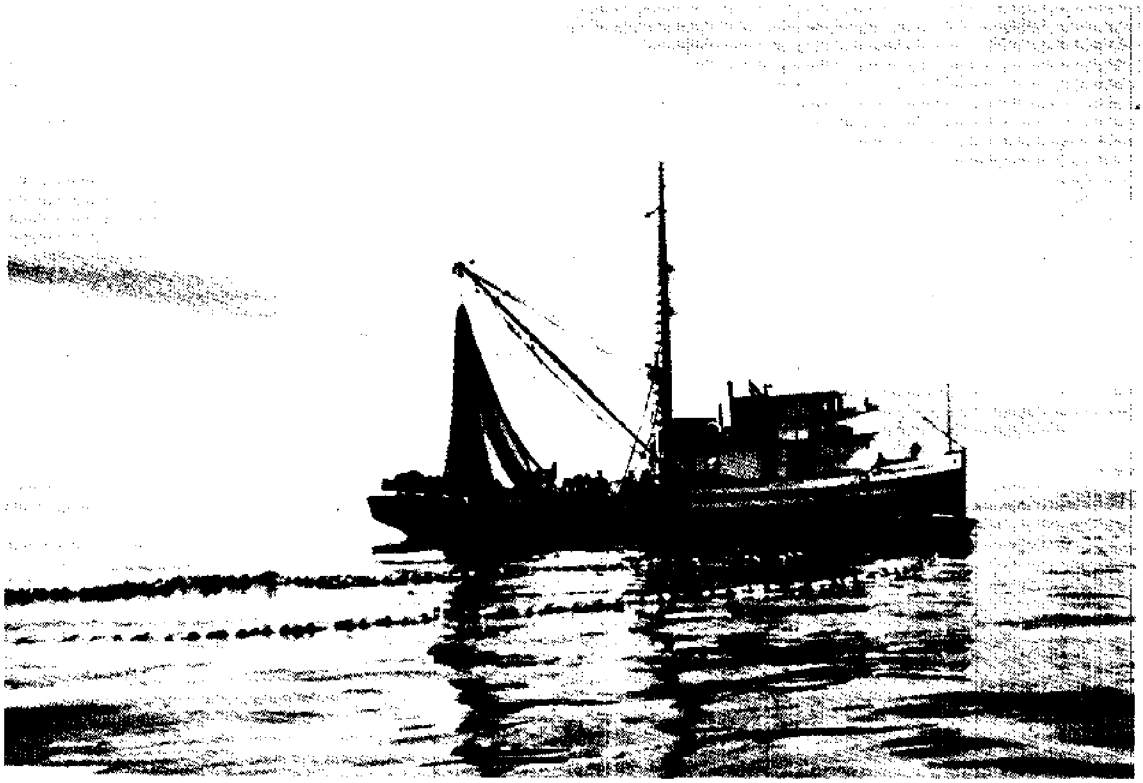

Figure 4. Fishing for herring by table seine.

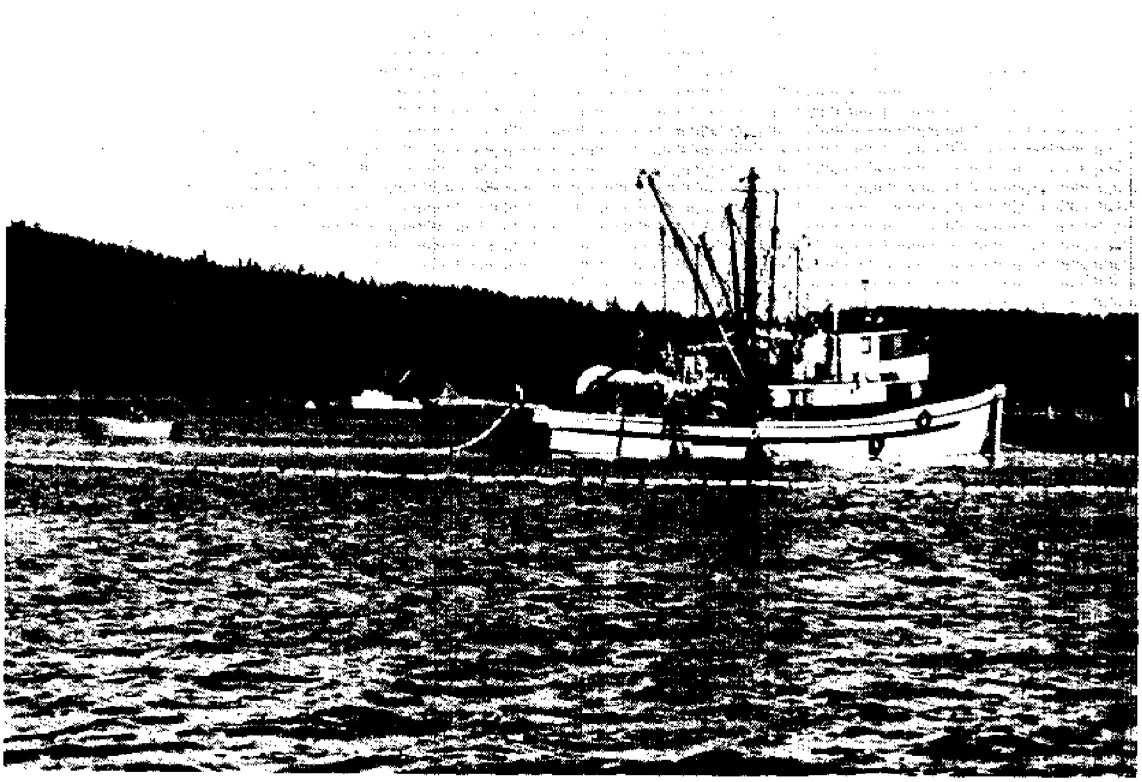

Figure 5. Fishing for herring by drum seine.

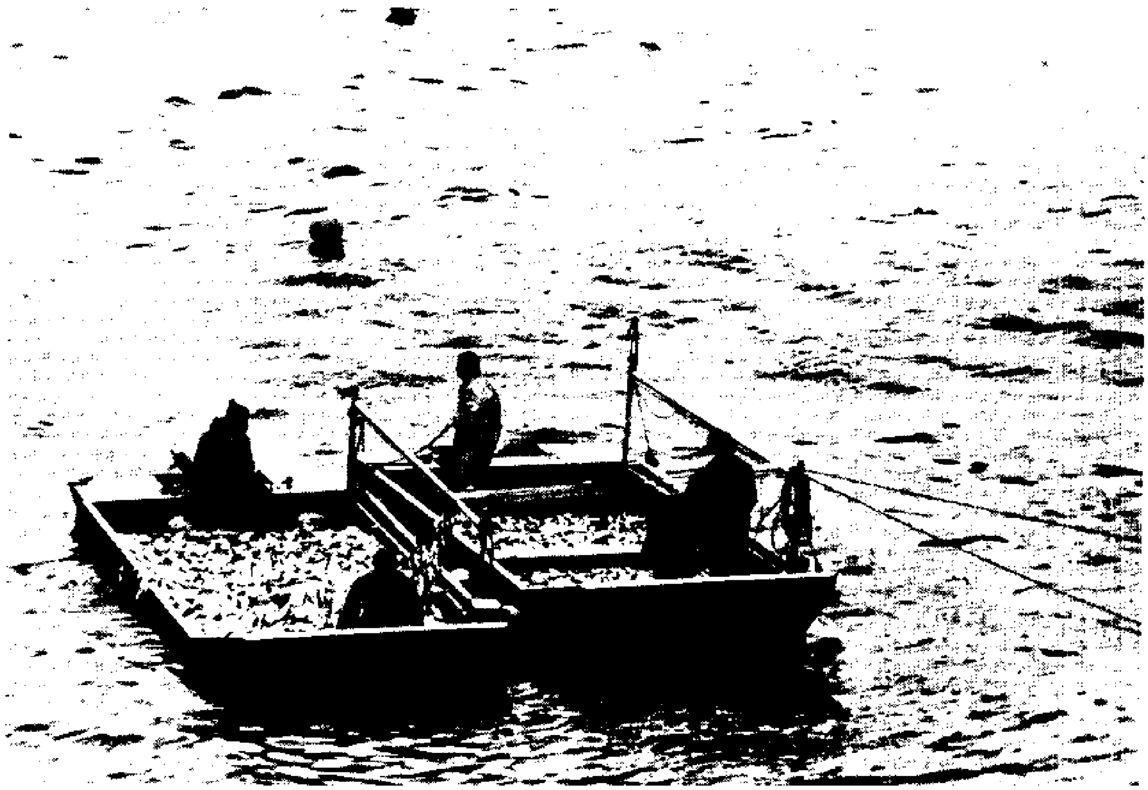

Figure 6. Fishing for herring by gillnet.

Figure 7. The herring seine fleet in operation.

the fishery a "gold rush" atmosphere (Figure 7). The fishery is opened and closed by radio announcement on the grounds by the local manager, whose control over the catch taken is largely limited to controlling the duration of the opening. The manager is provided with forecasts of the abundance of the run, the spawning escapement desired and the "gear split" for his area. On the basis of this information, supplemented by sounder surveys of the abundance of herring present by patrol, test fishing and commercial vessels, he finalizes his target catch levels and opens the fishery for the length of time he estimates will be required to catch that amount of fish. The opening must be timed to take place after the final stage of ripening (ovulation) when the roe is in prime condition, and before most of the fish have spawned (anywhere from a few hours to a few days). Test fishing is conducted for several days prior to the fishery to monitor the ripening process. The fish are considered ripe when the weight of mature roe in a sample of fish makes up 10 percent or more of the total weight of the sample. Where both gear types are involved, the gillnet fishery is usually opened first as this gear can fish closer inshore on the fish which mature and move onto the spawning grounds first. Because of the crowding on the grounds, the gillnet fishery is closed before the opening of the seine fishery, but may be reopened afterwards should further fishing be considered warranted.

Other fisheries are usually regulated on a permit system with catch limits for each individual permit. These include fisheries for food (local and export), bait (commercial, sport and export) and aquarium food which are conducted mainly by seine or trawl. In addition, 29 permits are issued annually for roe-on-kelp operations with a limit of 8 tons of product each. (One ton of product requires approximately 10 tons of fish.)

STOCK IDENTIFICATION

For the purpose of present management strategy, a stock may be defined as an aggregation of fish which is capable of supporting a geographically distinct roe fishery. Since the fish on a roe fishing ground are committed to spawning on adjacent spawning grounds, the amount of spawn deposition on these grounds will be determined by the escapement from that roe fishery. Seventeen such "management units" have been identified on the British Columbia coast, with the remainder of the coast divided into 18 other management units having few or no herring spawnings on a regular basis (Figure 8). Stock assessments and forecasts are prepared annually for each of the management units which support, or have the potential to support, appreciable roe fisheries. Other management units are grouped within the six major "divisions" on the coast for this purpose (Hourston and Hamer, 1979).

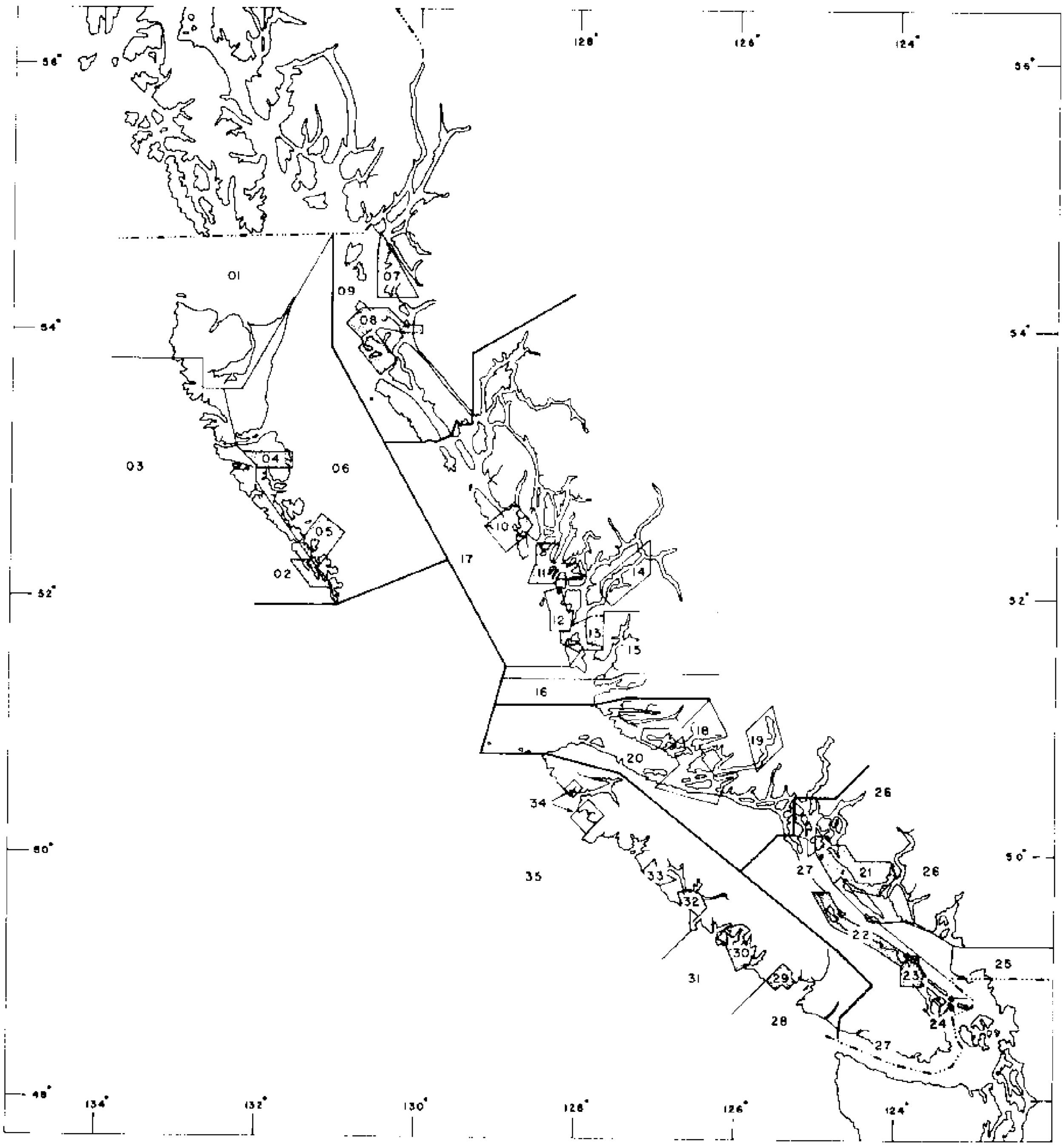

Figure 8. Management units on the British Columbia coast. Management units capable of supporting roe fisheries are shaded.

Identification of stocks in other fisheries is another matter. As long as these fisheries remain relatively small, their catches may be assigned to the various roe stocks on an approximate basis interpreted from tagging data in the 1950s and from age composition and growth rates. However, if such fisheries are to be directed toward non-roe stocks as much as possible (and hence increase the available catch from the resource), the stocks from which these catches are taken will have to be identified more precisely. To this end, a tagging program was initiated in 1979 with a planned duration of at least five years. Herring will be tagged on all the major existing and potential fishing grounds and tags recovered from all fisheries. The results of this program should also demonstrate the extent of mixing between and homing by the various roe stocks and hence the limits of precision within which individual stocks can be managed. This, in turn, is expected to increase the acceptable levels of exploitation for at least some stocks as safety margins are narrowed for spawning escapements. Concurrent with the tagging program, scale patterns and other biological characteristics will be tested for their potential use in stock identification.

STOCK ASSESSMENT

Quantitative stock assessments have been conducted annually since 1973 for the various management units. Annual monitoring data on catch , sampling and spawn depositions are processed by computer through an analysis which estimates, for each stock, the abundance (in numbers of fish and tons) and the average fish length, fish weight and sex ratio for each cohort (Figure 9). The weight, location, date and gear of each catch is recorded on sales slips when the fish are landed. Landings for individual fisheries are checked against hailed landings in the field for accuracy in reporting location of capture (Webb and Hourston, 1979). Random samples of about 100 fish are taken from an appropriate number of sets from each fishing area distributed throughout the period of the fishery (Humphreys and Hourston, 1978b). For each sample, the individual fish are processed for age (from scales), length, weight, sex and maturity (Hourston and Miller, 1980). Spawnings are surveyed to determine their location, date of deposition, length, width, and egg denisty (layers) by vegetation type (Humphreys and Hourston, 1978a).

The sampling data are used to convert weekly landings by section (subdivisions of management units) and gear into the number and weight of fish, the average fish length and weight, and the sex ratio for each cohort. These data are then compiled geographically by management unit and division and temporally by season.

I RAW DATA by - Locality - Date - Gear	Catch (each landing) - Tons - Disposal -	Sampling (each fish) - Age - Length - Weight - Sex - Maturity	Spawn (each deposition) - Length - Width - Layers - Substrate	PARAMETERS
II DATA SUMMARIES	- Totals by gear, section and week	- Averages at age by - 1) Sample - 2) Gear, section and week	- Numbers of eggs by - 1) Spawning ground - 2) Section	- Fecundity at age - Eggs per unit area by layers and substrate type
III STOCK ASSESSMENTS by (a) Geographic Region (i) Section (ii) Management Unit (iii) Division (b) Gear (i) Gillnet (ii) Seine (iii) Spawners (c) Age (year class)	(1) Age Composition (2) Average Length (3) Average Weight (4) Percent Females (5) Number of Fish (6) Tons			
IV FORECASTS by (a) Geographic Region (i) Management Unit (ii) Division (b) Units (i) Fish (ii) Tons	(1) Run (a) Returning Adults (b) New Recruits (2) Desired Spawners (3) Available Catch (allocated by fishery)			- Survival rate by age - Available spawning area - Optimum egg density

Figure 9. Stock assessment and forecast analysis.

The number of eggs deposited in each spawning is estimated by applying experimentally determined parameters for the eggs per unit area for the appropriate number of layers of eggs by vegetation type to the spawn survey data (Haegele et al., 1979a, b). These estimates are then totalled by section and converted to the numbers (and tons) of fish in each cohort which produced this egg deposition. This is accomplished by applying the appropriate data on age compo-sition, average weight at age and sex ratio, along with parameters for fecundity at age. These data are also compiled geographically by management unit and division and added to the corresponding catch data to give assessments by cohort for the population as a whole (eg. Hourston, 1979a).

DESIRED SPAWNERS

The optimum escapement to a spawning ground would be that number (or tons) of fish which would provide enough eggs to seed the available spawning area at a density which would provide for the maximum potential recruitment from that year-class. Studies of spawning behaviour (Hourston et al., 1977; Stacey and Hourston, 1980) have shown that herring interact with suitable vegetation types when depositing their eggs. Vegetation maps of the major spawning grounds (eg. Haegele and Hamey, 1976; Haegele, 1975) show the distribution of the major vegetation types utilized as spawning substrates. Current studies of the viable hatch from different densitities of egg deposition show that the rate of viable hatch decreases at higher egg densities and that the critical densities vary with substrate type. Once this information is arrayed, it should be possible to estimate the number of eggs which, if properly distributed, would maximize the viable hatch from an individual spawning ground. Then, the number (tons) of fish from a stock of known age composition, sex ratio and fecundity which would be required for this purpose can be estimated. Further refinements under consideration include taking into account various degrees of deviation from the optimum distribution of eggs to various sectors of the spawning grounds, the cost, in terms of lost catch, of achieving optimum egg deposition, and the effects of density dependent mortality during the larval stage on recruitment. Meanwhile, desired escapements are estimated each year for each management unit on the basis of average spawn depositions over periods of good recruitment, subjectively modified on the basis of the associated catch levels and any of the above information available for that sotck (Hourston, 1979a).

FORECASTS

The abundance, desired spawning escapement and available roe catch are forecast annually for each management unit (eg. Hourston, 1979b). Abundance is estimated in two parts. The number of returning adults is estimated for each cohort by applying survival rates (Tester, 1955) to the spawning escapement for the previous year. (Reassessment of survival rates on the basis of current data is planned for the near future.) The numbers of new recruits are estimated as the average for the preceeding years over a period for which the data are considered sufficiently reliable. The number of fish so estimated is converted into tons on the basis of average weight at age. The desired spawners (tons) are subtracted from the run to give the available catch. The tonnage from this management unit allocated to other fisheries is then subtracted to give the available roe catch. These forecasts are revised as sampling data becomes available from other fisheries, test fishing and the daily analysis of selected samples taken the previous day during the early part of the fishery. Any indications from sounder surveys of the diversion of fish from one spawning ground to another are also taken into account. After the season, the forecasts are compared with the actual runs and any major discrepancies analysed (eg. Hourston, 1979b).

AD HOC PROBLEMS AND OPPORTUNITIES

Gear Impact

Relatively poor recruitment to most stocks in recent years has led to concern that the operation of the roe fishery is somehow adversely affecting the survival of the eggs, larvae and/or young herring of the cohort produced that year and of the adult herring returning in subsequent years. Pollution on or near the spawning grounds from fish dropout, outboard motor oil, scales and other refuse from pumps and/or the noise from fishing vessels is thought to be diverting fish to less productive spawning grounds. Damage of spawning substrate by nets may also be involved. Appreciable shifts in some centers of spawning activity are cited in support of this contention. A few ad hoc observations of spawning grounds following roe fishing activities have failed to reveal any evidence of spawners being diverted from fishing areas or any appreciable damage to vegetation or egg depositions (eg. Humphreys, 1976). Moreover, centers of spawning have also been shifting in unfished areas. Nevertheless, the potential of gear impact damage to the stocks is too serious to be ignored and studies directed to this problem are planned for the immediate future.

Surveys of Feeding Grounds

Knowledge of the distribution, movements, abundance and composition of herring schools on the feeding grounds (where they spend most of the year) is limited to the results of a few surveys conducted in the early 1970s (eg. Taylor and Barner, 1974). An invitation to cooperate with scientists from the United States of America in such a survey in the waters of the two countries off Juan de Fuca Strait was accepted in 1979. Trawl catches from small summer food fisheries in Hecate Strait and Dixon Entrance have indicated the presence of large, mature herring after all known spawnings of any consequence in this area have been completed. The possibility of exploiting previously unutilized stocks could justify more active studies in this area. Such opportunities for investigative work will be embraced as resources permit.

Life History and Ecology

A broad understanding of the general biology of the animal is basic to a wide variety of more specific investigations. While limited resources presently preclude studies primarily directed toward such areas as life history and ecology, most other projects provide opportunities to expand our knowledge in this area on an ad hoc basis. Publications of studies prior to 1977 have been listed by Hourston (1977). Recent advances in this field include a detailed description of spawning behaviour (Hourston et al., 1977; Stacey and Hourston MS, 1980), sperm density in natural spawnings (Hourston and Rosenthal, 1976a), distribution of eggs on substrate surfaces (Humphreys and Hourston, 1978a), viable hatch from eggs torn loose from substrates (Hourston and Rosenthal, 1976b), patchiness of spawnings (Haegele et al., 1979a, b), effects of capture and fixation on the gut contents and body size of larvae (Hay, 1980), and predation on larvae by Hyperoche (Westernhagen, 1976; Westernhagen and Rosenthal, 1976; and Westernhagen et al., 1979). Other subjects under current examination include starvation periods for larvae and feeding rates of juvenile herring on larvae. Such studies will continue as the opportunities arise.

REFERENCES

Alderdice, D. R., and F. P. J. Velsen. 1971. Some effects of salinity and temperature on early development of Pacific herring. J. Fish. Res. Board Can. 28: 1545-1562.

Bilinski, E., L. ter Borg, D. Smith, M. Yamamota, and J. Zimmermann. 1975. Quality and quantity of roe obtained from Pacific coast herring under industrial processing conditions. Fish. Mar. Serv. Tech. Rep. 569: 22 p.

Boyd, J. W., J. Cheng, Minh Dieu Huynh, S. N. Williscroft, and H. Tsuyuki. 1980. Roe herring processing: preservation and factors affecting firming of roe. Can. Tech. Rep. Fish. Aquat. Sci. (In press).

Boyd, J. W., S. E. Geiger, and B. A. Southcott. 1972. Herring roe retrieval and processing. Fish. Res. Board Can. Tech. Rep. 336: 10 p.

Haegel, C. W. 1975. Vegetation mapping of herring spawnings grounds in British Columbia. Ocean 75 Record, IEEE Publication 76CH095-1 IOEC, New York, N.Y.: 840845.

Haegele, C. W., and M. J. Hamey. 1976. Shoreline vegetation maps of Nanoose and Ganges herring management units. Fish. Res. Board Can. MS Rep. 1408: 43 p.

Haegele, C. W., A. S. Hourston, R. D. Humphreys, and D. C. Miller. 1979a. Eggs per unit area in British Columbia herring spawn depositions. Fish. Mar. Serv. Tech. Rep. 894: 30 p.

Haegele, C. W., D. C. Miller, R. D. Humphreys, and A. S. Hourston. 1979b. Assessment of 1978 herring spawnings in the French Creek and Qualicum herring sections, using new egg determination procedures. Fish. Mar. Serv. Tech. Rep. 896: 43 p. (4).

Hay, D. E. 1980. Effects of capture and fixation on gut contents and body size of Pacific herring larvae. In R. Lasker and K. Sherman (eds.). Early life history of Fish II. Second International Symposium held in Woods Hole, 25 April, 1979. Rapp. Pv. Reum. Cons. Int. Explor. Mer. 1978: (In press).

Hourston, A. S. 1951. Preliminary studies of the juvenile stage of the Pacific herring (Clupea pallasii). Fish. Res. Board Can. MS Rep. Biol. Sta. 411: 38 p.

__________. 1958. Population studies on juvenile herring in Barkley Sound, British Columbia. J. Fish. Res. Board Can. 15(5): 909-960.

__________. 1977. Publications and reports on Pacific herring arising from investigations conducted at or in cooperation with the Pacific Biological Station. Fish. Mar. Serv. MS Rep. 1427: 21 p.

__________. 1978. The decline and recovery of Canada's Pacific herring stocks. Fish. Mar. Serv. Tech. Rep. 784: 17 p. (Also I.C.E.S. Symposium on the Biological Basis of Pelagic Fish Stock Management, Paper No. 6.)

__________. 1979a. Stock assessments for British Columbia herring management units in 1978 and forecasts of the available roe catch in 1979. Fish. Mar. Serv. MS Rep. 1493: 19 p.

__________. 1979b. Stock assessments for British Columbia herring management units in 1979 and forecasts of the available roe catch in 1980. Fish. Mar. Serv. MS Rep. 1556: 11 p.

Hourston, A. S., and J. M. Hamer. 1979. Definitions and codings of localities, sections, management units and divisions for British Columbia herring data. Fish. Mar. Serv. MS Rep. 1533: 79 p.

Hourston, A. S., and D. C. Miller. 1980. Procedures for sampling herring at the Pacific Biological Station. Can. MS Rep. Fish. Aquat. Sci. 1554: 24 p. (In press).

Hourston, A. S., and H. Rosenthal. 1976a. Sperm density during active spawning of Pacific herring (Clupea harengus pallasi). J. Fish. Res. Board Can. 33: 1788-1790.

__________. 1976b. Viable hatch from herring eggs torn loose from substrates by storms. Fish. Mar. Serv. Res. Dev. Tech. Rep. 653: 5 p.

Hourston, A. S., H. Rosenthal, and N. Stacey. 1977. Observations on spawning behaviour of Pacific herring in captivity. Meeresforschung 25: 156-167.

Humphreys, R. D. 1976. An evaluation of the extent of gillnet dropout in a roe herring fishery in British Columbia. Fish. Mar. Serv. Pac. Biol. Sta. Circ. 102: 2 p.

Humphreys, R. D., and A. S. Hourston. 1978a. British Columbia herring spawn deposition survey manual. Fish. Mar. Serv. Misc. Special Pub. 38: 40 p.

__________. 1978b. Sampling design for assessing the biological characteristics of British Columbia herring stocks. Fish. Mar. Serv. Tech. Rep. 848: 7 p.

Stacey, N. E., and A. S. Hourston. 1980. Observations on the spawning and feeding behaviour of captive Pacific herring. MS: 31 p.

Stevenson, J. C. 1962. Distribution and survival of herring larvae (Clupea pallasii Valenciennes) in British Columbia waters. J. Fish. Res. Board Can. 19(5): 735-810.

Taylor, F. H. C. 1964. Life history and present status of British Columbia herring stocks. Fish. Res. Board Can. Bull. 143: 81 p.

Taylor, F. H. C., and L. W. Barner. 1974. A herring survey of Juan de Fuca Strait in 1971. Report on P. KNIGHT cruises APK 71-3, -4, -5, -6, and -7 (July 22-December 12). Fish. Mar. Serv. Res. Dev. Tech. Rep. 503: 72 p.

Tester, A. L. 1935. The herring fishery of B.C. - past and present. Biol. Board Can. Bull. 47: 37 p. (Reprinted in Rep. British Columbia Commissioner Fish. for 1934: 76-102).

__________. 1945. Catch statistics of the B.C. herring fishery to 194344. Fish. Res. Board Can. Bull. 67: 47 p.

__________. 1949. Populations of herring along the west coast of Vancouver Island on the basis of mean vertebral number, with a critique of the method. J. Fish. Res. Board Can. 7(7): 403-420.

__________. 1955. Estimation of recruitment and natural mortality rate from age composition and catch data in British Columbia herring populations. J. Fish. Res. Board Can. 12: 649-681.

Tomlinson, N., G. A. Gibbard, S. E. Geiger, and E. G. Baker. 1975. Storage of roe herring at sea. Fish. Mar. Serv. Tech. Rep. 536: 16 p.

Tsuyuki, H., J. Cheng, S. N. Williscroft, and Minh Dieu Huynh. 1977. Causes of development of sponginess in roe produced from frozen herring. Fish. Mar. Serv. Tech. Rep. 739: 21 p.

Tsuyuki, H., and S. N. Williscroft. 1978. The preservative values of formaldehyde and its content in roe and carcasses before and after treatment of roe herring during processing. Fish. Mar. Serv. Tech. Rep. 82: 20 p.

Webb, L. A., and A. S. Hourston. 1979. Review of the 1976-77 British Columbia herring fishery and spawn abundance. Fish. Mar. Serv. Industry Rep. 110: 46 p.

Westernhagen, H. von. 1976. Some aspects of the biology of the hyperiid amphipod Hyperoche medusarum. Helolander wiss. Meeresunters. 28: 43-50.

Westernhagen, H. von, and H. Rosenthal. 1976. Predator-prey relationship between Pacific herring, Clupea harengus pallasi larvae and a predatory hyperiid amphipod, Hyperoche medusarum. Fish. Bull U.S. 74: 669-674.

Westernhagen, H. von, H. Rosenthal, S. Kerr and G. Fürstenberg. 1979. Factors influencing predation of *Hyperoche medusarum* (Hyperiida: Amphipoda) on larvae of the Pacific herring *Clupea harengus pallasi*. Mar. Biol. 51: 195-201.

HERRING MANAGEMENT ACTIVITIES IN WASHINGTON STATE

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INTRODUCTION

Washington state appears to be a transitional zone for Pacific herring along the west coast of North America with large stocks to the north and relatively small stocks to the south. Within Puget Sound, adult abundance is estimated at less than 30,000 tons, and about half of these fish are from a single area in northern Puget Sound. Across the Strait of Juan de Fuca in Canadian waters, spawning escapement for several groups of herring reaches tens of thousands of tons. The total population of herring known in Washington state is less than the harvest by our Canadian neighbors to the north. The smaller scale of abundance and harvest, however, does not protect us from management problems; we face all of the difficulties, uncertainties, and jurisdictional disputes common in areas of much larger resource magnitude.

Two dominant components jointly proscribe the manner of management in Washington. First is a biological part, which includes stock assessment, biological analysis and restrictions or quotas needed for conservation. The second involves allocation and the relationships between competing user groups. Two major actions enacted in the middle 1970s played key roles in management of herring fisheries in Washington. In 1973 and 1974, the state legislature passed bills which limited entry for the herring fisheries of Puget Sound. In 1974, the Boldt decision was issued, in which treaty Indian fishing rights were upheld by judicial review. These two actions are integral in subsequent management.

THE BOLDT DECISION

In February 1974, after several years of litigation, U.S. Federal District Court Judge George Boldt ruled that treaties signed in the 1850s gave certain Indian tribes of Washington state fishing rights to salmon and steelhead. In the treaties, the tribes relinquished claim to much of the land and consolidated on reservations. The tribes did retain previously held fishing rights at "usual and accustomed" fishing locations. Although Boldt's original ruling pertained to salmon and steelhead, subsequent hearings determined that the ruling applied to herring as well.

The most controversial and disruptive aspect of the Boldt decision was that the tribes were allocated 50 percent of the fish taken off reservations; fish caught on reservation, for subsistence, or for ceremonial purposes did not count in the 50 percent. The tribes were given a measure of self regulatory powers. Tribes proposed their own regulations and fished accordingly, unless the state could convince a tribe to change the regulations, or unless conservation issues were presented. The state could take enforcement action contrary to tribal regulations only for conservation reasons.

Non-treaty fishermen rebelled against the requirement that could potentially take a majority of the fish from them. Confrontation heightened when the State Supreme Court ruled that the state cannot allocate to treaty Indians as a special user group. Illegal salmon fishing became commonplace as commercial fishermen realized that the state could not enforce the Boldt decision allocations. The Federal District Court assumed direct management control of the salmon fishery for allocative purposes using federal agencies for enforcement.

In April 1975, Judge Boldt convened a hearing on herring, especially concerning sac-roe fishing, to establish authority and responsibility of the tribes and the Department of Fisheries. Judge Boldt ruled that 11 tribes had established rights to fish herring. Fishing for herring under guidelines of the Boldt decision did not reach levels of disarray experienced in the salmon fishery, but control was barely maintained on several occasions.

Finally in 1979, the U.S. Supreme Court heard appeals to the Boldt decision. The highest court upheld the basic Boldt decision, with the exception that reservation fish must be counted as part of the 50 percent allocation to treaty fishermen. Language in the opinion did indicate that the state was the sole regulatory body, but state action over treaty Indians generally was limited to conservation issues. The Supreme Court viewed the 50 percent allocation as the limit of the treaty right. The State Supreme Court subsequently followed with a ruling which allowed the Department of Fisheries to enforce allocation required by the Boldt decision.

LIMITED ENTRY

The Washington state legislature passed Senate Bill No. 2918 in 1973 which limited commercial herring fisheries in Puget Sound to those fishermen who could document landings of herring between January 1, 1971 and April 1, 1973. Fishermen could be validated only for the gear with which they made landings. Following this legislation, several fishermen mounted a legal challenge to the limited entry legislation; judicial review upheld the state's position.

A subsequent bill (Senate Bill No. 3116) in 1974 extended the general validation period to April 15, 1973. The bill also established an additional qualifying period for those persons who had been in the Armed Services during the general qualifying period. Hardship validations and full transferability of permits were allowed. The number of validations stabilized at 34 purse seine (three for bait only), six gillnet, 42 lampara, 46 dipnet, 10 drag (beach) seine, and one brush weir (trap).

When the limited entry legislation was enacted, the Boldt decision had not been handed down. The Boldt decision allowed a major increase in the herring fleet as Indians increased participation. The Indian fleet is currently under no growth restrictions.

DESCRIPTION OF THE FISHERIES

Three commercial fisheries for herring presently occur in Washington state: the Strait of Georgia sac-roe fishery in the spring (Trumble, 1979); the fall-winter fishery in northern Puget Sound for general purpose use (animal food, reduction, bait for longlines and pots); and the year around herring fishery throughout Puget Sound for use as bait by recreational fishermen. Landings since 1957 are presented in Figure 1.

SAC-ROE FISHERY

The sac-roe fish are valuable for their eggs, which are used as a food delicacy in the Orient. This fishery began in Washington in 1973, and is restricted to April and May in the Strait of Georgia and adjacent waters (Figure 2). The sac-roe fishery exploits the largest herring population in Washington state. This population ripens sexually over a several week period, and segments of the population spawn in irregular runs. The fishery is opened several days per week on a set schedule; daily fishing success is related to availability of ripe fish on open days. Nearly all landings are made by purse seine or gillnet. Yearly landings have varied from 2,000 to 4,500 tons.

Limited entry has been effective in the sac-roe fishery only by keeping a too-large non-treaty fleet from becoming larger. The non-treaty fleet has at least twice the catching capacity needed for efficient harvest (Trumble, 1977). Six gill netters and 31 purse seiners vie for approximately 1,000 tons of non-treaty allocation. Limited entry does not apply to the treaty fishermen who had excess catching capacity early in the fishery and continues to grow. The exact size is unknown, but may reach as high as 15 to 18 purse seiners and 200 gill netters in 1980.

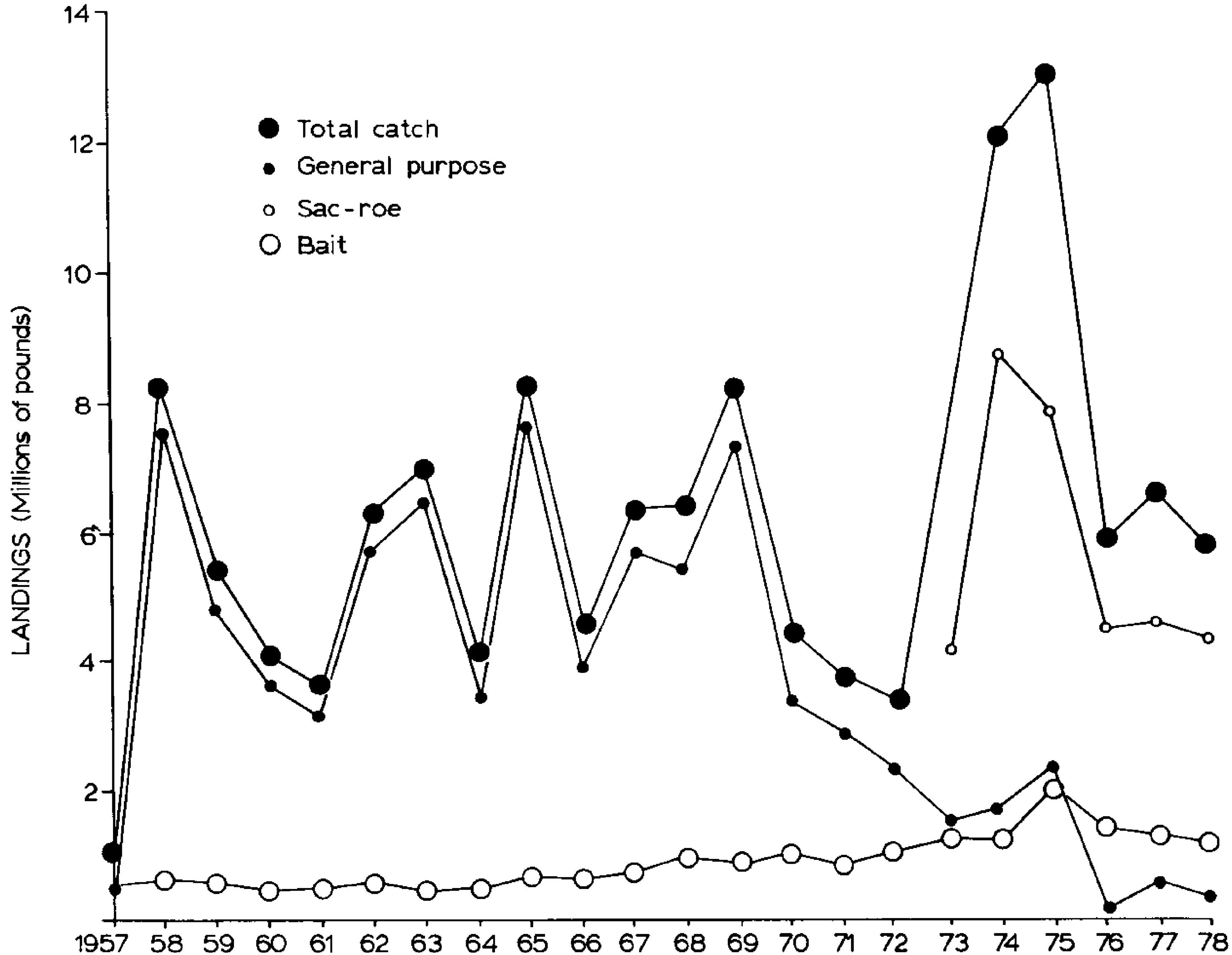

Figure 1. Washington State Commercial Herring Production, 1957-1978.

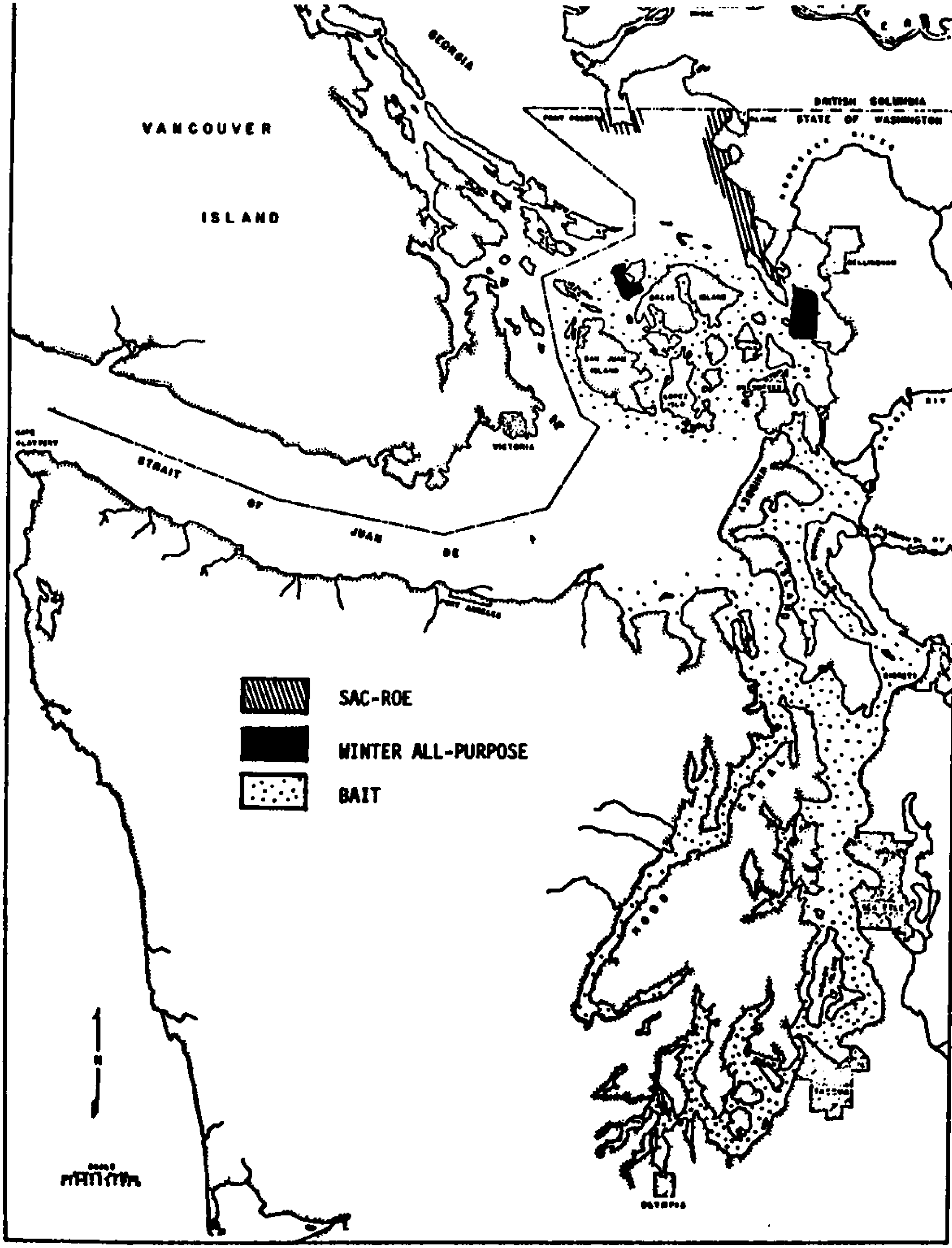

Figure 2. Location of Puget Sound herring fisheries.

As a safeguard, no fishing is allowed unless the total population exceeds, or is expected to exceed, 9,000 tons. The 20 percent harvest rate allows a 1,800 ton catch; smaller harvest quotas become increasingly difficult to manage with the large catching capacity of the fleet. The remaining 7,200 tons of spawning escapement is approximately one-half the maximum observed population size, and is an amount believed to be large enough to produce normal recruitment.

GENERAL PURPOSE FISHERY

Fish caught in the fall-winter general purpose fishery are utilized for zoo food, halibut bait, crab bait, and reduction to fish meal. This fishery, initiated in 1957, occurs from September through February in specified areas of northern Puget Sound (Figure 2). The majority of landings occur in November, December and January. An average of four to six purse seiners harvested from 1,500 to 3,500 tons of herring of mixed size and age annually until declines began in 1970 (Figure 1). The fishery is currently operating on a limited scale, harvesting between 300 and 1,000 tons per year. Large fluctuations in landings common since the beginning have been attributed to market demands and weather conditions. The consistent decline in landings since 1971 may indicate continued poor weather or market conditions culminating in lack of interest by most of the fishermen. However, the declines may also reflect change in migration routes of the herring or a reduction in stock abundance.

Limited entry has had little effect on this fishery. The fishermen of the general purpose fishery are the same as those of the sac-roe fishery, but only a few of the eligible fishermen actually participate. Potential for excess effort is present, but is controlled by market conditions, bad weather and alternate fisheries. During the fall, nearly all eligible seiners participate in the salmon fishery. Many of the herring fishermen leave Washington in November or December to participate in the California sac-roe fishery. Treaty Indians do not participate in the general purpose fishery to a large degree, although eligible tribes have submitted regulations.

SPORT BAIT FISHERY

The herring fishery for sport bait is directed primarily toward juvenile fish, as opposed to adult fish in previously described fisheries. The bait fishery occurs throughout Puget Sound (Figure 2), but most catches are taken from southern Puget Sound and northern Hood Canal. This fishery is unique in Washington state because herring to be used for sport bait must be held alive in pens for several weeks before processing. The bait fishery is conducted primarily with lampara and dip bag net gear. The past five-year average

The sac-roe fishery has the largest participation of Indian fishermen exercising treaty rights to herring under the Boldt decision. In 1975, Boldt ruled that state and tribal regulations must be compatible. During following years, the state and tribes have worked closely on management of this fishery. However, serious disagreements have occurred; in several years, court hearings immediately prior to or during the fishery have been required to settle differences. The state and federal Supreme Courts' review in 1979 should ease management difficulties in future seasons.

Estimates of total sac-roe herring abundance range from a maximum of 14,500 tons in 1973 to a minimum of 9,000 tons in 1979. Abundance is estimated from catch records, spawning escapement estimates, and hydroacoustic techniques.

Biologists representing Washington state, participating tribes, and the University of Washington agreed that a target quota should be 20 percent of the total population. This harvest rate derived from modification of results from a simple population model. Gulland (1970) and Alverson and Pereyra (1969) suggested that preliminary estimates of maximum sustainable yield can be obtained by setting instantaneous fishing mortality (F) equal to instantaneous natural mortality (M). Age composition analysis for the sac-roe population indicates that $M \approx 0.4$. Over a year, total deaths equal $1 - e^{-(F + M)} = 1 - e^{-.8} = 0.55$. One half of the deaths attributable to fishing = 0.55/2 = .28 or 28 percent. Reduction of the fishing deaths from 28 percent to 20 percent is based on the following considerations:

1) The model applies only under cetain conditions not fully met by herring. Herring are known to be susceptible to heavy fishing. Therefore, the model results should be considered an upper limit.

2) Management of herring in Washington recognizes that the herring is an important forage organism, and requires lower fishing mortality than might otherwise be possible.

3) Assessment of stock condition indicates that a series of weak year classes are currently in the fishery, and fishing intensity must be conservative.

4) The 20 percent harvest rate as used since 1975 appears to be effective, and has the support of industry as well as biologists.

of annual landings is about 600 tons, although landings are steadily increasing (Figure 1). Over 50 percent of the total is landed in southern Puget Sound.

The present level of non-treaty fishermen is generally able to meet market demands except during periods of unusual distribution, such as the 1974 and 1978 Puget Sound herring shortages, when the fish are not available because of abnormal migrations. The fishermen have occasionally flooded the market and generated excess inventory. Low prices which resulted restricted additional fishing. The fishery seems limited primarily by market conditions and processing facilities, and not by actual abundance of fish, although localized shortages of fresh or preferred-size bait may occur. Treaty Indians have expressed interest in the bait fishery, and the tribes have submitted regulations for this herring fishery. Several tribal members have tried bait fishing in the past, but no treaty fishermen currently participate.

STOCK ASSESSMENT

Nearly all herring research by the Washington Department of Fisheries is applied to stock assessment needed for management purposes. Stock assessment efforts are most intensive for the sac-roe fishery, in which abundance estimates must be available within a day after collection to set and maintain catch quotas. Population estimates combine three methods: surveys of the spawning grounds provide estimates of spawning escapement; hydroacoustic and midwater trawl surveys estimate pre-spawning herring abundance and provide biological samples; and a computerized catch reporting system provides easily updated records of landings. These methods are applied less intensively to other areas of Puget Sound. An additional project examines the early life history of herring in regions where the herring fishery for sport bait targets primarily on one- and two-year old herring.

JUVENILE HERRING STUDIES

The herring fishery for sport bait targets on fish in the 4-1/2 to 6 inch size range, which are from 9 months to 1-1/2 to 2 years old. Primary reliance on a single age group leads to serious disruptions when that age group has lower than normal availability. A study of herring early life history was implemented in 1975 to look at herring prior to recruitment into the bait fishery (Penttila and Stinson, in prep.).

Research began with intensive plankton tow surveys in southernmost Puget Sound, south and west of Tacoma Narrows, with additional surveys adjacent to spawning grounds in other areas of Puget Sound. High abundance of larvae resulted from concentrating mechanisms, in spite of the low magnitude of the spawning abundance. Large catches of larvae consistently occurred in areas of southern Puget Sound; in contrast, few larvae were caught adjacent to the exposed Strait of Georgia coastline, where the most intensive spawning in Puget Sound takes place.

Larval surveys offered very little predictive information. Efforts subsequently shifted to nearshore surface trawling in southern Puget Sound for young-of-the-year (3 to 6 months) herring during summer. During this period, these herring are very shoreline oriented, and reside near surface at night. Trawling expanded to central Puget Sound, to encompass the area between Olympia and Admiralty Inlet. Early in the summer, most young-of-the-year herring were found near spawning grounds, but dispersed through the summer. Recruitment to the bait fishery in southern Puget Sound appears to depend on migration from several spawning grounds to the north, rather than from local production. Duration of the bait fishery is related to the time the young herring reside in the fishing areas before migrating out.

SPAWNING ESCAPEMENT SURVEYS

The Washington Department of Fisheries began surveys of herring spawning grounds on a regular basis in 1972; more recently, federal and tribal biological staffs have also participated. The surveys, designed to provide a quantitative estimate of herring spawning escapement, follow procedures outlined by Hourston et al. (1972). The basic procedure is to sample vegetation along the shoreline, and note the intensity (egg layers) of spawn deposition. Standardized intensities and lineal distance of spawn are converted to an estimate of spawning escapement (Trumble et al., 1977; Meyer and Adair, 1978).

HYDROACOUSTIC AND MIDWATER TRAWL SURVEYS

Studies to assess Puget Sound herring stocks using hydroacoustic techniques were initiated in 1971 by the Department of Fisheries in cooperation with the Sea Grant Marine Acoustics Program of the Fisheries Research Institute, University of Washington. Through 1976, the surveys were largely developmental and exploratory. Since 1976, the surveys have been more systematic and standardized, and are now an integral part of herring management (Lemberg, 1978).

The hydroacoustic data acquisition system used through 1979 consisted of a modified 105 kH_z Ross 200A echosounder, an interface amplifier that reduces signal frequency from 105 kH_z to 5 kH_z, a Sony TC-377 tape deck which records the data on magnetic tape, and an oscilloscope to monitor system operation (Thorne, Nunnallee, and Green, 1972; Nunnallee 1973). The transducer is a downward projecting 7-1/2 degree conical beam model manufactured by Ross Laboratories. In 1980, the Ross 200A was replaced by a Biosonics 101 echosounder, which offers solid state electronics, higher accuracy, and improved reliability.

Periodic calibration of the echosounder and transducer is conducted by the Applied Physics Laboratory, University of Washington. During field operation a signal generator built into the unit is used to monitor and calibrate sounder receiver and tape deck gain.

The acoustic data is processed by the echo integration method with the aid of a PDP 11/45 computer (Thorne, 1977). A mean target strength of -33 dB for one kilogram of herring (wet weight) is used by the echo integration program to scale the fish echoes into estimates of absolute density (Thorne and Drew, 1975). Since target strength of Puget Sound herring has not been measured directly, -33 dB is a best estimate derived from comparisons of net haul and acoustic density. Direct target strength measurements conducted on Atlantic herring suggest that -33 dB is a reasonable mean value for the size range of herring sampled in Puget Sound (Nakken and Olsen, 1973).

Computer output is in the form of fish density (kg/m^3) at preselected depth intervals for each transect. The bottom is tracked automatically during processing, and integration is usually terminated 10 meters above the bottom. Biomass estimates are made by accumulating density within a depth zone (usually 5 to 40 meters below the surface) for each transect, and extrapolating the mean value (kg/m^2) over representative surface areas.

A midwater trawl series is conducted for each acoustic survey to obtain species composition and herring biological data. This information is used to apportion total acoustic biomass by species and by maturity category.

All trawl work is conducted at night to avoid heavy daytime concentrations; at night, Puget Sound herring form a layer which spreads over a wide area. Trawling takes place from a chartered commercial trawler. Through 1979, the Department used a four panel midwater trawl with 6.1 meter by 6.1 meter (20 feet) mouth opening and a 1.27 centimeter

(1/2 inch) stretch mesh codend liner. In 1980, this net was replaced by a rope trawl with 12.2 meter (40 feet) by 18.3 meter (60 feet) mouth opening.

During the roe fishery, echosounding and trawling are conducted at the same time using two vessels. Trawling locations were directed from the acoustic vessel on the basic target distributions and densities observed along transects. In other areas of Puget Sound, trawling and acoustic transecting may be conducted from a single vessel.

CATCH RECORDS

Summary records of daily landings from the sac-roe fishery, broken down by treaty-nontreaty must be readily available to all participants in order to maintain allocations and avoid overfishing. The Department of Fisheries has a computerized data retrieval system for preliminary catch statistics. Telephone reports of daily estimated catch, by noon of the day following the catch, are required from each buyer of sac-roe herring. These telephone reports are the primary data source. Telephone reports are replaced and catch data updated when fish receiving tickets arrive. Summary reports can be obtained by accessing the computer (Table 1).

ABUNDANCE ESTIMATION

Spawning escapement estimates, hydroacoustic and midwater trawl results, and catch records are combined throughout the sac-roe fishery to gain information about the progress of the fishery and the status of the stock. These data permit several computations of total population abundance. The simplest and most direct method is the sum of catch plus spawning escapement. Hydroacoustic surveys allow refinement of the population estimate. Acoustic-estimated abundance represents fish remaining to spawn, while cumulative catch and cumulative spawning escapement account for fish removed from the spawning population. The sum of the three offers a point estimate of total abundance. An average of point estimates through the season represents the best estimate of total abundance for the season. Figure 3 presents changes in acoustic estimates, catch, spawning escapement, and total estimated abundance throught the 1979 season. Point estimates of total abundance within a year agree closely. Figure 4 summarizes the yearly estimates for 1973 to 1979. For the four years of the fishery in which hydroacoustic estimates have been made, the final estimate of spawning escapement plus catch has been within 10 to 15 percent of the estimate using hydroacoustics.

Table 1. Final soft data system run, 1978 sac-roe herring fishery.

Day	Date	H/S[1]	Non-treaty tons Daily	Non-treaty tons Cumm.	Treaty tons On-reservation Daily	On-reservation Cumm.	Off-reservation Daily	Off-reservation Cumm.	Treaty Total Daily	Treaty Total Cumm.	Total Daily	Total Cumm.
Wed.	04/19	H	247.62	247.62	.00	.00	106.80	106.80	106.80	106.80	354.42	354.42
Thur.	04/20	H	88.59	336.21	.00	.00	33.68	140.48	33.68	140.48	122.27	476.69
Mon.	04/24	H	21.83	358.03	.00	.00	53.36	193.84	53.36	193.84	75.19	551.88
Tue.	04/25	H	.00	358.03	.00	.00	3.26[2]	197.10	3.26	197.10	3.26	555.13
Wed.	04/26	H	159.55	517.58	.00	.00	173.55	370.65	173.55	370.65	333.10	888.23
Thur.	04/27	H	288.35	805.93	.00	.00	143.28	513.93	143.28	513.93	431.63	1819.86
Mon.	05/01	H	48.66	854.59	.00	.00	188.61	702.54	188.61	702.54	237.28	1557.14
Tues.	05/02	H	.00	854.59	17.89	17.89	.68[2]	703.23	18.58	721.12	18.58	1575.72
Wed.	05/03	H	15.18	869.78	7.51	25.41	55.15	758.38	62.66	783.78	77.85	1653.56
Thur.	05/04	M	144.87	1014.64	.19	25.60	11.63	770.00	11.82	795.60	156.68	1810.24
Sun.	05/07	H	.00	1014.64	.25	25.85	1.54[2]	771.55	1.80	797.40	1.80	1812.04
Mon.	05/08	H	265.95	1280.59	1.10	26.96	55.43	826.97	56.53	853.93	322.48	2134.52
Total				1280.59		26.96		826.97		853.93		2134.52

[1] H=hard data, M=hard and soft data.

[2] Closed day, misreported landings.

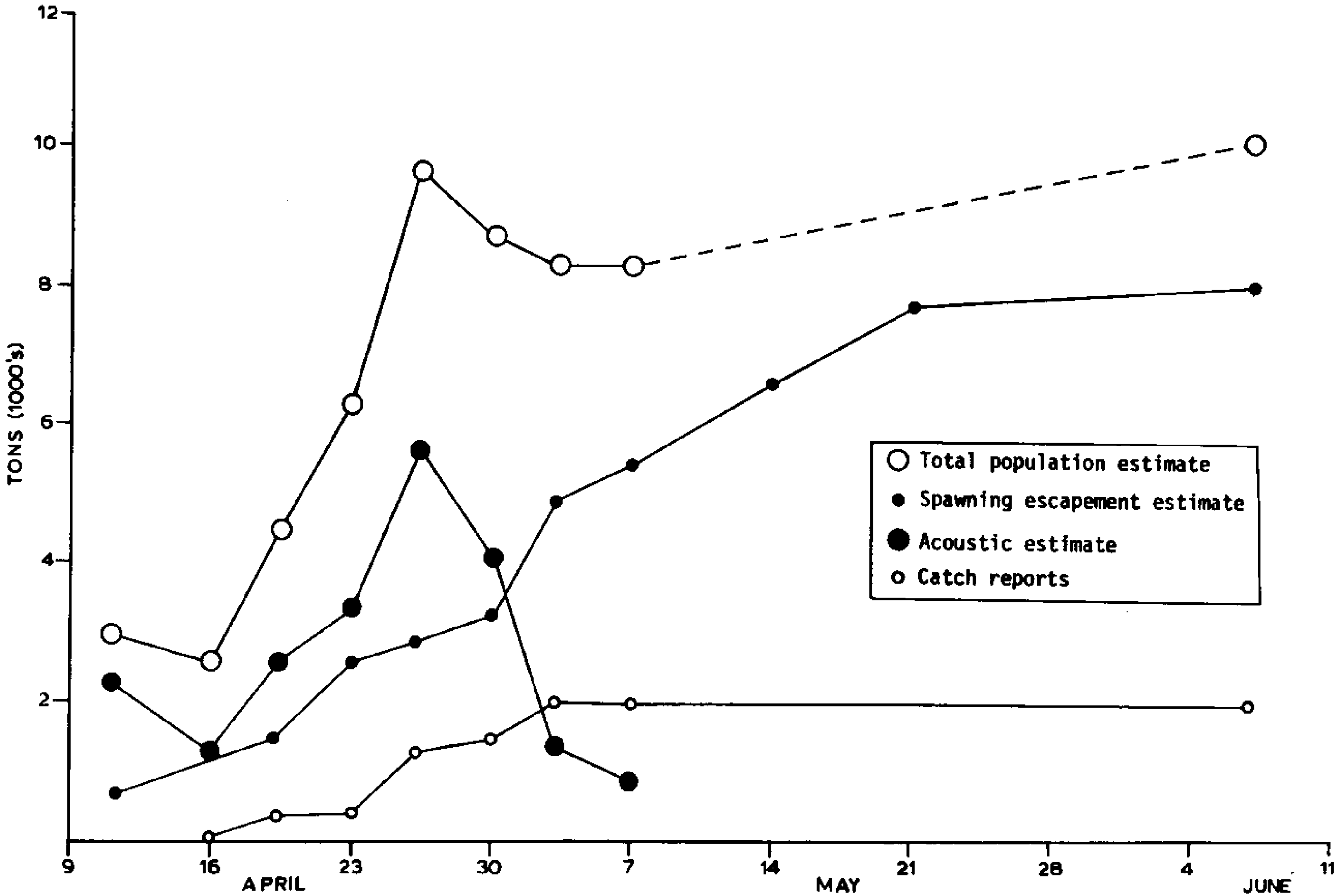

Figure 3. Summary of 1979 sac-roe herring population estimates.

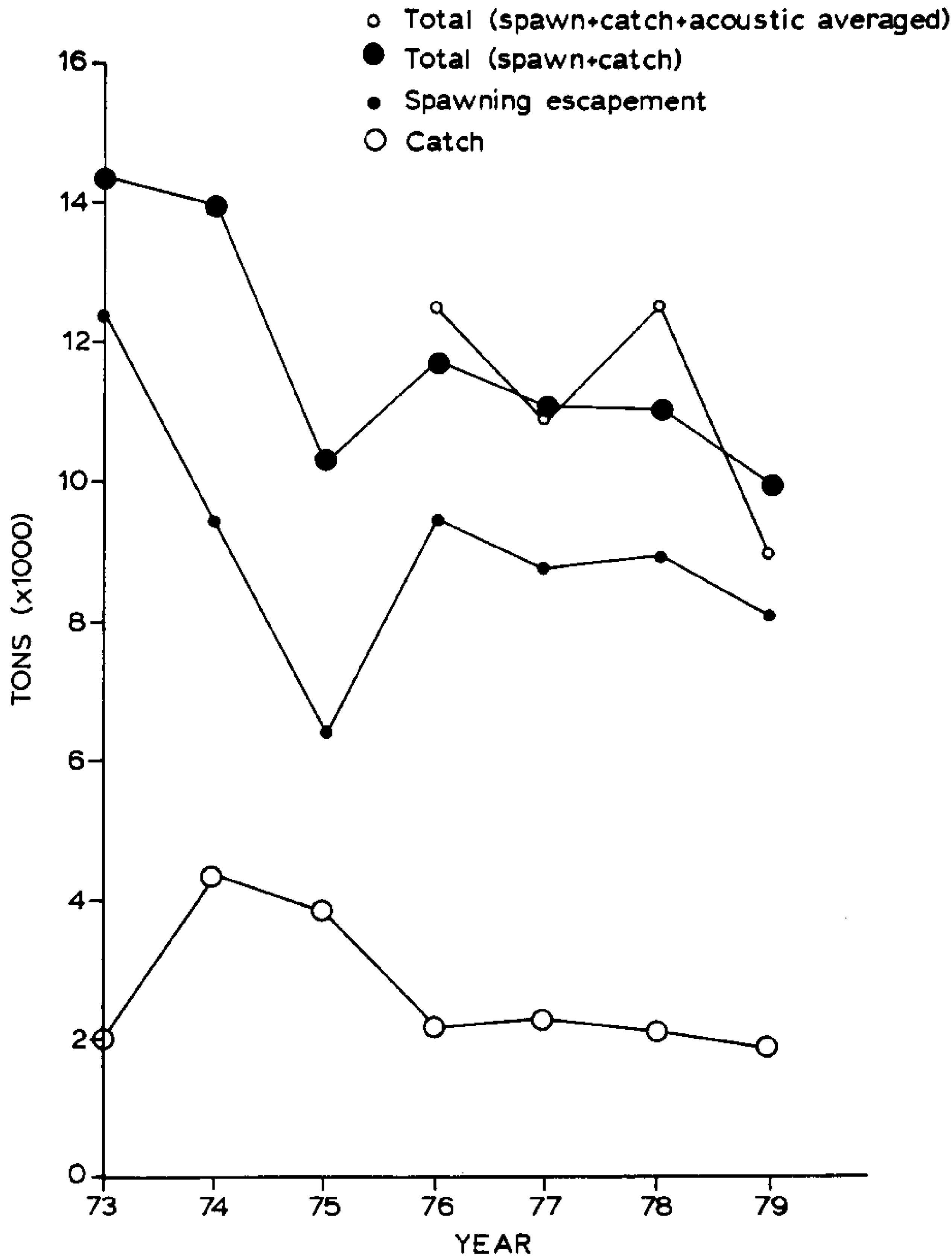

Figure 4. Sac-roe herring abundance estimates, 1973-1979.

BIOLOGICAL CHARACTERISTICS

Commercial fisheries and research cruises provide samples for analysis of biological data. Samples are analyzed for length, weight, sex, sexual maturity, and age using scales. With abundance estimates from hydroacoustics, catch records, and spawning escapement surveys, we can investigate age-specific abundance fluctuations within areas. Comparisons can be made for biological parameter differences between areas.

Age composition data are collected for all areas of Puget Sound, but are most complete for the intensively fished sac-roe herring population. Figure 5 shows fluctuations in year class strength for the Strait of Georgia from 1973 through 1979. Three strong year classes dominated the early years of the fishery. The 1969, 1968, and 1967 year classes provided the bulk of fish present in 1973 and 1974, the years of peak abundance. Weaker, subsequent year classes, especially 1970, 1971, and 1973, led to a decline of the population that has continued to the present (Figure 4). The strong 1975 year class recruited as 3-year-olds in 1978, while most year classes recruit at age 4; this strong recruitment, a year early, stopped an abundance decline which would have otherwise prevented the fishery in 1978. In general, recruitment has been too low for the population to grow, and 1979 estimates show the lowest abundance on record. These declines are caused by natural cycles, but are increased by fishing activity.

Length-at-age data for herring caught shortly before the spawning season from three areas of Puget Sound were fit to the von Bertalanffy growth equation, and compared statistically using a least squares technique (Kimura, in press). Analysis included data from two areas of southern Puget Sound (Case Inlet and Hale Passage-Carr Inlet) collected by midwater trawling in November and January, from 1974 to 1977, and data from the Strait of Georgia obtained from sac-roe herring commercial purse seine catches from 1973 to 1976. Comparison of the data from the three areas (Figure 6) shows Strait of Georgia herring consistently larger (L_∞ = 263mm) and continually growing (K = 0.36). In contrast, fish from Case Inlet grow rapidly to age 3 (K = 0.59), then grow very slowly to a small size (L_∞ = 197). Fish from Hale Passage-Carr Inlet show intermediate size (L_∞ = 230) and growth rate (K = 0.48). Two of the three von Bertalanffy growth parameters, L_∞ and K, showed significant differences between the three areas at the 1 percent level when compared using least squares analysis.

Growth characteristics previously described for Case Inlet, Hale Passage-Carr Inlet, and the Strait of Georgia

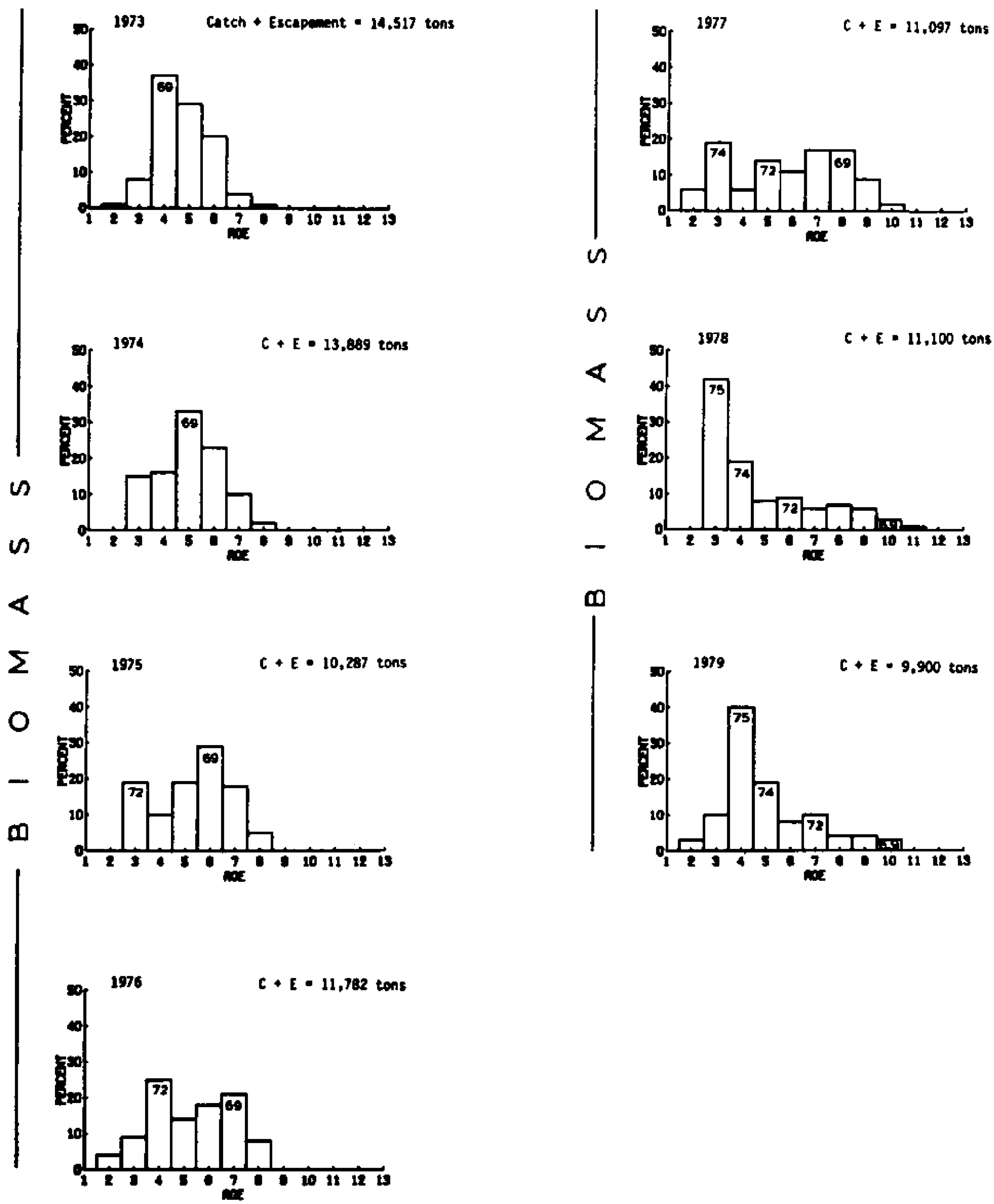

Figure 5. Age composition of 1973 through 1979 Gulf of Georgia spawning population in terms of percent of biomass, as deduced from weekly seine market sample data weighted by weekly run size (total catch plus spawning biomass).

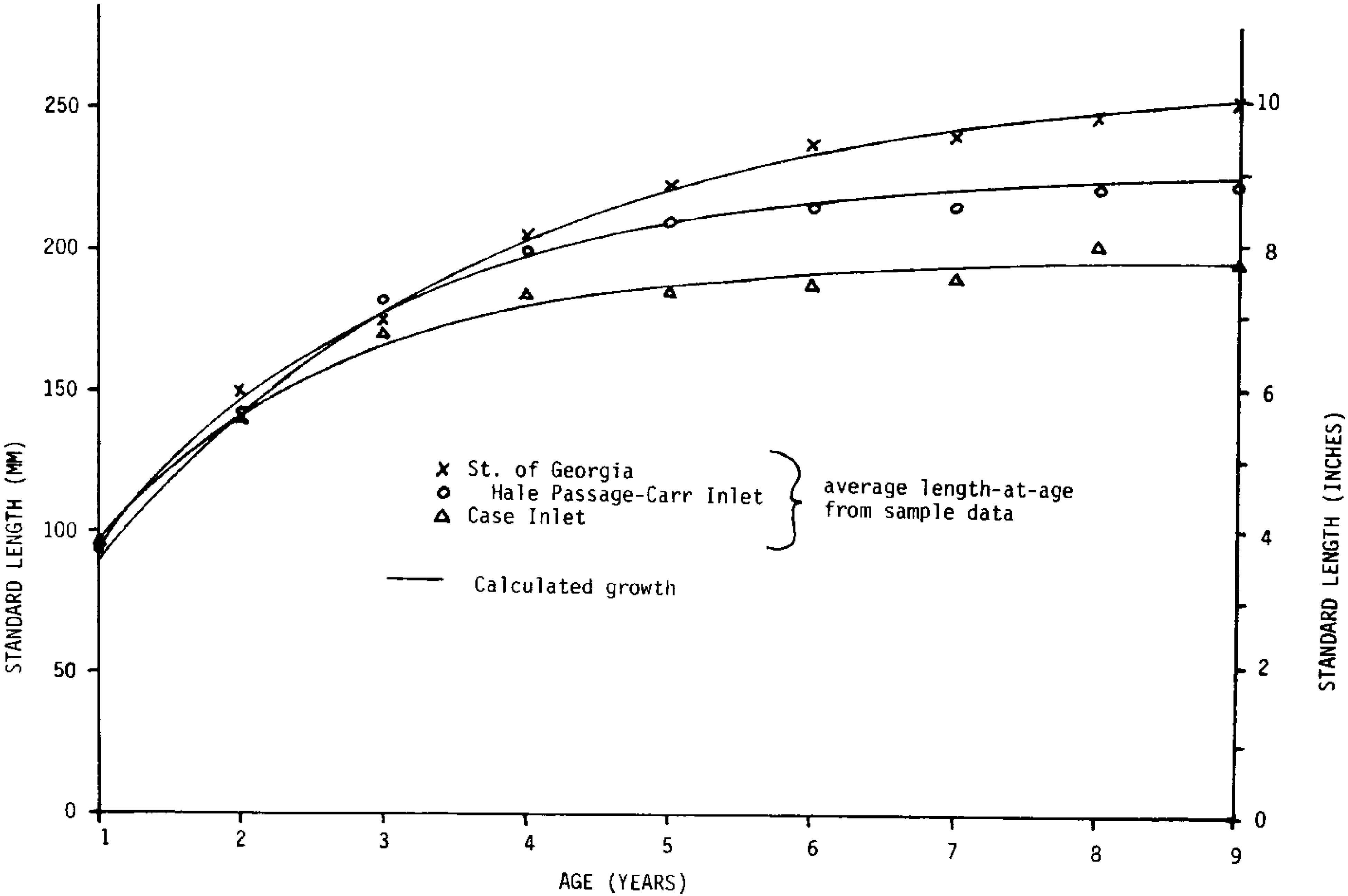

Figure 6. Growth of Pacific herring from three areas of Puget Sound, calculated from the von Bertalanffy growth equation compared to averages of actual data.

also show up on scales. Additionally, the character and quality of scales vary by area. In general, Case Inlet scales show rapid growth for early years and very little growth after age 3; each annulus is very clear and easy to distinguish from other annuli. Hale Passage-Carr Inlet fish share the clear, easy to read annuli with their southern Puget Sound neighbors, but are distinguished by growth continuing as the fish ages. Fish from the Strait of Georgia typically have a small diameter first annulus, relative to later growth rings; growth continues in subsequent years in a manner similar to Hale Passage-Carr Inlet. Strait of Georgia fish are also separated from other herring because scale quality is very bad in terms of clarity and reliability. False annuli are common and make age determination difficult. Strait of Georgia scale quality is further reduced by blurred or indistinct annuli, and by scales which have regenerated to replace lost scales. Scale patterns do not develop consistently enough to identify individual fish to a distinct population, but an experienced scale reader can often distinguish samples of fish from areas for which experience has been gained.

Consistent differences between growth rates and scale patterns for areas of Puget Sound strongly suggest that the areas may contain separate populations of herring. Other circumstantial evidence supports this conclusion. Spawning timing and location occurs very consistently throughout Puget Sound. The magnitudes of abundance estimates for various areas remain consistent year after year. Infestation of the roundworm parasite Anasakis occurs much more heavily for the sac-roe herring than for herring elsewhere in Puget Sound.

The Department of Fisheries contracted an electrophoretic analysis of spawning herring from California to British Columbia, to determine if biochemical genetics could identify separate populations. The contract report included herring from Alaska and Asia, as well (Grant, M.S., 1979). The study identified 40 loci. At each locus, likelihood analysis was used to test for within-and-among-regional heterogeneity. Nei's index of gene identity was calculated from allele frequencies at 40 loci for each sample pair. The study identified major genetic differences between eastern and western North Pacific stocks, but showed little genetic differentiation within the major regions (Figure 7).

The electrophoretic study does not prove that separate stocks do not exist in the eastern North Pacific, but strongly suggests that straying between populations is sufficient to keep the gene pools mixed. However, the circumstantial evidence supporting presence of separate stocks indicates that straying is not great enough to break down the consistent patterns of behaviour displayed by herring in many areas.

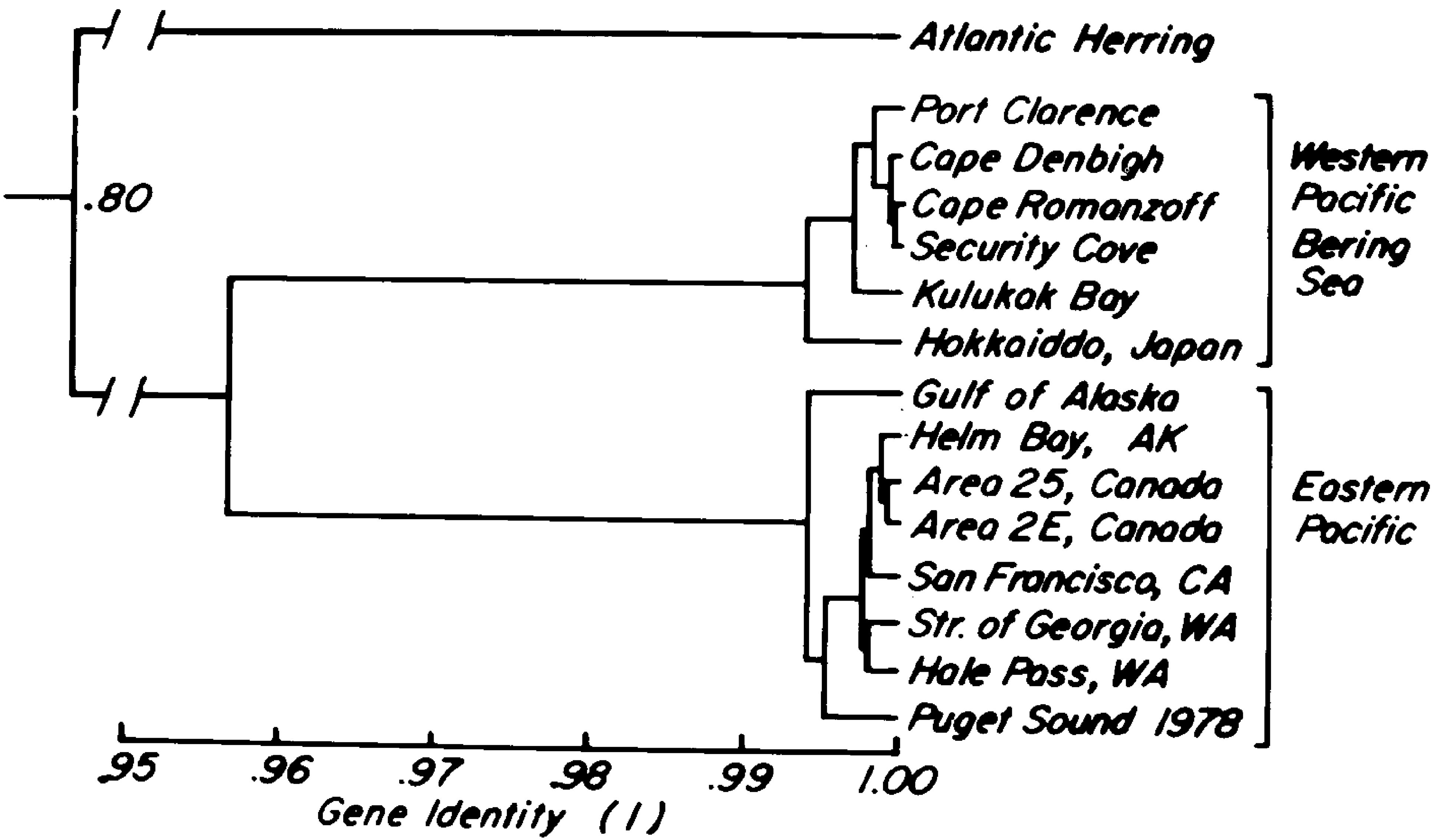

Figure 7. Dendrogram based on Nei's index of gene identity (I) of samples of herring collected from the eastern North Pacific Ocean.

OFFSHORE HERRING FISHING

At the present time, fishing for herring does not occur in open ocean areas off the coast of Washington state. Responsibility for managing fisheries in the U.S. 3 to 200 mile Fishery Conservation Zone (FCZ) off Washington, Oregon and California falls with the Pacific Fishery Management Council (PFMC). Such management, however, cannot occur for domestic fisheries until a Fisheries Management Plan has been prepared by the PFMC and accepted by the Department of Commerce. Washington state closed its offshore waters to herring fishing until the PFMC can assume authority.

The team of scientists preparing the Fishery Management Plant for herring identified a serious lack of information for the offshore phase of the herring life cycle. Two experiments were conducted in 1979 to gain data on offshore herring. The first was a hydroacoustic-midwater trawl research cruise conducted off the northern Washington-southern Vancouver Island coasts (Nunnallee, et al., in prep.); the second was an experimental offshore herring fishery along the northern coast of Washington state (Trumble and Pedersen, M.S., 1980).

The research cruise took place from late August through mid-October as a cooperative effort between the United States, Canada, and the state of Washington. The survey design consisted of systematic east-west transects of two to four mile spacing; when aggregations of fish were located, a zig-zag search pattern was used to define limits of the distribution. Approximately 200,000 metric tons of herring were estimated during this survey (Table 2), with 80 to 90 percent being adults (age 3 or older). Over 160,000 metric tons were located in Canadian waters, primarily on La Perouse Bank, with smaller quantities at Swiftsure Bank. The majority of herring in U.S. waters were found at Cape Flattery Spit.

Experimental herring fishing in offshore waters of Washington state was designed to supplement biological data from the research cruise, and to add commercially oriented information such as catch rates, quality, utilization, and market potential for the offshore herring resource. The fishery was limited to the northern Washington coast, and up to four vessels could participate at any time by obtaining a special permit. An observer was required to be on board during all herring fishing. Almost no herring fishing occurred during the July to November experimental period, and only two tons of a 1,500 ton quota were landed. Participating fishermen blamed lack of adequate gear and lack of market as the reasons for low catches. The experiment was

Table 2. Estimated mean densities, Std. Dev. and biomasses for the four aggregations of herring defined during the 1979 US - Canadian herring survey.

Aggregation Area	Area (NM^2)	Mean Dens. (Kg/m^2)	Std. Dev. Cluster	Std. Dev. Simple	Biomass (MT)
La Perouse (upper)	23.2	0.198	0.033	0.030	15,746
La Perouse (lower)	35.0	0.825	0.184	0.062	99,000
Swiftsure Bank	56.7	0.348	0.068	0.045	67,675
Cape Flattery Spit	54.0	0.168	0.055	0.055	31,118
			TOTAL		213,539

useful to identify factors presently limiting the fishery, but did not provide useful biological, catch rate, or utilization data.

The Herring Plan Development Team will use biological and socioeconomic data relating to herring and herring fisheries to prepare management alternatives for the PFMC. Following a series of public reviews and hearings, the Regional Council will recommend, and the Secretary of Commerce will adopt regulations to prohibit or allow herring fishing in the FCZ.

REFERENCES

Alverson, D. L. and W. T. Pereyra. 1969. Demersal fish explorations in the northeastern Pacific Ocean - an evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. J. Fish. Res. Board Can. 26: 1185-2001.

Grant, S. 1979 (MS). A search for biochemical genetic markers for stock identification of eastern north Pacific herring. Contract Completion Report, Wash. Dept. Fisheries. 18 pp.

Gulland, J. A. 1970. The Fish Resources of the Ocean. Fishing News (Book) Ltd., Surrey, England.

Hourston, A. S., D. N. Outram and F. W. Nash. 1972. Millions of eggs and miles of spawn in British Columbia herring spawnings 1951 to 1970. (Revised 1972). Fish. Mar. Serv. Res. Dev. Tech. Dept. No. 359: 154 pp.

Kimura, D. K. In press. Likelihood methods for the von Bertalanffy growth curve. Fish. Bull., U.S. 77(4).

Lemberg, N. A. 1978. Hydroacoustic assessment of Puget Sound herring, 1972-1978. Wash. Dept. Fish. Tech. Rept. No. 41: 43 pp.

Meyer, J. H. and R. A. Adair. 1978. Puget Sound herring surveys, including observations of the Gulf of Georgia sac-roe fishery, 1975-1977. U.S. Fish and Wildl. Serv., Olympia, WA: 71 pp. plus appendix.

Nakken, O. and K. Olsen. 1973. Target strength measurements of fish. ICES/FAO/ICNAF. Symposium on acoustic methods in fisheries research, Bergen, June 1973 (contribution No. 24): 33 pp.

Nunnallee, E. P. 1973. A hydroacoustic data acquistion and digital data analysis system for the assessment of fish stock abundance. Univ. Wash. Fish. Res. Inst., Circ. 73-3. 47 pp.

Nunnallee, E. P. (and others). in prep. Joint U.S.-Canada herring survey off Washington state and Vancouver Island, August to October, 1979. National Marine Fisheries Service, NWAFC. Seattle.

Penttila, D. E. and M. A. Stinson. in prep. Juvenile herring studies in southern Puget Sound, Washington, 1976-1977. Wash. Dept. Fish.

Thorne, R. E. 1977. A new digital data processor and some observations on herring in Alaska. J. Fish. Res. Bd. Canada. 34: 2288-2294.

Thorne, R. E., and A. W. Drew. 1975. Acoustic assessment of baitfish stocks in Puget Sound. Univ. Wash. Fish. Res. Inst., UW-FRI-7510. 8 pp.

Thorne, R. E., E. P. Nunnallee, and J. H. Green. 1973. A portable hydroacoustic data acquisition system for fish stocks assessment. Wash. Sea Grant Publ. 72-4. 14 pp.

Trumble, R. J. 1977. Effects of limited-entry legislation on management of Washington state commercial herring fisheries. Wash. Dept. Fish. Prog. Rept. No. 12. 35 pp.

Trumble, R. J. 1979. Summary of the 1978 herring fishery for sac-roe in northern Puget Sound. Wash. Dept. Fish. Prog. Rept. No. 83. 25 pp.

Trumble, R. J. and M. G. Pedersen. 1980 (MS). Summary of the 1979 experimental offshore herring fishery with results of observer coverage of herring and groundfish fishing activities off the Washington coast. Wash. Dept. Fish. 22 pp.

Trumble, R. J., D. Penttila, D. Day, P. McAllister, J. Boettner, R. Adair, and P. Wares. 1977. Results of herring spawning ground surveys in Puget Sound, 1975 and 1976. Wash. Dept. Fish. Prog. Rept. No. 21. 28 pp.

A REVIEW OF THE HERRING FISHERIES, THEIR ASSESSMENT, AND MANAGEMENT IN THE GEORGES BANK - GULF OF MAINE AREA

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INTRODUCTION

Atlantic herring (Clupea harengus harengus L.) have been harvested from inshore waters along the New England coast for at least 400 years. The Indians had herring weirs along the Maine coast before the Europeans arrived and the Plymouth Colony had a herring weir at least as early as 1641. During the seventeenth century, herring were caught for trade from North Carolina to Newfoundland. The major fishery for herring in the Northwest Atlantic during the early part of the nineteenth century was for large herring in eastern Maine. The canning of "sardines" began in 1875 and was the leading fishery for herring through the first half of the twentieth century. The catch in the Northwest Atlantic (Newfoundland and south) from 1920 to about 1940 remained fairly constant, fluctuating between 60,000 and 100,000 metric tons (Figure 1). In 1948, however, the catch increased to 242,000 tons and then gradually declined to an approximate level of 180,000 tons through the 1950s. During the 1960s the catch increased dramatically to over 900,000 tons as new fisheries developed. The very important Georges Bank fishery began in 1961, the Nova Scotia adult purse seine fishery began in 1964-1965, the Gulf of St. Lawrence fishery intensified after 1965, and the Western Gulf of Maine - Jeffreys Ledge fishery for adult herring began in 1967 (Figure 2, Table 1).

There are three adult fisheries in the Georges Bank - Gulf of Maine area and two inshore juvenile fisheries. The two juvenile fisheries occur, respectively, from Portland, Maine, to the Canadian border and from the border to St. John, New Brunswick. The adult fisheries are those on Georges Bank, Jeffreys Ledge (western part of the Gulf of Maine) and off southwestern Nova Scotia. All three adult herring fisheries began as autumn fisheries harvesting spawning herring of age 4 and older (herring generally greater than 25 cm total length). Gradually the fisheries changed to using various gear types and fishing throughout the year.

The Georges Bank fishery collapsed in 1977, and catches were significantly reduced in the Jeffreys Ledge and Nova Scotia fisheries by 1978-1979 (Table 1).

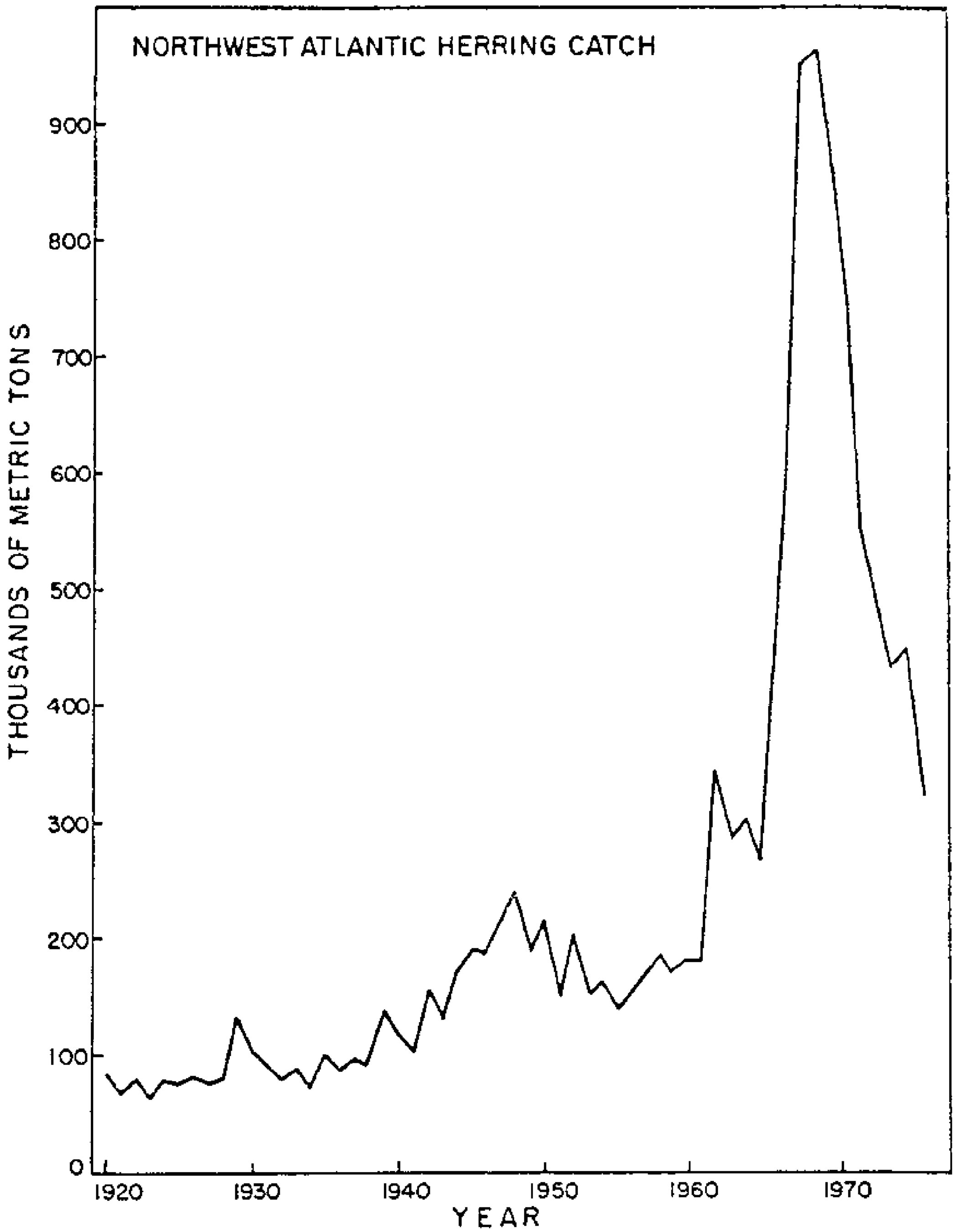

Figure 1. Catches of herring (*Clupea harengus*) from the Northwest Atlantic.

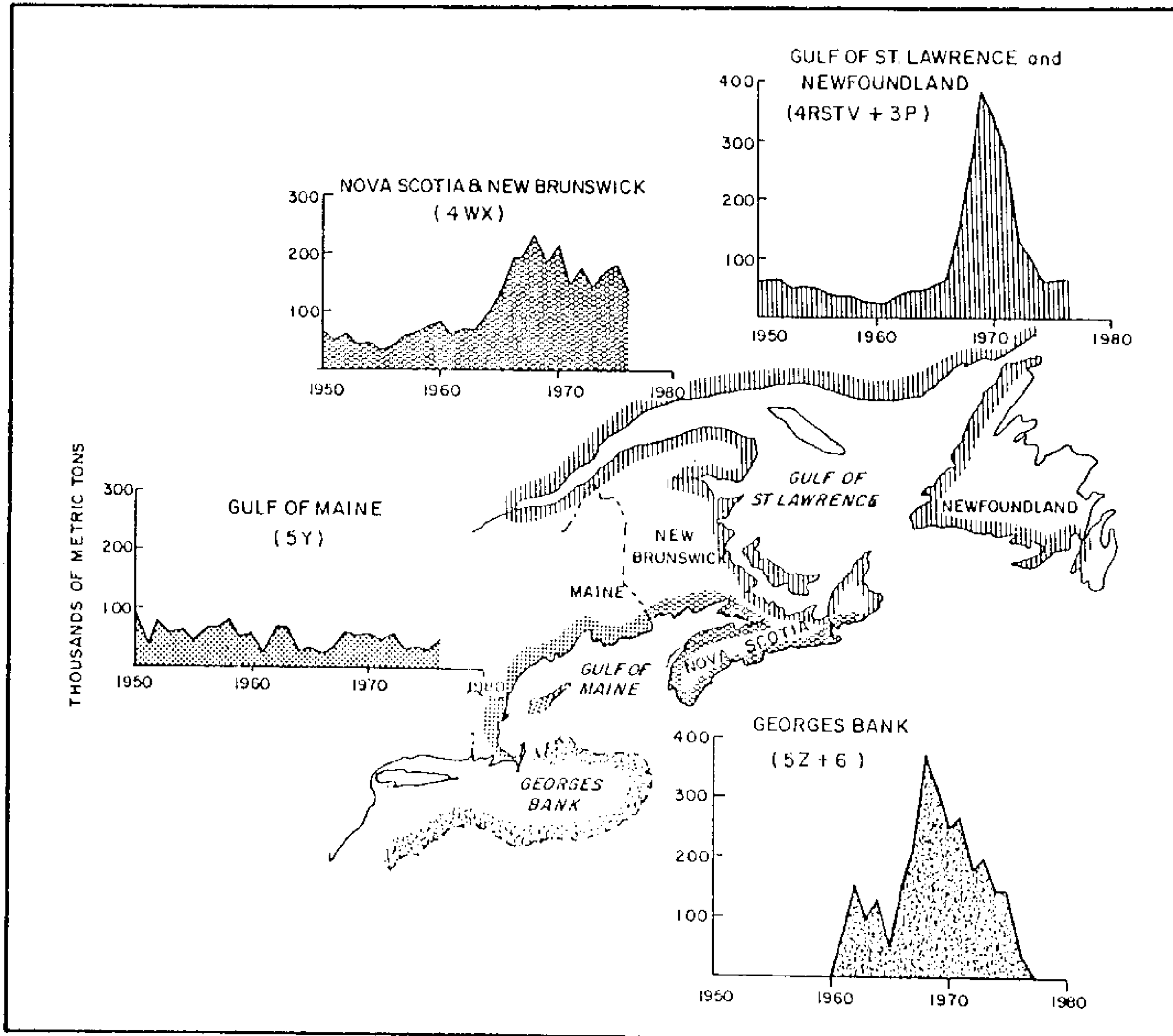

Figure 2. Catches of Atlantic herring from the major areas of the Northwest Atlantic.

Table 1. Herring catches in major fishing areas of the Northwest Atlantic for the years 1950 through 1979

	METRIC TONS						
	Maine Juvenile Fishery	Gulf of Maine Adult Fishery	Georges Bank (5Z & 6)	New Brunswick (4WX) Juvenile	Nova Scotia (4WX) Adult	Gulf of St. Lawrence and Newfoundland (4RSTV & 3P)	Total
1950	90,557	3,661		62,981[1]		60,707	217,906
1	34,411	1,305		51,316[1]		64,671	151,703
2	79,139	1,596		62,399[1]		64,555	207,691
3	58,337	2,032		44,961[1]		49,632	154,962
4	64,067	1,303		46,716[1]		54,706	166,792
5	43,506	1,561		33,313[1]		52,304	131,184
6	66,494	2,038		21,533	22,712	41,547	154,344
7	68,623	3,007		33,733	27,114	36,479	168,956
8	80,759	3,182		18,854	46,444	38,156	187,395
9	53,037	1,472		47,762	28,771	28,943	159,985
1960	59,348	1,126		49,563	32,216	27,401	169,654
1	24,131	3,178	67,655	18,614	41,272	23,188	178,038
2	69,376	2,485	152,242	34,403	35,367	48,568	342,441
3	66,895	5,217	97,968	41,450	27,233	46,354	285,117
4	26,295	8,815	131,438	49,748	44,851	46,899	308,046
5	32,088	2,635	42,882	49,101	82,074	56,340	265,120
6	26,177	4,360	142,704	61,593	150,501	65,316	450,451
7	28,576	7,807	218,743	50,920	140,689	145,966	592,701
8	31,072	31,900	373,598	79,094	151,238	278,651	945,553
9	25,852	32,406	310,758	44,832	137,267	383,903	935,018
1970	15,617	40,187	247,294	33,134	178,422	337,920	852,574
1	12,408	38,575	267,347	17,513	128,450	279,038	743,331
2	19,498	42,918	174,190	33,046	144,230	130,206	544,088
3	16,400	15,926	202,335	27,314	112,515	103,929	478,919
4	19,142	18,098	149,310	29,159	143,590	62,194	421,693
5	15,182	21,530	146,096	25,020	158,125	63,294	429,247
6	30,195	20,125	43,307	33,234	102,670	66,072	295,803
7	32,357	17,891	2,157	24,724	111,465	70,391	259,485
8	29,858	18,558	2,059	39,882	89,565	65,000[2]	244,720
9	40,218	25,508	1,090	36,199[2]	80,000[2]	65,000[2]	246,015
TOTAL	1,257,615	376,424	2,773,573	1,202,411	2,196,579	2,858,330	10,664,932

[1]Can't be separated into juvenile and adult

[2]Preliminary figures

Juvenile herring of ages 1 and 2 are rarely caught in the area of the adult fisheries. Recruitment to the adult fisheries begins at about age 3. Juvenile herring are concentrated in commercial quantities only along the Maine and New Brunswick coasts (and in limited amounts along the southeastern shore of Nova Scotia) where they have provided the basis for important fisheries since 1875.

These fisheries are the major herring fisheries south of the Gulf of St. Lawrence. ICNAF (International Commission for the Northwest Atlantic Fisheries) attempted to manage the three adult fisheries of Georges Bank, Nova Scotia, and the western Gulf of Maine beginning in January 1972. In spite of catch quotas, the abundance declined in all three areas (except for the brief period of recruitment of the 1970 year class), and the catch from the Georges Bank fishery since 1976 has been nearly zero.

The purpose of this paper is to review the development, assessments, interaction, and management of these fisheries.

HISTORY OF THE FISHERIES

The majority of Atlantic herring caught along the Maine and New Brunswick coasts since 1875 have been of the age groups 1-3 from a fishery selective to age 2 herring, of about 17 cm total length. The capture of larger fish has been of minor importance. Stop seines and purse seines have been the primary gear type in western and central Maine. Purse seines are used only for catching the larger herring which tend to remain in deeper waters or for the small herring in those years when they are not available to the inshore gear (stop seines or weirs). Purse seines tend to smother the young herring and reduce their quality which must be kept at a high level in canning young herring as "sardines." In eastern Maine and New Brunswick, weirs are used to take almost all of the juvenile herring for the "sardine" industry.

The catch of herring in the Maine juvenile fishery has fluctuated greatly since 1880 (Figure 3, Table 1). From 1896 to 1916, the catch averaged around 60,000 tons, then declined to around 25,000 tons from 1917 to 1940, after which the catch increased again. From the late 1940s through the 1950s, the catch resembled that from 1896 to 1916 at about 60,000 tons per year. From 1964 to 1969, the catch was consistently low at about 28,000 tons, and from 1970 to 1975, the catch along the Maine coast averaged only 17,400 tons. From 1976 to 1979, the Maine juvenile fishery began to improve again with catches varying from 30,000 to 40,500 tons.

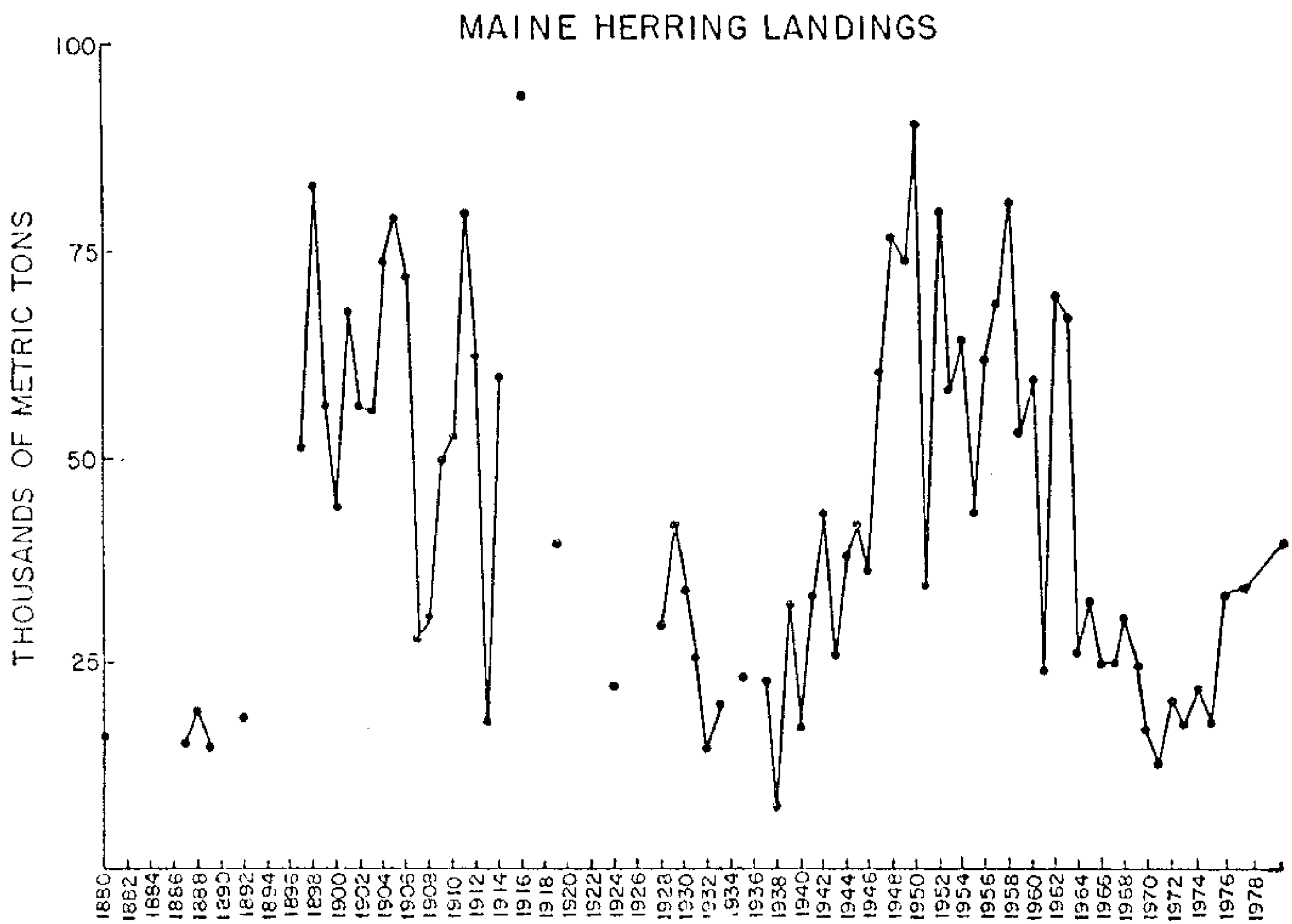

Figure 3. The catch of Atlantic herring along the coast of Maine used primarily by the sardine industry.

The New Brunswick juvenile fishery has fluctuated in a similar fashion to that in Maine, although at a higher level of catch. The catch of herring from the New Brunswick juvenile fishery averaged 55,800 tons from 1964 to 1969, 28,000 tons from 1970 to 1976, and 33,600 tons from 1977 to 1979.

The Gulf of Maine fishery for adult herring (mainly in the Cape Ann - Jeffryes Ledge area) began in 1967 with catches of 7,800 and 31,900 tons in 1967 and 1968, respectively. Catches averaged 38,500 tons from 1969 to 1972 as the accumulated stock was harvested heavily. From 1973 to 1979, catches were dependent on surplus production and ranged only between 16,000 and 24,000 tons. The adult fisheries of the Gulf of Maine have employed small side trawlers with bottom otter trawls, pair trawls, and purse seines.

Prior to 1975, the fishery was exploited primarily during the autumn on the spawning grounds by both the domestic and distant water fleets (Table 2). Since 1975, the catch has been taken principally by US fishermen, and a newly-developed pair trawl fishery began during the winter-spring period. This winter fishery harvests overwintering and migrating herring from the Gulf of Maine and Southwest Nova Scotia stocks. The area of fishing was also expanded to the south into Massachusetts and Cape Cod bays. Catches during the winter-spring period increased from 5,400 tons in 1975 to 13,000 tons in 1977 but declined to 6,600 tons in 1979. During the period 1975 to 1979, the winter-spring catches accounted for 43 percent (tons) of the annual catch.

The herring fishery off southwestern Nova Scotia has been in existence since the 1800s. It began as a gillnet fishery, with a weir fishery developing around 1820 and a purse seine fishery about 1940. In recent years, there have been seven different herring fisheries in the Bay of Fundy - Nova Scotia area (Miller and Iles, 1975). In addition to the New Brunswick juvenile weir fishery already mentioned, there exists a New Brunswick purse seine - midwater trawl fishery, a Nova Scotia purse seine fishery, a Nova Scotia weir fishery, a Nova Scotia gillnet fishery, a Grand Manan purse seine fishery, and a Chedabucto Bay purse seine winter fishery.

The New Brunswick purse seine - midwater trawl fishery exploits age 1 (less than 12 cm total length) herring in the late fall and winter months. This fishery supplied the fish meal and pearl essence market prior to 1970 and produced catches as high as 42,000 tons annually (Stobo et al., 1978). Canadian legislation in 1970 ended the fish meal fishery except that small amounts of very small herring (brit) are still taken for food.

Table 2. Catch of herring in Gulf of Maine

Year	USA Juvenile fishery	USA Adult fishery	USA Total catch	Canada	Germany(FR)	Germany (DR)	USSR	Poland	Japan	Bulgaria	Other	5Y Total	Total without juvenile fishery
1967	28,577	2,581	31,158	5,226								36,384	7,807
1968	31,073	10,403	41,476	21,497								62,973	31,900
1969	23,853	4,834	28,687	10,106	10,446	7,020						56,259	32,406
1970	15,617	13,564	29,181	17,912	6,079	2,580		43	9			55,804	40,187
1971	12,408	19,077	31,491	15,518	1,723	2,257						50,983	38,575
1972	19,498	18,698 (21,000)	38,196	11,638 (6,000)	2,930 (2,500)	9,296	256 (other =	100 500				62,416	42,918 (30,000)
1973	16,400	5,201 (19,750)	21,601	4,107 (4,000)	876 (1,000)	5,284	69 (other	11 250)		378		33,259	15,926 (25,000)
1974	19,142	10,233 (16,750)	29,376	4,044 (6,000)	2,463 (1,000)	1,008 (1,000)	98 (others	103 250)			149	36,916	18,098 (25,000)
1975	15,182	16,410 (10,750)	32,046	4,500 (4,200)	57 (500)	(500)	(others	71 71)			38	36,655	21,530 (16,000)
1976	30,195	19,150 (6,000)	49,398	921 (990)							(10)	50,399	20,125 (7,000)
1977	32,357	17,891 (6,000)	50,248	(990)							(10)	50,248	17,891 (7,000)
1978	29,858	18,558	48,416									48,416	18,558
1979	40,218	23,508	63,726									63,726	23,508

Note: National allocation in parentheses.

as 152,000 tons in 1962. During this period the USSR diverted much of their effort away from herring on to silver hake in 1963 and 1964 and on to red hake and haddock in 1965 and 1966. The catch of hake and haddock by the USSR in 1965 and 1966 totaled 422,000 and 371,000 tons, respectively. Their herring catch in 1965 was only 36,300 tons, although herring were very abundant. Heavy fishing did not develop on Georges Bank until 1967 when several other nations began intensive fishing operations.

Poland began intensive fishing for herring on Georges Bank in 1966, landing 14,000 tons (Table 3); their catch increased sharply to 75,000 tons in 1968. The Federal Republic of Germany (FRG) entered the fishery in 1967, taking about 28,000 tons, but in 1968 their catch was nearly as great as that of Poland. The German Democratic Republic (GDR) also began fishing for herring on Georges Bank in 1967. Subsequently, herring on Georges Bank were harvested by the US, Canada, USSR, Poland, FRG, GDR, Romania, Iceland, Japan, Norway, Bulgaria, and Cuba (Table 3).

Gillnets were used extensively by the USSR during the first three years of the Georges Bank fishery. Although pair trawling was tried in 1964, the bottom otter trawl was the major gear type used by the USSR from 1964 to 1968. In 1968, the USSR introduced purse seines, and catches by this gear increased steadily until 1975 and then sharply declined. Side and stern trawlers fishing bottom trawls were dominant in this fishery until the German Democratic Republic introduced mid-water trawling in 1971. The side trawlers were primarily less than 900 gross registered tons (GRT) and the larger stern trawlers were generally greater than 1800 GRT.

The herring catch from Georges Bank rapidly increased after 1966 to 374,000 tons in 1968, and averaged 283,000 tons per year from 1967 to 1971. This fishery was exploiting three very good year classes (1960, 1961, and 1963) that had increased the stock biomass (ages 4 and older) to over 1,100,000 tons by 1966. This accumulated stock began to decline almost immediately under heavy fishing (Table 4). Stock biomass declined about 25 percent per year during 1969 to 1971, 45 percent from 1971 to 1972, and 42 percent from 1972 to 1973 to only 137,000 tons at the beginning of 1973 (Table 4). The very good 1970 year class was recruited during 1973 which supported the fishery until 1977 when it collapsed.

LIFE HISTORY AND GENERAL BIOLOGY

Adult herring (age 4 and older) occur throughout the northwestern Atlantic from Labrador to Cape Hatteras, North Carolina, on both offshore banks and within coastal waters.

In 1964, a large fish meal plant was built in southwestern Nova Scotia and several other plants expanded their fish meal operations shortly thereafter due to the presence of a large body of herring off Nova Scotia and the increase in fish meal prices. This purse seine fishery rapidly increased into the largest herring fishery off Nova Scotia reaching a catch of 178,000 tons by 1970 (Table 1).

The Nova Scotia weir fishery is smaller than the New Brunswick weir fishery with catches of 2,000 to 12,000 tons per year of fish ages 2 to 5, compared to as high as 50,000 tons annually in New Brunswick.

The Nova Scotia gillnet fishery exists on the Nova Scotia side of the Bay of Fundy and along the Atlantic coast (east coast) of Nova Scotia from Cape Sable Island to Cape Breton Island. The Bay of Fundy fishery exploits primarily adult herring in pre-spawning and spawning aggregations. Historically, catches in this gillnet fishery have remained relatively constant at about 2,000 to 6,000 tons per year. In 1977, however, a substantial increase in effort occurred resulting in a catch in excess of 18,000 tons. The Atlantic coast gillnet fishery apparently exploits a number of local stocks, and these catches have never entered into the assessments and management programs for this region.

The Grand Manan purse seine fishery has existed recently on an intermittent basis for large herring. Only in 1972 and 1973 were substantial amounts of fish harvested. In the 1800s, this fishery for large herring was one of the largest in the Gulf of Maine area. By 1875, however, the herring fishery of New Brunswick changed to a weir fishery inshore for the taking of sardines.

The Chedabucto Bay (Northeastern Nova Scotia) fishery is important since it occurs from November through February when catches are low in other areas. This fishery began in 1969 and annual catches have ranged from 7,000 to 52,000 tons (Stobo, 1974; 1975). Tagging experiments in the Bay of Fundy in 1973 and 1974 (Stobo et al., 1975) indicated that the herring fisheries in the Bay of Fundy exploit a stock complex, part of which migrates to the Chedabucto Bay area during winter while another portion moves westward as far south as Cape Cod. Most of these fisheries have declined in recent years due to the reduction in abundance of large fish.

In 1961, the USSR began the first intensive fishery for large herring on Georges Bank, landing 68,000 tons that year (Table 1). From 1961 to 1966, the USSR was the only nation significantly involved in this fishery with catches as high

Table 3. Catch of herring in ICNAF Divisions 5Z and SA 6

Year	USA	Canada	FRG	GDR	USSR	Poland	Japan	Bulg	France	Iceland	Norway	Romania	Others	Cuba	Total
1960															
1961	105				67,550										67,655
1962	101				151,864	277									152,242
1963	322				97,646										97,968
1964	489				130,914	35									131,438
1965	1,191				38,262	1,447						1,982			42,882
1966	4,308			1,133	120,113	14,473						2,677			142,704
1967	1,211	1,306	28,171	22,159	126,759	37,677	40					1,420			218,743
1968	758	13,674	71,086	67,719	143,097	75,080	171			292		1,656	65		373,598
1969	3,678	945	61,990	44,624	138,673	45,021	583	812		12,786	1,224	337	85		310,758
1970	2,011	7	82,498	28,063	61,579	70,691	1,412	348				685			247,294
1971	3,822	12,863	54,744	18,447	81,258	88,325	2,466	4,551				898			267,374
1972	2,782 (4,000)	53 (5,800)	27,703 (31,600)	40,016	48,072 (48,200)	49,392 (49,400)	1,161 (1,200)	2,355	500			2,156 (600)	(8,200)		176,190 (150,000)
1973	4,627 (5,250)	5,083 (5,050)	31,501 (31,600)	53,326	52,340 (48,200)	49,275 (49,400)	1,722 (1,200)	1,380	2,784			297 (1,300)	(8,000)		202,335 (150,000)
1974	3,385 (6,955)	217 (2,980)	23,690 (23,900)	31,510 (31,440)	41,541 (41,725)	39,312 (39,000)	2,442	1,773	3,617			2,018	(4,000)		147,970 (150,000)
1975	4,582 (8,400)	0 (3,000)	22,957 (23,750)	30,901 (31,150)	40,945 (41,100)	38,392 (38,400)	1,878	421	3,304			1,544	(4,200)	1,162	146,086 (150,000)
1976	739 (12,400)	-- (1,000)	8,805 (9,200)	7,891 (9,300)	12,996 (12,190)	10,517 (11,000)	868 (1,100)	105 (900)	1,166 (1,100)			115 (800)	3 (10)	298 (1,000)	43,507 (60,000)
1977	381	2	-- (4,725)	-- (4,825)	1,492 (3,400)	119 (5,100)	1	-- (100)	-- (1,000)			9 (100)		153 (700)	2,157
1978	2,059														2,059
1979	1,090														1,090

Note: National allocations in parentheses, there were no allocations for the years 1978-1979.

Table 4. Management Scenario - Georges Bank Herring

Year	Year Class	Recruitment age 3 (000 tons)	TAC (000 tons) Recommended by scientists	Accepted by ICNAF	Catch age 3 and older (000 tons)	Stock size at end of year age 4 and older (000 tons)
1965-1967	1962-1964	239	-	-	134	1078
1968	1965	222	-	-	373	752
1969	1966	236	-	-	306	592
1970	1967	149	-	-	247	440
1971	1968	104	-	-	263	240
1972	1969	96	50-135	150	174	137
1973	1970	496	83-135	150	199	325
1974	1971	33	150	150	146	203
1975	1972	22	90-150	150	146	65
1976	1973	16	60	60	43	34
1977	1974	12	50	33	2	40
1978	1975	?	8		2	?
1979	1976	?	15		2	?

Optimum stock level	- 50 MT
Optimum catch level	- 100-150,000 MT
Minimum stock level constraint	- 225,000 MT
Maximum TAC in ICNAF unless at optimum stock size	- 150,000 MT 1973 through 1975 60,000 MT 1976 through 1977

Herring spawn in waters less than 50 fathoms deep on Georges Bank, off southwest Nova Scotia, on Jeffreys Ledge just east of Gloucester, Massachusetts, and all along the Maine coast to Passamaquoddy Bay (Figure 4). Spawning occurs during August to November, with the larvae moving into inshore nursery areas in the fall or by the following spring. This movement into estuary areas has been well documented by Graham, et al. (1972).

The slender scaleless larvae undergo metamorphosis into the juvenile form (known locally as "brit") by May. Metamorphosis takes place when the herring are about 5 cm long and involves changes in behavior, development of the scales, and deepening of the body. These small herring begin to form large schools during early June, but by mid-summer some of these concentrations break up into smaller groups. In autumn, these groups again gather into larger schools and become vulnerable to the juvenile fishery for the first time (at about 12 cm in length). They apparently overwinter in the deeper waters near the coast. The following summer these two-year-old juveniles become the mainstay of the "sardine" fishery.

Juvenile herring (ages 2 to 3) typically begin to move into the coastal waters of Maine and New Brunswick about the middle of June where they remain until fall. During summer, they move only short distances (25 to 50 miles) along the coast. In autumn, some of these fish move southward into waters off Massachusetts and Rhode Island and a few move into waters off southwestern Nova Scotia. The extent and magnitude of these movements are still uncertain, and it is known that some herring, which could be migrants from Canada, also overwinter in the deeper waters off the Maine coast. Those fish that move to other areas, or into deeper waters, return to the Maine coast in spring, although some (the larger individuals at age 3) begin to join the older herring in the offshore areas at this time. These three-year-old fish are near spawning size, and a few spawn for the first time in the fall.

This same sequence of southerly movements in the fall and northerly movements in the spring occurs every year with the larger fish remaining offshore. Spawning generally begins at age 4 although some do not spawn until age 5 or 6. There is some evidence that larger herring undertake longer migrations, with very large herring from the Georges Bank stock being found as far south as Chesapeake Bay in the winter.

Parrish and Saville (1965) have separated Northeast Atlantic herring stocks into three types of populations: "oceanic," "shelf," and "coastal." The "shelf" complex of herring is restricted to the continental shelf, spawns in

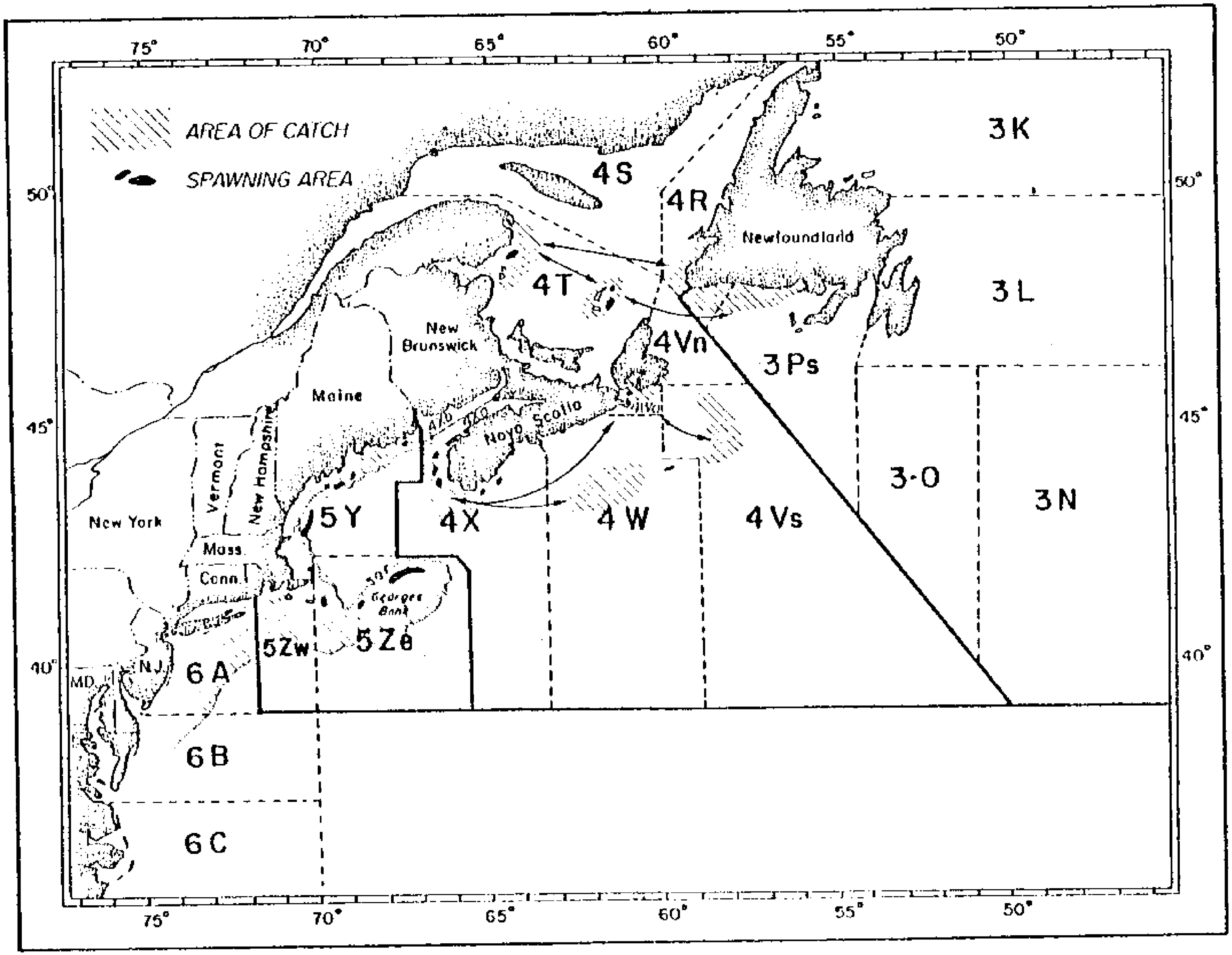

Figure 4. Herring stock structure in Subareas 4 and 5 and Statistical Area 6.

summer-autumn, and has a short life span of 12 to 16 years. They are small, with an L_∞ of 28 to 32 cm and have a high K value of 0.35 to 0.50. The "shelf" group has relatively high fecundity, small egg size, low vertebral (including the urostyle) count (55.5 to 57.0), and hyaline otolith nucleus. The Georges Bank herring resemble the "shelf" group most closely. These herring spawn in autumn, have a life span of about 14 years, an L_∞ of about 34 cm, a K of 0.38 (Table 5), high fecundity, and low vertebral count. The egg count for Georges Bank herring varies from 18,000 eggs at 25 cm (total length) to 140,000 eggs at 33 cm, according to Perkins and Anthony (1969), and 40,000 eggs at 25 cm to 132,000 eggs at 33 cm, according to Schultz (1974). This compared with 23,000 eggs at 28 cm and 90,000 eggs at 38 cm for the Norwegian spring spawners, and 35,000 eggs at 24 cm and 72,000 eggs at 28 cm for the Buchan spawners (Parrish and Saville, 1965). Of the year classes examined (1958 to 1965), the vertebral count (including the urostyle) averaged 56.2. Scattergood (1952) found that Gulf of Maine herring mature (50 percent point) at a length of 26.9 cm which, in 1977, occurred in August at age 4. Boyar (1968) found that the proportion of herring that were mature at age 3 from Georges Bank varied from 6 to 62 percent for the 1960 to 1965 year classes with an average of 29 percent. Recent estimates of maturity are not available.

The "oceanic" group of herring, according to Parrish and Saville (1965), reaches a large size with an L_∞ of 35 to 37 cm with a low K value of 0.17 to 0.30 (Table 5). Herring from Nova Scotia, Eastern and Western Maine and Jeffreys Ledge all resmeble the "oceanic" type (Table 5).

The growth rate (K) increased, beginning with the 1968 year class, in the Georges Bank, Jeffreys Ledge and Maine areas (Table 6). The calculated value of K increased from 0.350 (1960 to 1963 year classes) to 0.357 (1964 to 1967 year classes) to 0.510 (1968 to 1971 year classes) for Georges Bank. The K values for the same year classes from the Jeffreys Ledge fishery were 0.250, 0.303, and 0.400. This increase in growth is especially evident in the Maine juvenile fishery (Table 6); even the very good 1970 year class grew rapidly. The reason for the increase in growth for all recent year classes may be due to the decline in stock biomass.

Density-dependent growth was exhibited by the 1957 to 1966 year classes (Anthony, 1971) with the good year classes of 1958, 1960, 1961, and 1963 having the slowest growth and the poor 1959 and 1962 year classes having the fastest growth. This density dependence was lost as all year classes, good and bad, grew rapidly beginning with the 1968 year class.

Table 5. Growth parameters of various herring stocks throughout the North Atlantic (Beverton, 1963; Beverton and Holt, 1959)

AREA	L_∞	K	T_{max}
GEORGES BANK	34.1	0.377	13
JEFFREYS LEDGE	36.7	0.311	15
COASTAL MAINE			
WESTERN MAINE	35.1	0.335	16
EASTERN MAINE	38.0	0.277	16
NOVA SCOTIA	39.0	0.179	18
NORWAY			
(ATLANTO-SCANDIAN)	35-37	0.17-0.25	23
(LUSTERFJORD)	21	0.65	
ICELAND	36-37	0.20-0.30	18
GREENLAND	41	0.20	17
NEWFOUNDLAND	34-37	0.20-0.30	19-22
NEW BRUNSWICK CHALEUR BAY	34	0.30	19
S. GULF OF ST. LAWRENCE	35-37	0.25	16
NORTH SEAS NORTH (BUCHAN)	30.5-31.5	0.35-0.43	16
SOUTH (EAST ANGLIAN)	28.5-29.5	0.35-0.40	12
SCOTTISH W. COAST (MINCH)	30-33	0.30-0.40	
CLYDE	30-33	0.30-0.40	
IRISH SEA NORTH (MANX)	29.5	0.30	12
SOUTH (DUNMORE)	29.5	0.39	11+
BALTIC SEA NORTH (GULF OF BOTHNIA)	25	0.15	17
SOUTH (BORNHOLM)	22.5	0.55-0.60	10

Table 6. Mean lengths (cm) of herring of recent year classes (1968 and later) compared with lengths of earlier year classes for two areas (length weighted over year classes by number sampled)

Georges Bank

Age	1960-1963 Length (cm)	1964-1967 Length (cm)	1968-1971 Length (cm)
2.00	15.1		14.7
2.25	16.5	15.5	16.5
2.50	21.3	20.6	21.7
2.75	20.1	20.9	21.5
3.00	20.2	21.6	22.8
3.25	21.7	22.2	21.5
3.50	24.5	24.3	25.0
3.75	24.4	25.1	25.0
4.00	23.9	25.9	27.0
4.25	26.1	26.4	27.7
4.50	27.4	27.2	28.4
4.75	27.1	27.2	29.1
5.00	26.7	27.5	29.8
5.25	27.9	28.0	30.0
5.50	29.0	28.9	30.3
5.75	29.1	29.2	30.4
6.00	29.7	30.4	30.7
6.25	30.0	29.6	
6.50	30.4	30.4	
6.75	30.6	30.6	
7.00	30.6	32.9	
7.25	31.3	29.8	
7.50	31.8	32.5	
7.75	31.8	32.0	
8.00	31.5	33.8	
8.25	32.2		
8.50	32.8		
8.75	32.6		
9.00	32.5		
9.25	32.4		
L_∞	34.1	34.5	33.3
K	.350	.357	.510
t_o	.228	.257	.803

Western Maine

Age	Month	1957 - 1967 Length (cm)	1957 - 1967 Number	1968 - 1973 Length (cm)	1968 - 1973 Number
1	May	4.8	200		
1	June	4.7	200	5.8	100
1	July	5.6	131	6.2	100
1	Aug.	11.0	228		
1	Sept.	12.3	1217	14.3	4
1	Oct.	13.0	1054	14.5	53
1	Nov.	14.7	411	15.1	73
2	Jan.	12.6	154		
2	Feb.	12.7	581	13.5	93
2	Mar.	13.2	853	15.3	40
2	Apr.	13.8	299		
2	May	15.8	1733	16.9	55
2	June	15.9	3830	17.4	220
2	July	16.7	3425	18.6	379
2	Aug.	16.8	3340	18.9	227
2	Sept.	18.5	2049	20.8	130
2	Oct.	19.0	1656	21.0	355
2	Nov.	18.9	219	20.1	158
3	Jan.	16.8	19	20.9	14
3	Feb.	17.1	109	17.6	12
3	Mar.	17.3	238	18.0	10
3	Apr.	18.1	81		
3	May	17.5	117		
3	June	18.7	1222	22.7	64
3	July	19.9	735	22.3	61
3	Aug.	21.7	442	22.9	17
3	Sept.	22.6	513	25.9	64
3	Oct.	22.7	477	25.0	94
3	Nov.	23.0	74	23.6	44

The von Bertalanffy growth curve for Georges Bank herring is shown in Figure 5, based on data from the 1960 to 1971 year classes. Herring reach their maximum weight each year in August-September and their minimum in February-March. The two von Bertalanffy growth curves in Figure 5 represent weight at age before spawning (July) and after spawning (November).

HERRING RESEARCH

Although research on juvenile herring had been underway in Maine and Canada for many years, assessment studies on the adult herring fisheries did not begin until the late 1960s and early 1970s. Detailed catch statistics were collected beginning in 1947 in the Maine juvenile herring fishery, and biological sampling began in 1963. A fine data base existed for this fishery by 1970, and much of the data had been analyzed (Anthony, 1972). Herring scientists retired and new scientists were hired by Canada during the 1960s which interrupted and changed the research on herring in the New Brunswick juvenile fishery. The first formal assessment of the Nova Scotian herring stock was in 1974 (Miller and Halliday, 1974), whereas assessments were available beginning in 1971 for Georges Bank herring (Schumacher and Dornheim, 1971) and in 1972 for the Gulf of Maine herring (Anthony and Brown, 1972).

The major assessment problems in 1970 were: 1) the interrelationship between the juvenile and adult herring fisheries, and 2) the estimation of changes in stock size and mortality rates. The ICNAF Standing Committee on Research and Statistics recommended serological, biochemical, and larval dispersion studies combined with carefully designed tagging experiments to solve the stock definition problems, and surveys of egg production to estimate stock abundance. An otolith exchange program was begun as age reading differences were noted among the various countries.

HERRING STOCK IDENTIFICATION

The definition of herring stocks in the Georges Bank - Gulf of Maine area has been very difficult. Stock definition has been attempted with larval drift (Tibbo et al., 1958; Tibbo and Legaré, 1960; Colton and Temple, 1961; Boyar, 1966; Das, 1968; Graham and Venno, 1968; Tibbo and Lauzier, 1970; Iles, 1971; Graham et al., 1972; Boyar et al., 1973; and Davis and Morris, 1976), parasites in inshore areas (Sindermann, 1957), serological and biochemical methods (Sindermann and Mairs, 1959; Sindermann, 1962; Ridgway et al., 1969), meristic counts (Anthony and Boyar, 1968; Anthony, 1972) and more recently by tagging (Stobo et al., 1975; ICNAF, 1976).

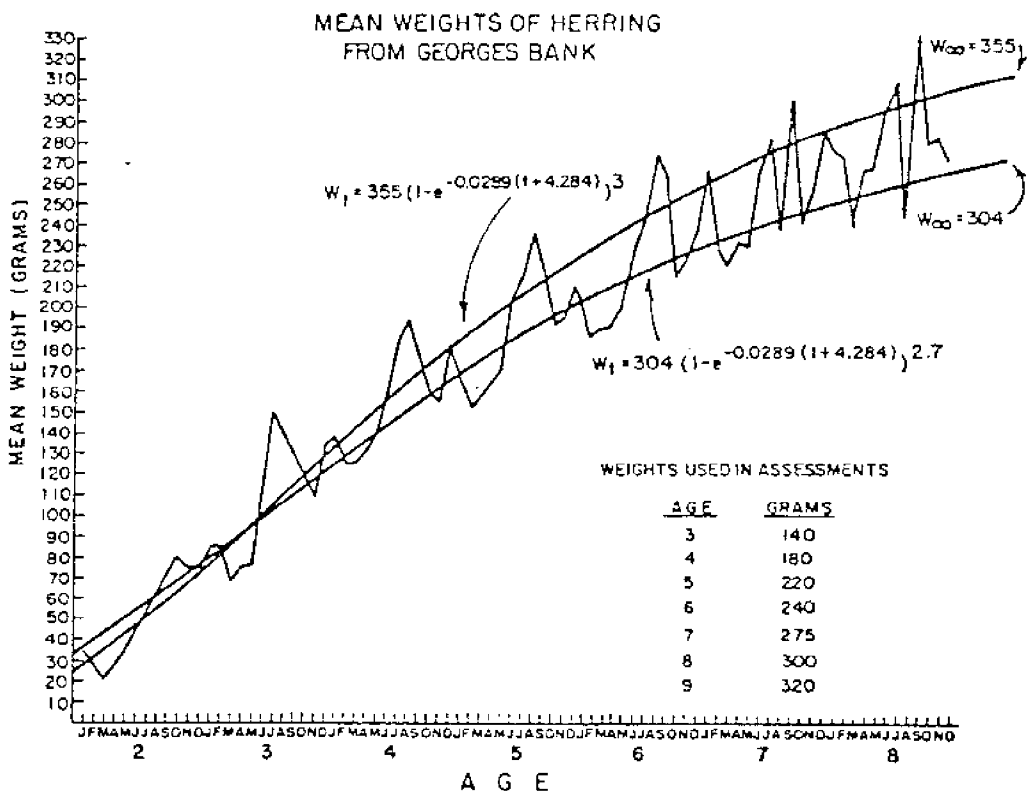

Figure 5. Mean weights of herring from Georges Bank by month, and average weights by age as used in the assessments, with two extended Von Bertalanffy growth curves in weight, representing average weight before and after spawning.

of juvenile herring could not really be determined from these original tagging studies. Tagging studies conducted by Speirs (1978), however, have confirmed the limited movement of juvenile herring during the summer months. Juvenile herring in autumn did move south from Maine waters into Cape Cod Bay where they overwintered and returned to coastal Maine waters in the spring.

In 1973 to 1974, 48,000 herring were tagged by Canadian scientists (Stobo et al., 1975) in the Bay of Fundy and along southwestern Nova Scotia (Figure 6). Based on preliminary results of this tagging study, an International Herring Tagging Program was formed within ICNAF (ICNAF, 1976) to address the stock identification and migration problem. During 1976 to 1978, 75,000 herring were tagged at Cultivator Shoals, Jeffreys Ledge, off Cape Cod, and the Great South Channel (Figure 7) by US and USSR scientists. The State of Maine tagged 41,000 herring along its coast during 1976 to 1978, and Canada tagged an additional 142,000 herring in the western Gulf of St. Lawrence, St. Georges Bay, Chedabucto Bay, and on the Lurcher Shoals - Trinity Ledge spawning ground off southwestern Nova Scotia (Figure 6).

In all the tagging studies conducted in the 1970s, yellow Floy anchor (FD-68B) type tags were employed following the techniques outline by Stobo (1976).

The Canadian tagging studies indicate that herring tagged in the autumn in the Bay of Fundy and off Nova Scotia migrate north to Chedabucto Bay (ICNAF Subdivision 4W[a]) and south to Cape Cod Bay and Block Island Sound to overwinter (Figure 6).

Returns from the tagging of spawning fish on Jeffreys Ledge and Georges Bank have been negligible, probably as a result of high tagging mortality. Limited fishing in 1976 and 1977 on Georges Bank may also have been a reason for few tag returns.

Herring tagged in the spring of 1977 in the Great South Channel and on Jeffreys Ledge have been recovered all along the coast from Ipswich Bay, Massachusetts, into the Bay of Fundy and along southwestern Nova Scotia in the summer-autumn herring fisheries (Figure 7). During the winter of 1978, recoveries of these fish were made in the winter fisheries in Chedabucto Bay, Cape Cod Bay, and in Block Island Sound.

These preliminary results indicate a degree of stock intermixture, the extent yet to be determined, among the herring inhabiting the coastal waters from Chedabucto Bay to southern New England. Herring move north throughout the Gulf of Maine in the spring (April-May) and remain along the

Studies of larval herring movements are not conclusive. They show an unusual ability of larvae to move upstream in an estuary, and to avoid being swept off Georges Bank and being lost to the fishery as suggested by Colton and Temple (1961). They have been observed on Georges Bank in the early spring but are also widely distributed throughout the Gulf of Maine. Parasitological work on the myxosporidian, Kudoa clupeidae, larval nematodes (Anisakis sp.) and larval cestodes suggested some limitations of juvenile herring movement along the Maine coast and the possible existence of two groups of fish. The serological and biochemical findings were found to be unreliable as racial indicators.

Of the meristic counts examined (vertebrae, dorsal, anal, and pectoral fin rays), only the vertebral counts and pectoral fin ray counts showed promise of stock discrimination, with the pectoral fin ray counts the most promising (Anthony and Boyar, 1968). Significant differences (pectoral counts) were found between adult herring from Nova Scotia - Maine and from Georges Bank - Nantucket Shoals and between juveniles along the Maine coast and adults along the Maine coast of the same year class. These differences in counts existed in the 1958 to 1963 year classes but not in the 1964 to 1966 year classes. Recent year classes have not been examined.

The movements of the Georges Bank adult herring have been followed by commercial fishing vessels (Zinkevich, 1967), and the weekly catches of juvenile herring along the Maine coast have indicated general movement patterns (Anthony, 1972). The ability of fishermen to follow large schools of herring has been very useful in defining migration patterns.

Tagging studies were reinstituted in 1973 (Stobo, 1976) in an attempt to clarify movements of Georges Bank - Gulf of Maine herring. Tagging had been conducted in 1957 and 1958 in the Passamaquoddy Bay area (McKenzie and Skud, 1958) and along the Maine coast in 1960 and 1963. Very few fish were recovered because of apparently high handling mortality and non-reporting of tags. The majority of fish tagged were age 2 (15 to 19 cm in total length) and were tagged in 1957 - 1958 with a celluloid opercular tag (McKenzie, 1950) and with a "spaghetti" dart tag under the dorsal fin in 1960 and 1963 (Watson, 1963). Of 161,117 herring tagged and released from 1957 to 1963, only 2.5 percent were recovered and they all were close to the area of release. A large number of the recaptures occurred within one day of release and, in many cases, within the weir from which they were tagged. It was assumed that juvenile herring migrated little during the summer months.

There were no adult herring fisheries during the period 1957 to 1963 off Nova Scotia or in the western Gulf of Maine and only a limited Georges Bank fishery, so extensive migrations

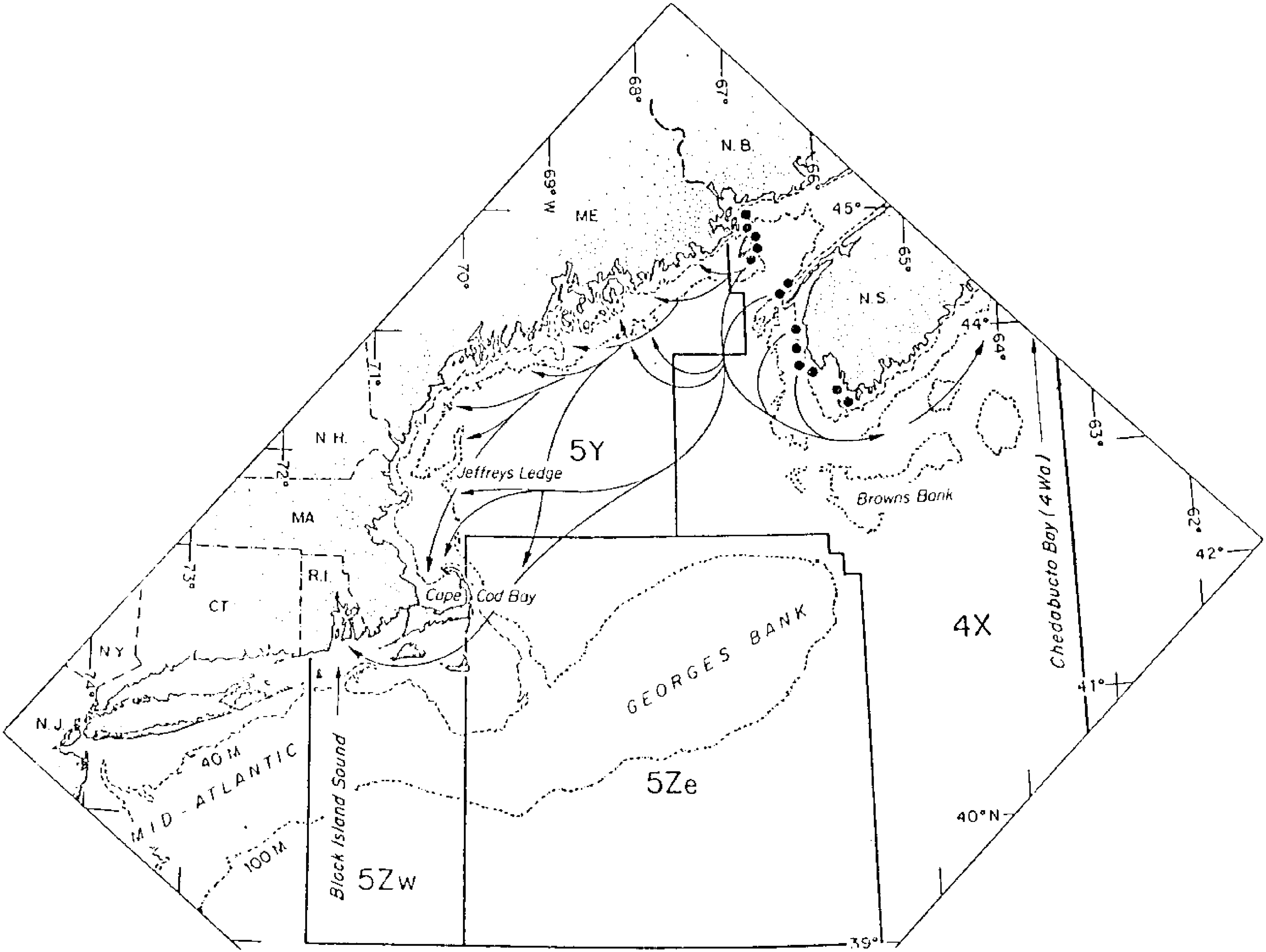

Figure 6. Distribution of recaptured herring tagged by Canada in the Bay of Fundy and along SW Nova Scotia 1973-1977.

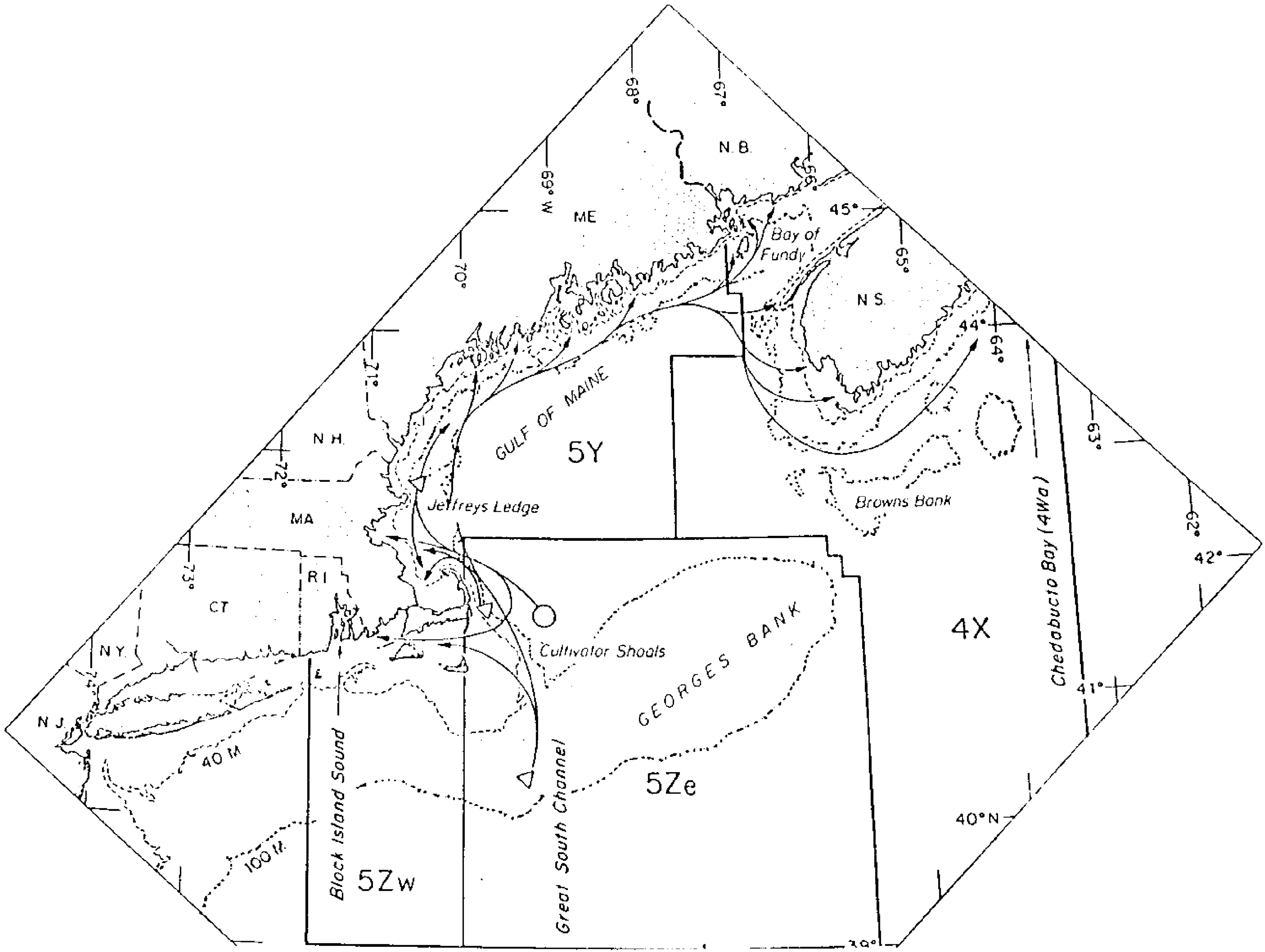

Figure 7. Distribution of recaptured herring tagged in 1976 circle (o) and 1977 triangles (Δ) by the International Herring Tagging Program.

Maine coast and off southwestern Nova Scotia all summer and then return to Cape Ann - Cape Cod Bay or south of Cape Cod to overwinter from November to April. The fall migration north from south-western Nova Scotia to Chedabucto Bay is less understood.

The movements of Georges Bank herring have not been well defined from tagging results. The overwintering migration of adult herring in a southerly direction has been documented, but the movements of the larvae and juveniles are still unknown. After spawning on Georges Bank, the herring move as far south as Chesapeake Bay to overwinter, returning to Georges Bank in May-June. Larger, older herring move further than young herring. The herring, in fact, that are found off Chesapeake Bay in the winter are called "Labrador herring" due to their very large size.

LARVAL HERRING SURVEYS

Larval herring surveys have been conducted sporadically since the late 1950s and annually in autumn-early winter since 1971; spring larval surveys began in 1975. The longest time-series is for selected stations along the Maine coast and particularly in the Sheepscot estuary of western Maine where annual larval surveys have been conducted by Graham since 1963 (Graham et al., 1972). The surveys have been used to estimate recruitment to the juvenile fisheries, explain stock distribution, and to estimate the spawning stock size.

The ICNAF cooperative larval herring surveys, initiated in 1971, were conducted according to a grid of standard stations (Lough, 1976). The standard 61-cm bongo sample (0.505-mm and 0.333-mm mesh nets) was used in a single oblique tow to a maximum depth of 100 meters and retrieved at 10 m/ minute while the ship was underway at 3.5 knots. Production of larvae was determined as the number of herring larvae caught per 10 m^2 summed over the stations in the Nantucket Shoals - Georges Bank area (Lough, 1976). Estimates of larval abundance of the 1973 to 1975 year classes were considerably greater than for the 1971 and 1972 year classes (ICNAF, 1975). Schnack (1975) indicated that there were four to ten times as many larvae caught in December 1973 and 1974 than were caught in December 1971 and 1972. This was presumed to be due to the recruitment of the large 1970 year class to the spawning stock in 1973 and 1974. Larval abundance in December 1975 was considerably lower than in 1974 and 1973, but February abundance estimates were similar during 1974 to 1976 (Lough, 1976). The production of larval herring from Georges Bank in December 1976 was the lowest ever observed (ICNAF, 1977).

The usefulness of these larval surveys remains to be demonstrated. While the 1971 and 1972 year classes were

The usefulness of these larval surveys remains to be demonstrated. While the 1971 and 1972 year classes were poor, which was indicated by the larval surveys, it is not yet known whether the 1973, 1974, and 1975 year classes are significantly better. The catches of these latter year classes in the Maine juvenile fishery are in agreement with results from the larval surveys indicating that they are stronger than the 1971 and 1972 year classes. The 1976 year class, however, appears to be a good year class in spite of poor larval catches.

RECRUITMENT INDEX FROM MAINE JUVENILE CATCHES

An unusual phenomenon of the herring fisheries in the Georges Bank - Gulf of Maine area is the consistency of good and bad year classes throughout the entire area. Figure 8 shows that the 1970 year class was abundant in all three adult fisheries, Nova Scotia, western Gulf of Maine, and Georges Bank, and the 1969 year class was very poor in all areas. The 1966 year class was larger than the three succeeding and two preceding year classes in all areas. The 1963 year class was larger than the 1966 year class in Nova Scotia and on Georges Bank and unknown for the western Gulf of Maine stock. The catches from the Maine juvenile fishery also demonstrated the existence of the very good 1960 year class, the good 1963 and 1966 year classes, and the poor 1969, 1971, and 1972 year classes (Table 7 and Figure 9). One possible explanation for this correspondence in year-class strength is extensive mixing of herring from several spawning grounds.

This agreement in year-class strength also suggests that the catches in the Maine juvenile fishery can be used as an index of recruitment. An index of abundance was calculated for age 2 herring from standardized catch per man information for 63 stop seine fishermen in Central and Western Maine (Anthony, 1972) and is compared with the total Maine catch by stop seines and weirs in Figure 10. The agreement is a very good indication that the catch is a measure of abundance and that the exploitation rate is relatively stable. The catch of age 2 herring by stop seines and weirs, therefore, has been used as a relative index of abundance of age 2 herring along the Maine coast and of age 3 herring recruiting to the Georges Bank fishery.

Multiple regressions were run on age 2 and 3 catch data from the Maine juvenile fishery against Georges Bank recruitment for the 1960 to 1969 year classes to predict recruitment to the Georges Bank fishery (Figure 11). This relationship gave a multiple correlation coefficient of 0.90, although the prediction equation overestimated the abundance at age

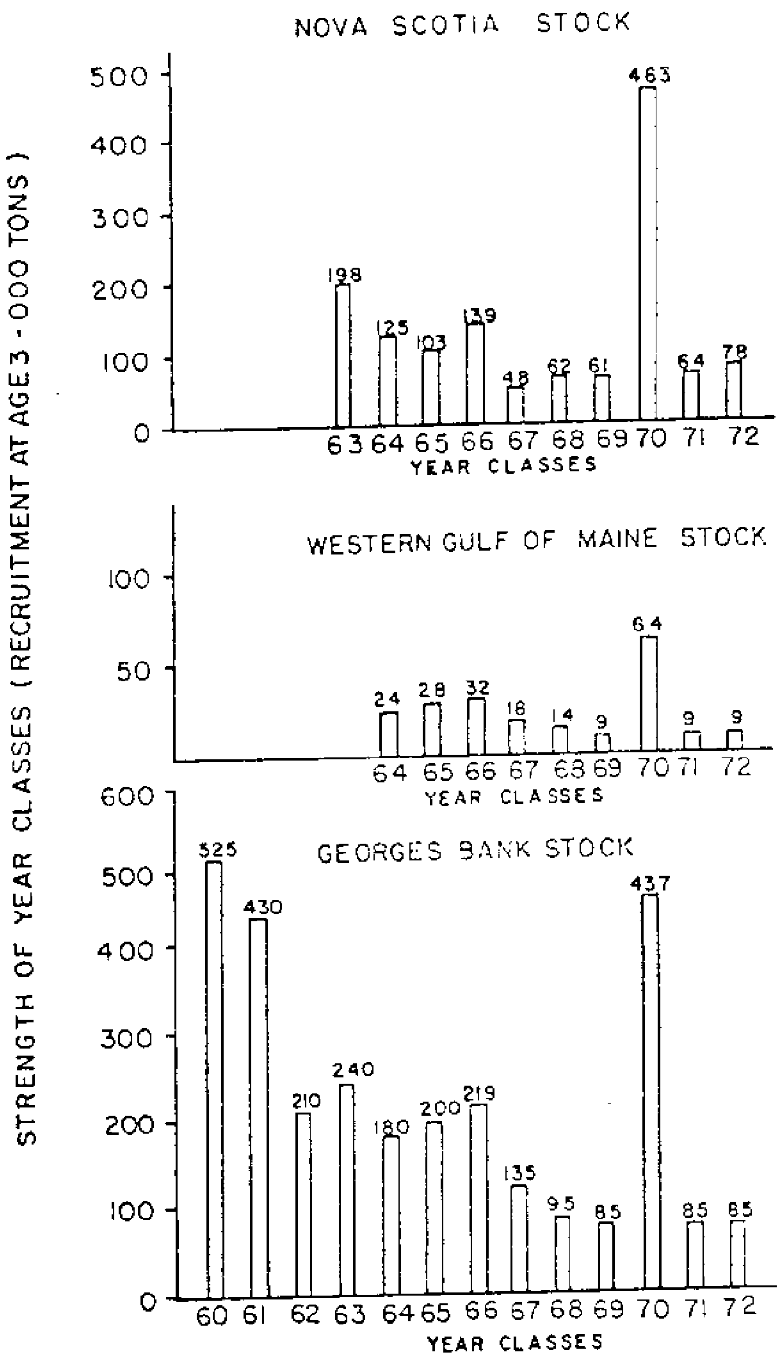

Figure 8. Comparison of year class strength among 3 adult fisheries.

Table 7. Total Maine herring catches in metric tons by age groups

Year \ Age	1	2	3	4	5	6	7	8	8+	Total
1947	1,369	32,501	31,616							65,486
1948	4,342	27,441	44,654							76,437
1949	11,993	29,915	32,121							74,029
1950	281	30,644	59,632							90,557
1951	18,017	8,049	8,345							34,411
1952	5,358	44,618	29,163							79,139
1953	20,033	18,271	20,033							58,337
1954	6,067	19,970	38,030							64,067
1955	8,714	19,238	15,554							43,506
1956	5,293	33,307	27,894							66,494
1957	3,218	43,802	21,603							68,623
1958	4,498	36,592	39,669							80,759
1959	2,238	15,805	34,994							53,037
1960	950	37,864	20,534							59,348
1961	2,703	14,575	6,853							24,131
1962	624	64,520	4,232							69,376
1963	736	17,928	48,231							66,895
1964	1,209	16,645	4,023	4,155	263					26,295
1965	449	24,676	5,872	353	738					32,088
1966	174	6,330	18,452	275	648	199	75	25		26,178
1967	225	6,635	14,576	5,819	113	698	-	-	424	28,490
1968	80	21,037	7,932	744	376	-	33	-	-	30,202
1969	72	6,702	15,909	882	72	95	72	24	24	23,852
1970	294	6,258	4,422	2,673	531	726	294	265	118	15,581
1971	1,909	2,838	1,731	3,388	1,793	409	127	126	86	12,407
1972	3	17,360	833	492	242	318	264	-	-	19,512
1973	164	8,100	7,456	193	164	80	121	55	66	16,399
1974	486	9,074	5,489	3,780	230	75	9	-	-	19,143
1975	796	9,451	2,538	924	1,249	96	8	120	-	15,182
1976	478	13,228	12,740	1,203	1,122	1,390	11	6	16	30,194
1977	1,316	18,541	8,022	2,161	535	381	1,358	3	40	32,357
1978	242	12,398	8,025	1,816	2,969	388	739	3,055	210	29,842
1979	27	25,839	11,485	1,708	191	329	196	104	179	40,058

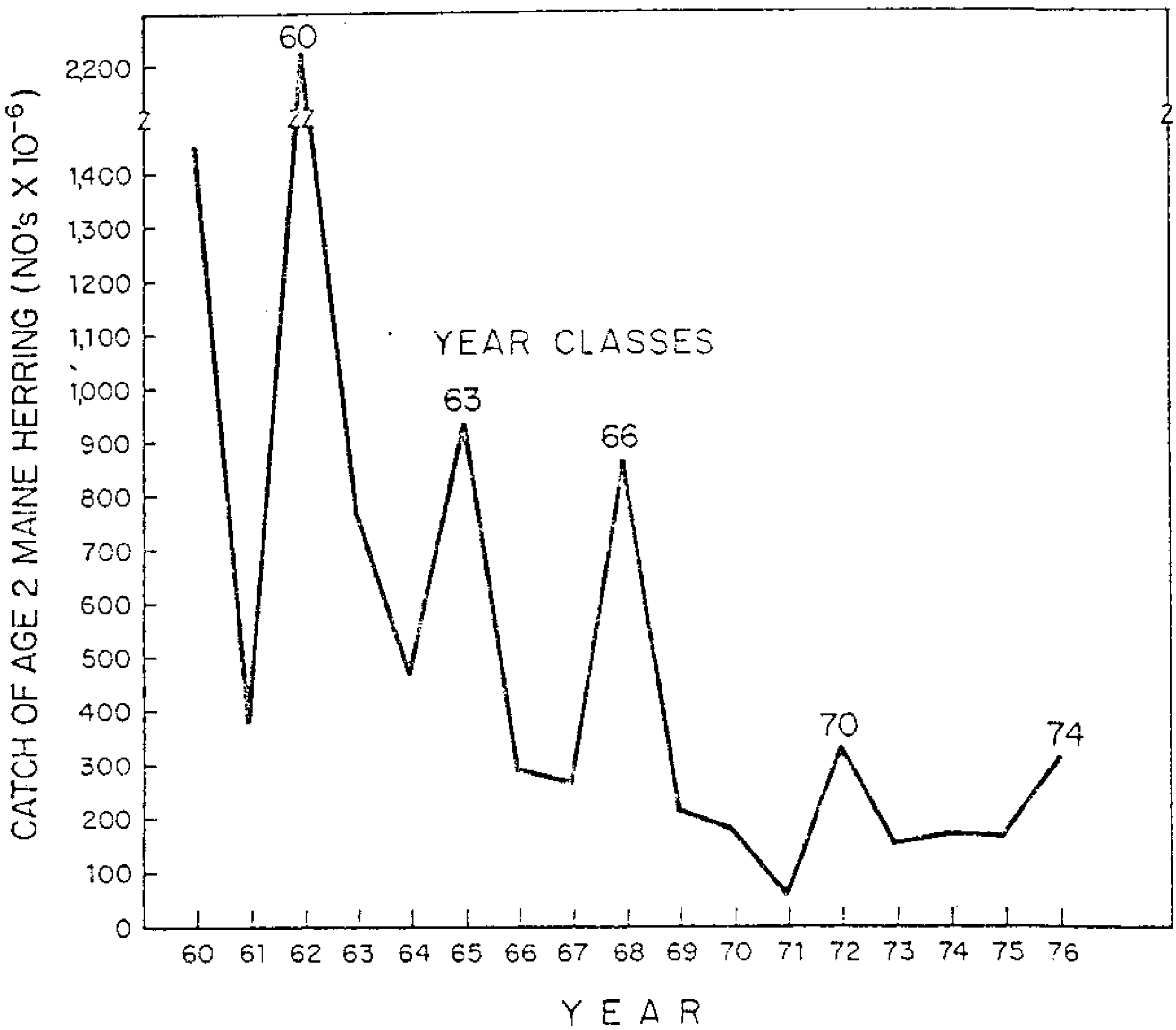

Figure 9. The catch of age 2 herring in the Maine juvenile fishery.

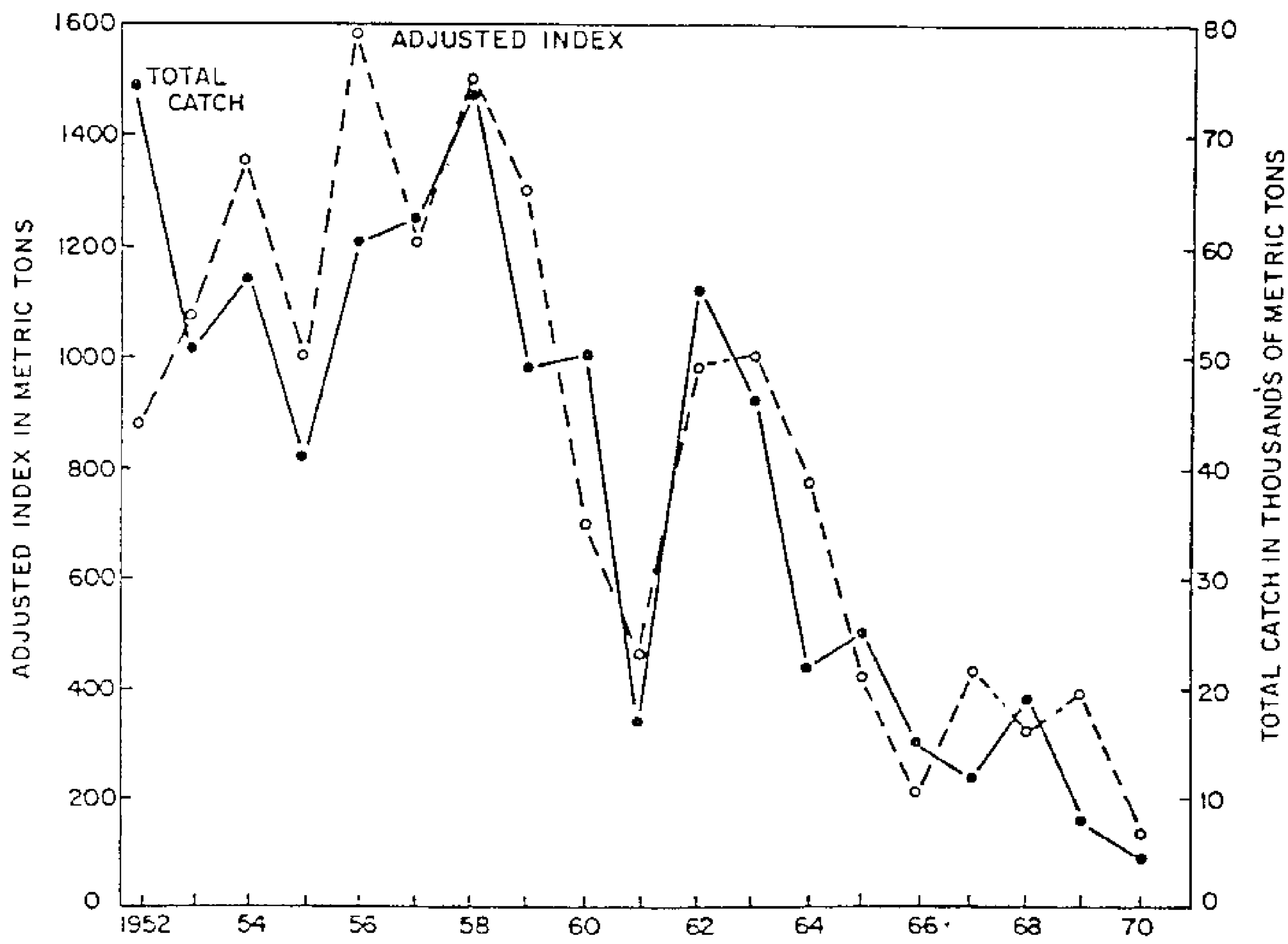

Figure 10. Adjusted index of catch per stop seine fisherman for both central and western Maine compared with the total catch of herring from stop seines and weirs (index adjusted for effects of moon phase).

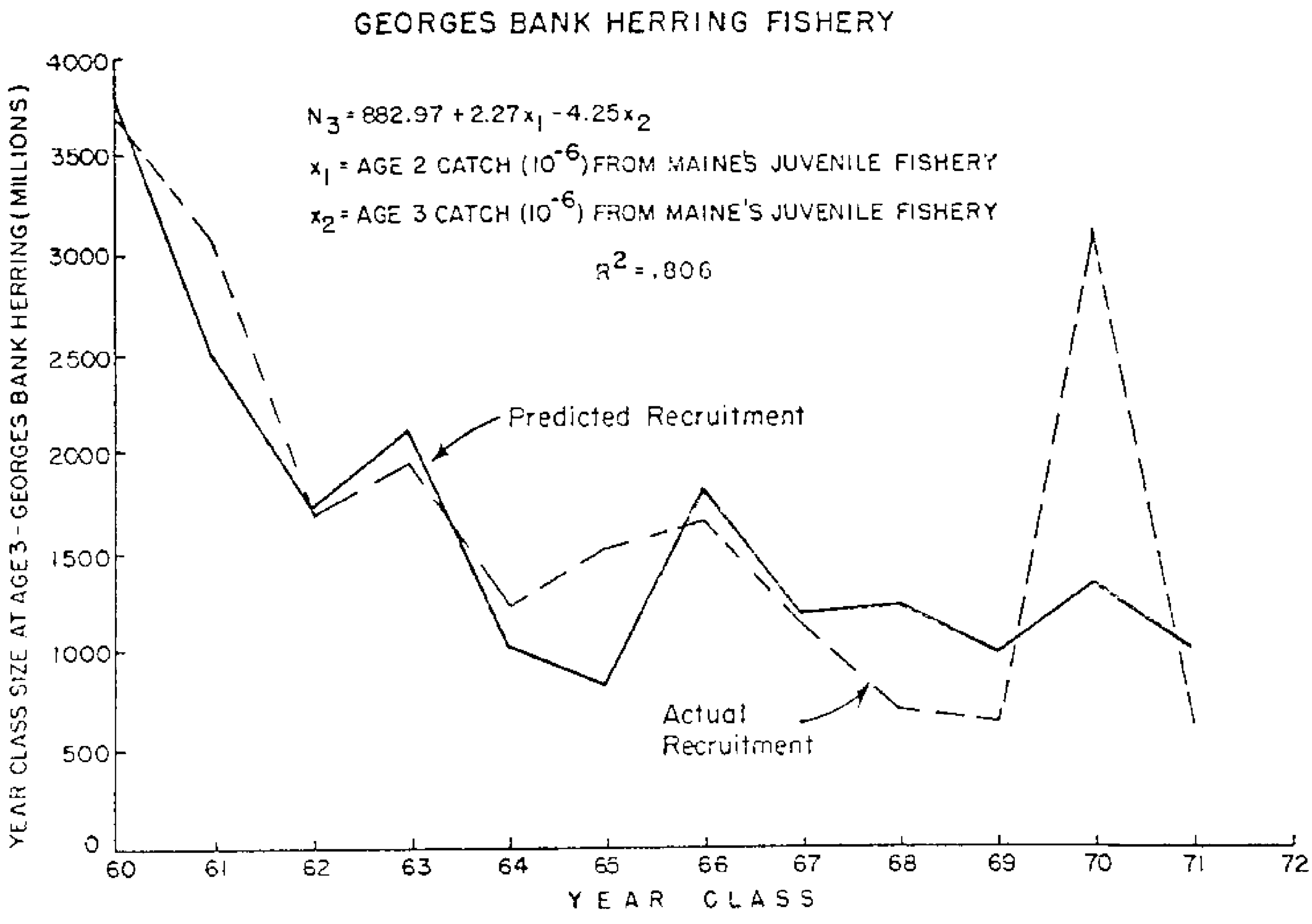

Figure 11. Prediction of recruitment (age 3) to the Georges Bank herring fishery from Maine juvenile herring catches.

3 of the 1968 year class by 82 percent, the 1969 year class by 64 percent, and underestimated the abundance of the 1970 year class by 58 percent. While the relationship between catches of herring from the Maine juvenile fishery and recruitment to Georges Bank is quite good, the correspondence cannot be relied upon to predict the actual abundance of recent year classes. The availability of age 2 herring to the inshore fishing gear varies from year to year for unknown reasons.

YOUNG HERRING SURVEYS

A juvenile herring survey was first conducted in the Georges Bank area in early 1972 by the USSR. Large catches of age 2 (1970 year class) herring and the later confirmation of a good 1970 year class indicated that coordinated juvenile surveys might be valuable in predicting recruitment to the Georges Bank fishery. The winter period (February-March) was chosen as the time to conduct the surveys assuming that herring would be more evenly distributed on the bottom than at other times and hence be most susceptable to abundance estimation by stratified random sampling. The area from the Nova Scotia shelf to Long Island, New York was subdivided into sampling areas to be covered by research vessels from several ICNAF member countries (FRG, GDR, and Poland) utilizing bottom otter trawls. The surveys were conducted from 1973 to 1979. The area was divided into five blocks (Figure 12) for analytical purposes based on the distribution of juvenile herring catches from the US R/V Albatross IV spring survey catches during 1968 to 1974 (Anthony et al., 1975). Two-year-old herring were found in reasonable quantities only in 1972 and 1978, and it was concluded that age 2 herring may only be found in the offshore areas when they are very abundant.

The FRG survey data correctly indicated a strong 1970 year class and poor subsequent year classes, although the estimates of these latter year classes varied greatly. The 1973 year class was estimated to be 13,000 times smaller than the 1970 year class, and the 1972 year class was estimated to be 229 times larger than the 1974 year class. The 1973 year class was not that poor, and the 1972 year class was actually smaller than the 1974 year class. The value of these surveys was, therefore, limited to indicating whether a year class was very good or very poor.

Since 1968, the US R/V Albatross IV has been conducting spring bottom trawl surveys, based on a stratified random sampling design according to depth and area (Figure 12). These surveys, mainly due to the area covered and the long time-series, have been the most useful in predicting recruitment to the Georges Bank stock. The survey design and sampling methods are described by Grosslein (1974). Catch-

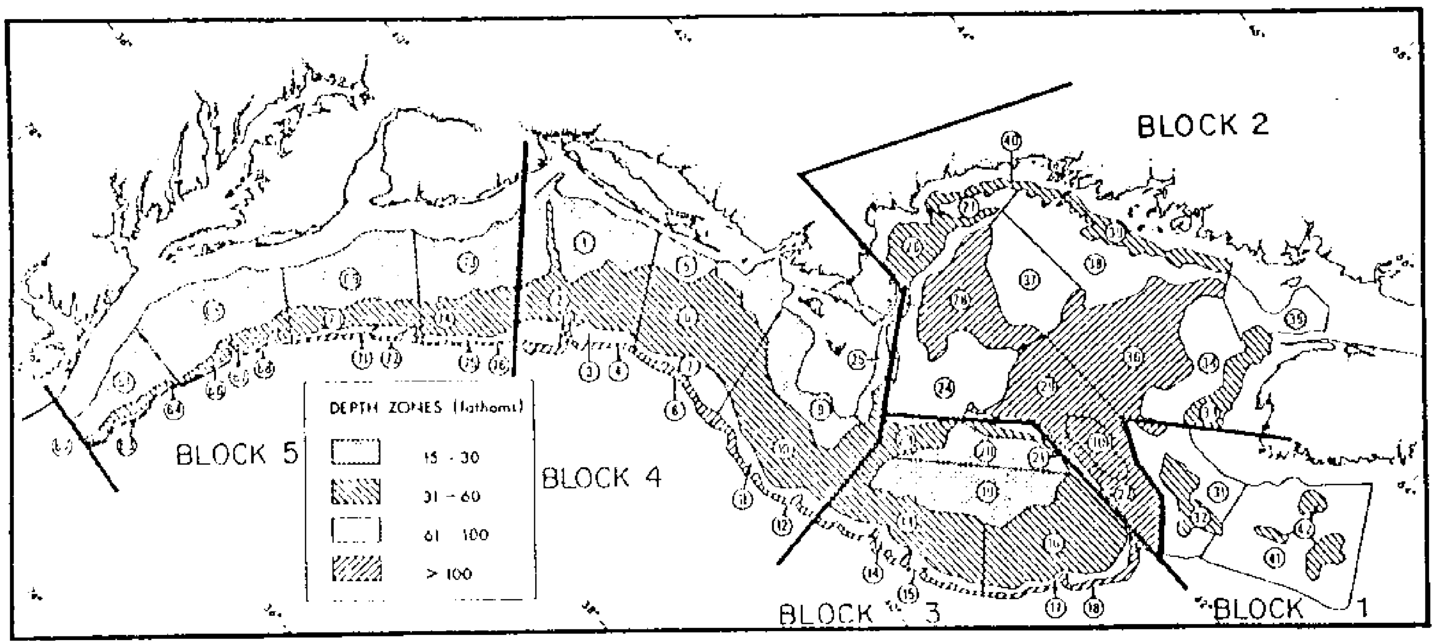

Figure 12. Depth strata used in USA bottom trawl surveys grouped into blocks for investigation of juvenile herring abundance.

per-tow data from Block 1 (Nova Scotia shelf) have provided useful estimates of age 3 abundance (r = 0.92). Table 8 compares survey predictions of abundance at age 3 with the year-class sizes calculated from cohort analysis for the 1965 to 1971 year classes and the assumed values of the 1972 and 1973 year classes for Georges Bank herring. These data and those collected by other research vessels only provide indications of very good or very bad year classes. Since the stock on Georges Bank in the mid 1970s consisted largely of age 3 recruitment, much more precise recruitment estimates than those obtained from the surveys were required in order to calculate the recommended total allowable catches (TACs).

ESTIMATES OF STOCK ABUNDANCE

During the development of the Georges Bank, Gulf of Maine, and Nova Scotia fisheries, catches in the juvenile fisheries were declining (Figure 3) which indicated that the year class strengths of herring during the late 1960s were also declining. If these year classes were weaker than those of the early 1960s, then the spawning stocks to which they recruited must have also declined under the heavy fishing pressure. Indices of abundance from several sources were examined to determine the decline in abundance on Georges Bank. Indices of herring abundance were developed from US R/V Albatross IV spring bottom trawl surveys for the Middle Atlantic (Cape Hatteras to Long Island) and Southern New England (Long Island to Nantucket Shoals) areas and from the fall survey for Georges Bank (Table 9). All three surveys indicated extensive declines from 1966 though 1971, except the Middle Atlantic survey between 1970 and 1971. The average annual decline from 1966 to 1970 was approximately 60 percent.

In 1963, the USSR began studies to estimate spawning stock size from estimates of the number of eggs laid on the spawning beds of Georges Bank (Noskov and Zinkevich, 1967). This method likely progressively underestimates the abundance of the spawning stock as it declines. The rate of stock decline, as estimated from egg surveys, therefore, was probably an overestimation of the actual decline.

Figure 13 compares indices used in January 1972 for the Georges Bank stock calculated from: 1) US research vessel surveys, 2) USSR spawning population estimates from egg studies, 3) USSR catch per effort in the spawning month of September, and 4) the international total catch per effort, taking into account the fishing power of each fleet. All indices indicated strong declines in spawning stock from 1964 to 1971.

Catch-per-effort information from the distant water fleet on Georges Bank was analyzed to obtain estimates of relative abundance. Catch and effort data were available by

Table 8. Georges Bank abundance at age 3 predicted from retransformed *Albatross IV* spring survey data for Block 1 and corresponding values calculated from cohort analysis[1]

Year Class	Age 3 stock size millions: From Cohort Analysis	Predicted
1965	1411	1704
1966	1538	1209
1967	955	1545
1968	675	660
1969	582	63
1970	3024	3301
1971	201	686
1972	(131)	152
1973	(99)	3148

[1]Values in parentheses based on 1980 assumptions of year class size.

Table 9. U.S research cruise indices of herring abundance (mean NO/TOW)

YEAR	FALL CRUISES GEORGES BANK STRATA 13,16,21,22, 23,24	SPRING CRUISES SO. NEW ENGLAND STRATA 1,2,5,6,9,10		SPRING CRUISES MID-ATLANTIC STRATA 61,62,65,66,69, 70,73,74	
1963	7.02				
1964	1.13				
1965	6.45				
1966	10.41				
1967	3.26				
1968	1.36	120.6[2]		17.4[2]	
1969	1.14	45.8[2]		6.4[2]	
1970	0.66	34.7[2]		1.2[2]	
1971	0.55	4.1[2]		3.7[2]	
1972	1.07	5.7[2]		2.6[2]	
1973	0.12	7.42[2]	19.9[1]	5.64[2]	15.5[1]
1974	0.12	2.07[2]	5.7[1]	1.25[2]	3.4[1]
1975	0.02	0.04[2]	0.11[1]	.01[2]	.02[1]
1976	0.01	0.68[2]	1.88[1]	0.55[2]	1.50[1]
1977	0.01	1.18[2]	3.24[1]	0.10[2]	0.28[1]

[1]Yankee #41 trawl.
[2]#36 trawl.

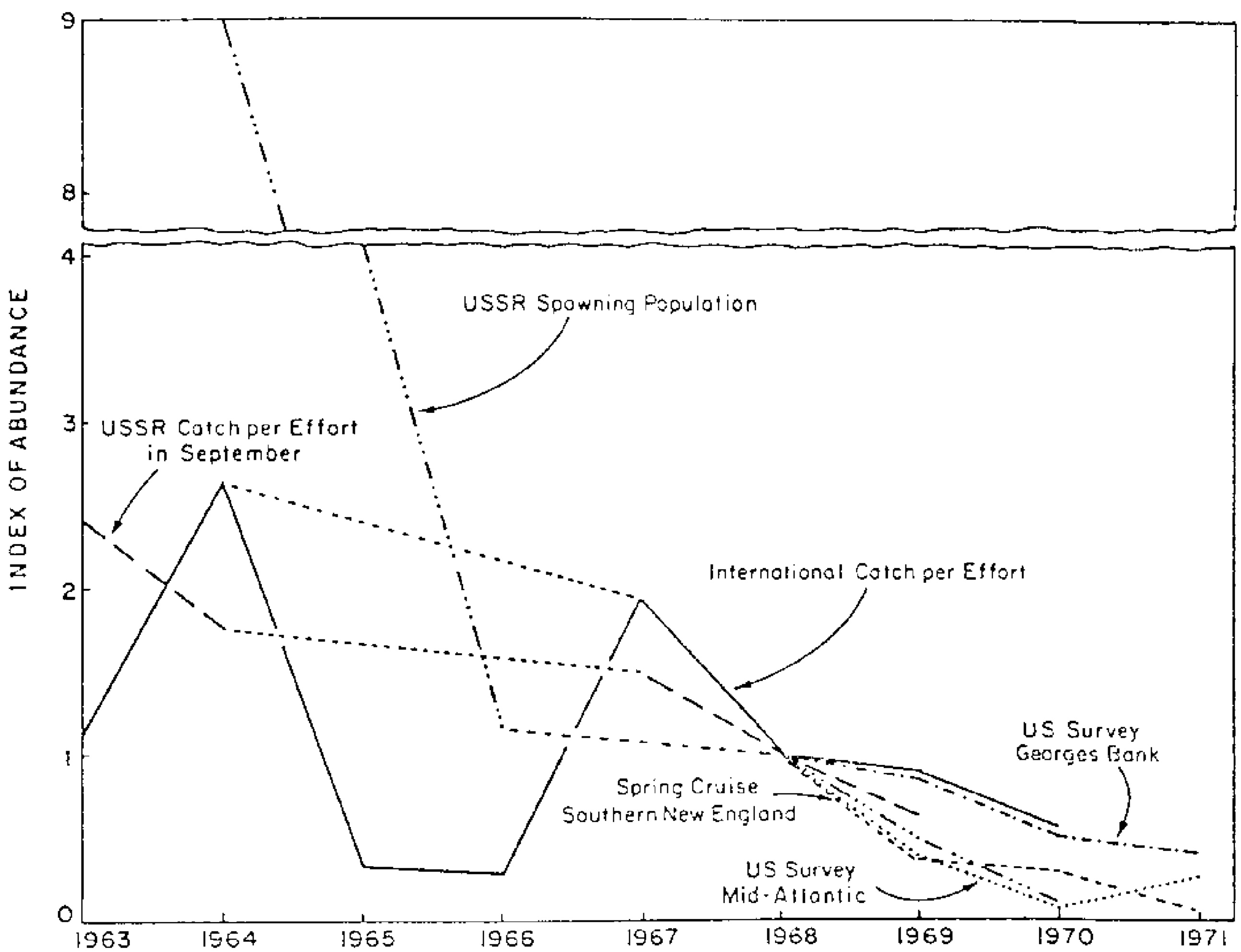

Figure 13. Indices of abundance of Atlantic herring of the Georges Bank stock.

country and vessel tonnage class on a monthly basis, but for rather large areas. Fishing power coefficients were calculated by month by country for each vessel class by ICNAF Division or Subdivision (Anthony, 1972). To obtain the effective effort on the Georges Bank herring stock, the individual efforts by each vessel class for each country were weighted by their fishing power to provide an estimate of the total standardized effort for each year (Table 10). The original catches per standardized day for 1965 and 1966 had to be adjusted for nondirected fishing for herring, and all efforts were adjusted for "learning factors" (Anthony, 1972).

Catch per standardized effort provides a good estimate of changes in stock size (Figure 14) except for 1974 to 1975. The fishing power calculations for 1975 were based on coefficients in 1974. Most of the effort from 1972 to 1975 was from mid-water trawls whose fishing power coefficients were determined using 1971 to 1974 data when the stock abundance was very low. The fishing power coefficients were, therefore, underestimated because the mid-water trawl catch per unit of effort data were compared with data from earlier years when stock abundance was high. The standardized effort was underestimated from 1971 to 1974 to the extent that mid-water trawls were used.

Catch per effort data are often not reliable for pelagic species but in this case with large changes in spawning stock size this method and several others (Figure 13) were adequate to indicate the decline.

FORMATION OF ASSESSMENT ADVICE FOR MANAGEMENT

The ICNAF herring assessments were conducted jointly by scientists from member nations each year usually in January to provide advice for management in that year. As many as four assessment meetings were held in some years as decisions were postponed or new data or new assessments became available. The details of these assessments are summarized in the Herring Working Group Reports in the ICNAF Redbook series and for Georges Bank in Anthony and Waring (1980).

Scientists were instructed to bring to the working group meetings catch data from their respective fisheries for the previous year on a monthly basis. Data were collated by applying age-length keys to length frequency information for each country separately on a monthly basis. The country catch-at-age data were combined to provide a total catch-at-age table (Table 11). Virtual population analysis or cohort analysis (Pope, 1972) was employed to estimate stock size and fishing mortality rates. Information from sources other than catch data was examined to learn the status of

Table 10. Catch-effort statistics of Georges Bank herring

YEAR	TOTAL CATCH[1] (METRIC TONS)	TOTAL EFFORT (THOUSANDS OF DAYS FISHED)	CATCH[1] /DAY	TOTAL STANDARDIZED EFFORT (THOUSANDS OF DAYS FISHED)	CATCH[1] /STANDARDIZED DAY
1961	67,550	5.9	11.40	12.4	5.45
1962	152,141	21.5[2]	7.09	117.7	1.29
1963	97,102	17.2	5.64	24.4	3.98
1964	130,758	18.5	7.06	13.7	9.54
1965	37,796	17.3	2.19	4.5	8.40
1966	135,723	21.2	6.41	17.6	7.71
1967	216,185	25.0	8.65	29.9	7.23
1968	358,638	38.7	9.26	99.3	3.61
1969	290,645	46.3	6.28	95.1	3.06
1970	243,516	36.9	6.60	122.6	1.99
1971	250,689	47.9	5.23	136.0	1.84
1972	171,355	46.2	3.71	138.4	1.24
1973	192,625	33.4	5.77	126.1	1.53
1974	145,929	28.2	5.18	46.9	3.11
1975	141,503	24.0	5.91	39.5	3.58
1976	42,760	5.0	8.53	-	-

[1]Does not include catches for which no effort data were reported.
[2]Not reported, effort was based on ratios of C/E for 1961, 1963, 1964.

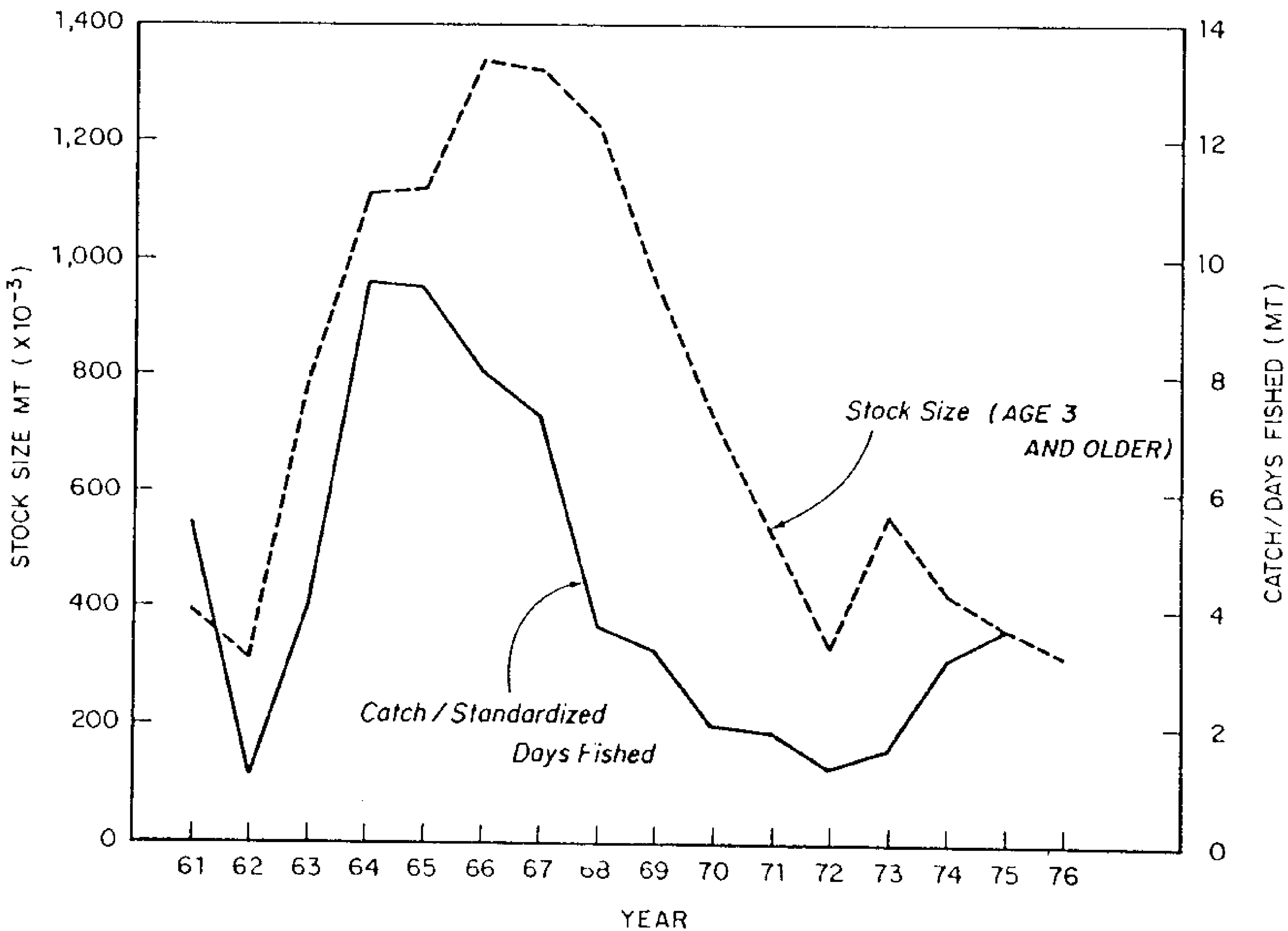

Figure 14. Comparison of Georges Bank herring abundance (age 3 and older) as calculated from cohort analysis with the catch (all ages) of Georges Bank herring per standardized days fished.

Table 11. Catch in numbers at age for the Georges Bank herring fishery

Year	2	3	4	5	6	7	8	9	10	11	TOTAL
					CATCH AT AGE (MILLIONS)						
1961	.0	13.8	45.2	171.8	64.1	13.8	7.0	.0	.0	.0	301.9
1962	.0	.0	43.4	99.5	299.1	140.4	18.3	2.7	.0	.0	603.4
1963	.0	190.3	66.1	145.6	67.6	14.7	5.9	.0	.0	.0	299.9
1964	16.5	150.8	230.5	128.4	97.5	34.9	.0	.0	.0	.0	491.3
1965	.4	10.3	34.9	103.0	25.5	12.7	9.3	.0	.0	.0	185.4
1966	.3	12.8	34.6	178.0	280.1	65.1	13.6	2.0	.0	.0	573.4
1967	1.8	6.9	60.6	108.0	250.7	379.2	49.4	11.1	10.0	.0	869.2
1968	2.5	52.1	133.3	336.0	233.4	432.9	336.4	21.8	6.6	.0	1500.6
1969	.0	73.4	210.8	277.1	278.1	188.5	190.5	109.7	23.6	.0	1278.3
1970	12.6	125.4	450.5	270.3	122.3	92.9	51.6	29.6	17.7	.0	1034.9
1971	12.9	332.5	275.5	284.6	175.8	103.9	50.4	13.9	21.8	.0	925.9
1972	28.0	35.0	110.0	214.0	158.0	100.0	45.0	29.0	21.0	.0	677.0
1973	10.0	1026.0	266.0	64.0	33.0	23.0	12.0	3.0	5.0	.0	406.0
1974	1.9	39.9	608.9	68.6	12.9	6.1	3.5	2.1	.0	.0	702.1
1975	1.4	11.3	76.8	503.0	34.6	12.5	6.2	4.2	.1	.0	637.4
1976	.5	7.5	6.8	18.6	140.8	5.1	2.3	1.2	.3	.0	175.1
1977	.1	.3	6.7	1.2	.2	1.9	.1	.1	.0	.0	10.2
1978	.1	5.6	2.3	4.3	.5	.3	1.2	.0	.0	.0	8.6
1979	.1	5.1	2.1	.4	.4	.0	.1	.0	.0	.0	2.9

the fully-recruited stock in the present year, since virtual population analysis provides very little information for recent years. Catch per effort and effort changes were examined when data were available in an attempt to learn about the stock status in recent years.

Trends in mortality and abundance declines were examined for each year class, and values were extrapolated forward to the current year when possible. All estimates of recruitment were considered, and assessment advice was generally provided to ICNAF for a range of recruitment levels if recruitment was a significant portion of the fishable stock. In 1974, "conventional levels" of recruitment were derived for poor year classes and for year classes when information was very limited. For both Georges Bank and the Gulf of Maine, the poorest year class ever observed was the 1969 year class. When a year class was known to be very poor, therefore, and its abundance at age 3 was not known, it was assigned a conventional level equal to that of the 1969 year class at age 3, as calculated in 1974. A conventional level for unknown recruiting year classes was also adopted. For Georges Bank and the Gulf of Maine, this level was approximately 50 percent of the 1966 year class at age 3. For the Nova Scotia fishey, the conventional level was one-third the size of the 1966 year class at age 3. These levels were conservatively chosen to be less than the long-term average recruiting year class. During the 1970s, the recruiting year classes were generally very poor except for the good 1970 year class, so this conventional year class was not used very often. When it was, however, it was designed to reduce the probability of overexploiting the year class at age 3, since maximum yield per recruit occurs at older ages.

ICNAF generally requested advice on catch levels which would result in certain stock levels in the following year. Advice was, therefore, given according to Figure 15. This figure was used in June 1975 for determining the TAC for 1976. The 1976 catch (age 3 and older) and resulting 1977 spawning stock size (age 4 and older) are shown for a range in fishing mortality in 1976. Catch and stock size were projected for two levels of recruitment for the 1973 year class in 1976.

The assessment of herring under ICNAF for management purposes began when a special meeting was held in June 1971 to produce advice on the allowable levels of herring catches in the Nova Scotia, Gulf of Maine, and Georges Bank areas. It was decided that management would consist of setting an annual total allowable catch (TAC) corresponding to a certain fishing mortality or to maintain a particular level of stock size. Since sufficient information for setting a TAC for

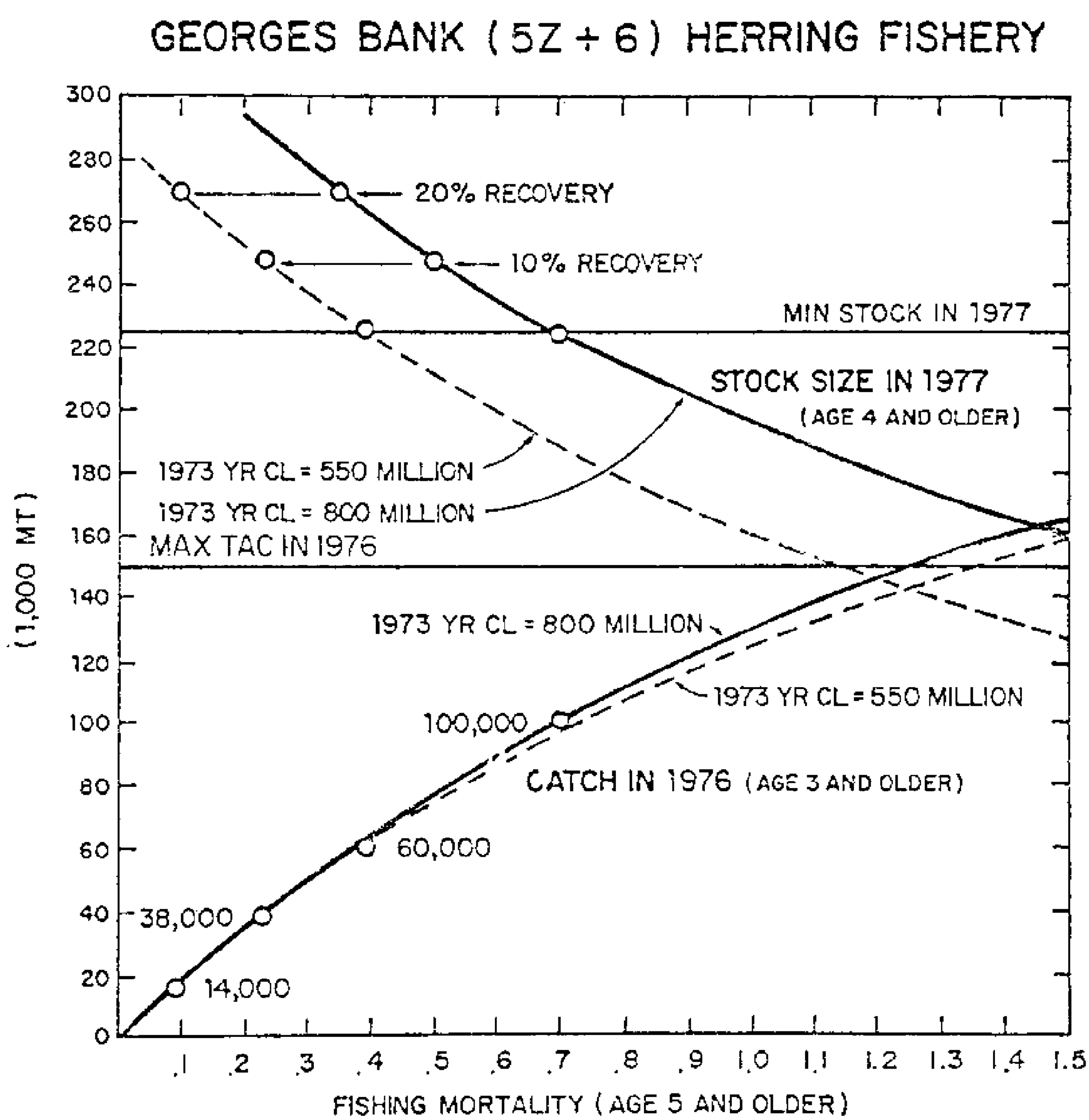

Figure 15. Advice presented to the Commission in June of 1975 for determining the 1976 TAC.

1972 was not available in 1971, the Herring Working Group was asked to consider three questions in January 1972: 1) what is the level of maximum sustainable yield (MSY); 2) what is the current level of the sustainable yield; and 3) what should the catches be to initiate a program of stock rebuilding. Because of the uncertainties associated with certain aspects of herring biology and, in particularly, the large fluctuations in year-class size, the concept of MSY, which had proven somewhat useful in the management of other species, was considered to be less useful for providing advice on herring.

The yield per recruit curve for Georges Bank herring was determined by Schumacher and Dornheim (1971) and Anthony (1972). The curve has no maximum with the right hand side of the curve becoming asymptotic as fishing mortality (F) increases. The curve shows a rapid increase in yield per recruit as F increases to 0.4 to 0.6, but then increases only slightly for further increases in mortality. An F of 0.6 on a long-term basis will provide 95 percent of the yield per recruit realized from an F of 1.6 (assuming M = 0.2).

Herring, therefore, have the potential for producing very high yields in those years immediately following good recruitment. Conversely, when recruitment is poor, a very high fishing mortality can significantly reduce the spawning stock. Since the spawning stock is composed of herring of ages 4 to 8 for the Gulf of Maine - Georges Bank area, a one-year reduction in spawning stock would require, at least, four years to rebuild. As early as 1972, then, the Herring Working Group was opposed to recommending any sustained level of catch (such as MSY) and certainly not catches corresponding to the level of fishing mortality (F_{max}) which would produce maximum yield per recruit, which was normally used for other species.

The Herring Working Group in 1972 attempted to answer the following questions: 1) what are the average annual catches possible if the stock is to be maintained at the level which will provide good recruitment; 2) what values of fishing mortality would provide a high yield per recruit while maintaining a proper level of spawning stock; 3) what would be the changes in spawning stock size following the adoption of the TACs; and 4) what TACs would be necessary to restore the stock at different rates.

A "conventional" level of fishing mortality ($F_{0.1}$) was derived which was thought to provide a high yield per recruit and be closer to the economic optimum while maintaining a spawning stock which would be sufficient to provide reasonable levels of recruitment (Gulland and Boerema, 1973). The fishing mortality level of $F_{0.1}$ is defined as the level of F at which the change in yield per recruit with respect to the change of F will be 1/10 of that which would occur in an unexploited stock; that is, the point when the net addition to the total catch achieved by an additional vessel is only 1/10 the yield taken by the first vessel operating in the fishery. This value of F was about 0.38 for herring of ages 3 to 9, and was used to calculate a total allowable catch which would provide a reasonable yield per recruit but also take into account, to some extent, the spawning stock-recruitment relationship.

The advice given to ICNAF was nearly always based on spawning stock size. While the scientists could not determine a stock-recruitment relationship, we did agree that some minimum level of spawning stock size should be maintained to insure a high probability of providing good recruitment. The Herring Working Group determined that the optimum spawning stock sizes for Georges Bank and the Gulf of Maine were 500,000 and 110,000 to 120,000 tons, respectively. These stock sizes were intended as a guide to management and were based on the average stock size in the 1960s which produced good year classes. Even though these levels of spawning stock were estimated from limited information, they were very useful, especially in January 1973, when catch quotas were being discussed with a view toward rebuilding the stock to some optimum level.

Most of the scientific advice on herring given to ICNAF during 1973 to 1977 dealt with stock abundance and the effects on the stocks of various catch levels and fishing mortality rates. The tagging information changed some stock boundaries and TACs, but generally the assessments consisted of estimating stock size and recruitment, and predicting changes in stock size. ICNAF had adopted the goal of rebuilding both the Georges Bank and Gulf of Maine stocks to a level capable of producing MSY. Maintaining the stock sizes at these levels was considered necessary to reduce the likelihood of recruitment failures which had resulted in the collapse of most other herring fisheries. Rebuilding the stocks could only be accomplished by harvesting less than the yearly increases produced by growth and recruitment. At the depressed stock sizes, the annual surplus depended almost entirely on recruitment, which was the greatest problem in offering advice on catch levels. In order to examine the long-term consequences of specific management options, assuming certain levels of recruitment, catch, and stock size, several projections were made. For example, the information pictured in Figures 16, 17, and 18 was presented to ICNAF in 1976. The stock size for Georges Bank for 1975 to 1981 was examined by applying a constant annual TAC of 60,000 tons and constant annual recruitment of 550 million fish (the conventional low level for poor year classes). This strategy resulted in a continuous increase in stock

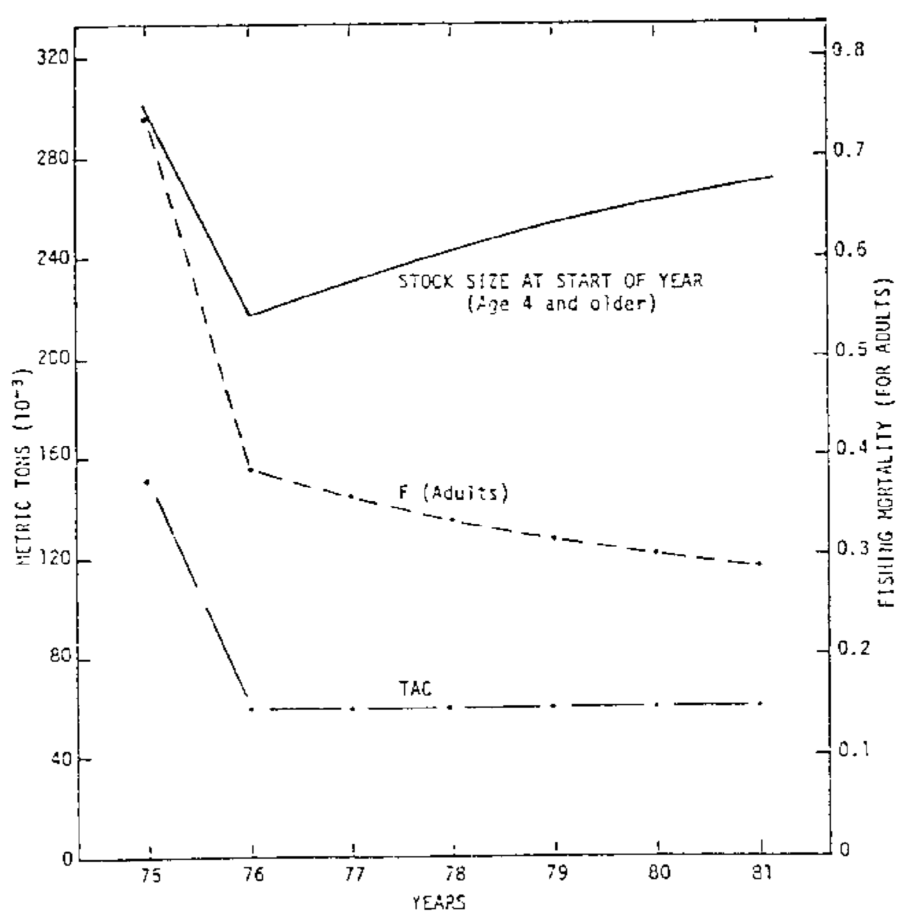

Figure 16. Georges Bank herring: simulated projections with constant recruitment of 550 million fish and TAC of 60,000 tons.

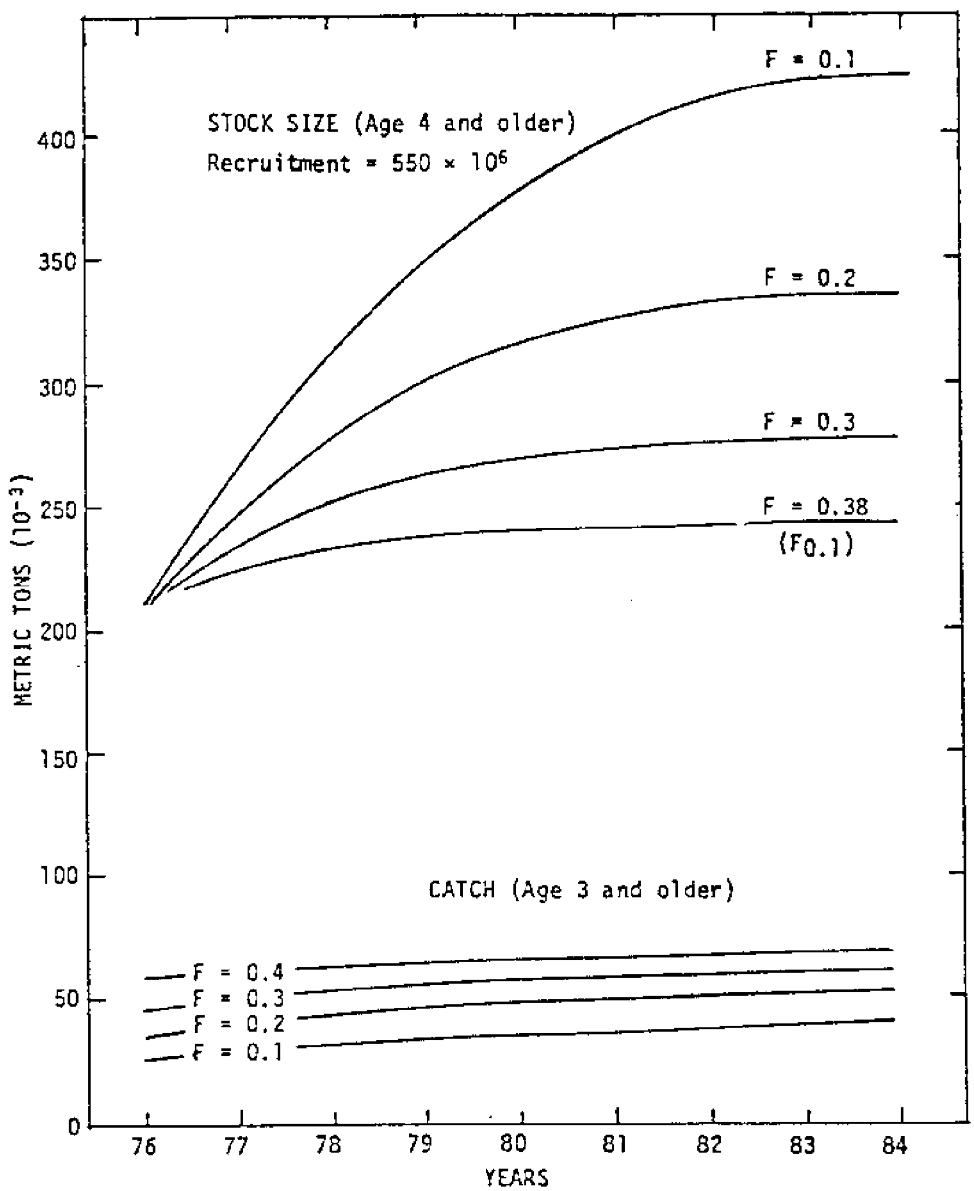

Figure 17. Georges Bank herring: simulated projections for four levels of fishing mortality with recruitment constant at 550 million fish.

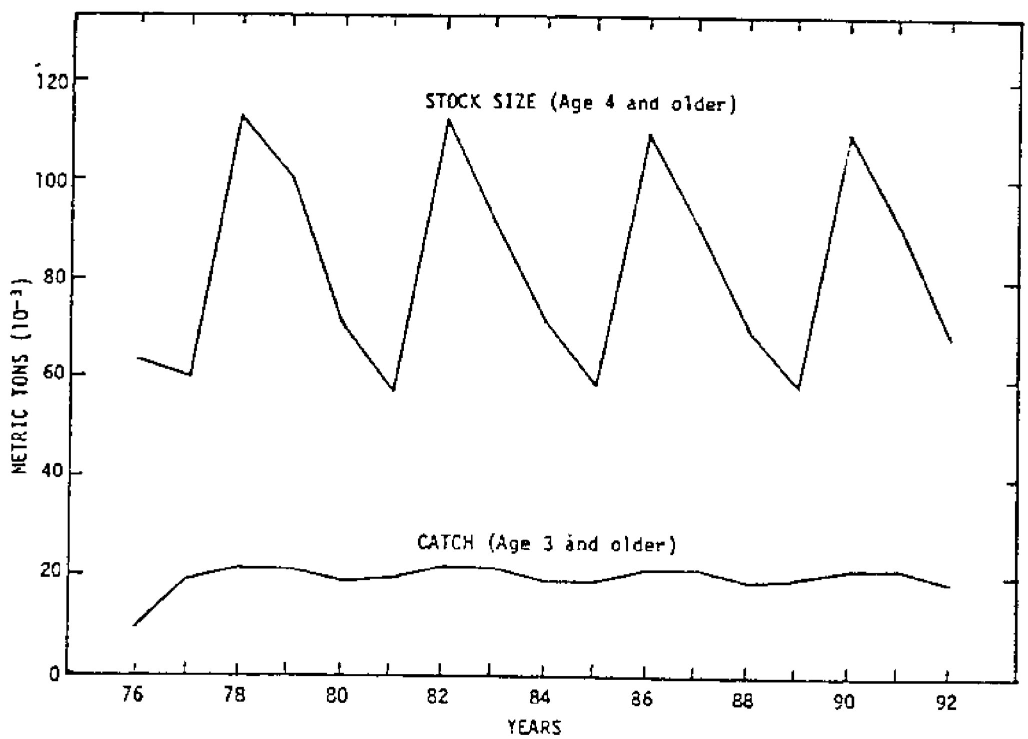

Figure 18. Gulf of Maine herring: simulated projections with fixed mortality at $F_{0.1}$, good recruitment (533×10^6 fish) every fourth year and poor recruitment (63.5×10^6) for the other years.

size, but by 1982 stock size would still be less than in 1975 and be only 58 percent of the desired level of 500,000 tons (Figure 16). In order to demonstrate a faster recovery rate, projections of catch and stock size were made using constant annual recruitment of 550 million fish and a range of constant fishing mortalities (Figure 17). Since good year classes occasionally occur in herring fisheries, other simulations were done using a fixed mortality rate of $F_{0.1} = 0.38$ (Figure 18). This simulation was done with the Gulf of Maine fishery with a good year class being recruited every fourth year (equal to the very good 1970 year class) and low recruitment of 64 million fish (the conventional level for poor year classes) for the other three years. The result indicated that the catch would nearly stabilize at about 20,000 tons. These simulations indicated the consequences of excessive fishing and the possible time required for stock recovery.

MANAGEMENT OF HERRING IN THE GEORGES BANK - GULF OF MAINE AREA

Fisheries management in the Northwest Atlantic was conducted under tha auspices of ICNAF during 1950 to 1976 by Canada, and by the US after 1976 when each country extended their jurisdiction to 200 miles. Management of herring did not begin until January 1972, since the ICNAF convention did not provide for the national allocation of catch quotas, and countries did not wish to compete for the total allowable catch without national allocations. On December 15, 1971, Article VIII of the Northwest Atlantic Treaty Convention was changed to allow for the national allocation of TACs. The First Special Meeting of ICNAF was held in January 1972 to formulate management objectives and methods for the herring stocks in ICNAF Subareas 4 and 5 and Statistical Area 6. The spawning stock decline in the Gulf of Maine and on Georges Bank was well recognized, and most countries felt that some management action was urgently needed. The ICNAF Standing Committee on Regulatory Measures had indicated that limited fishing was the most effective regulatory measure. All countries agreed that catch quotas were a possiblity. The USSR wished to see restrictions placed on fishing for both adults and juveniles at the same time, as well as a 9 to 10 inch (22.9 to 25.4 cm) size limit with a 10 percent weight exemption. Poland preferred closed seasons and areas, a minimum size limit, and a ban on fishing for juvenile herring. Proposals for a TAC for Georges Bank herring ranged from 70,000 to 250,000 tons. It was argued that the Georges Bank quota could be greater than that recommended by the assessment scientists because of limited scientific data, the "high larval abundance" recorded in the larval surveys, and the increase in Polish catch per unit of effort in recent years. After considerable deliberations, TACs of

150,000; 30,000; and 65,000 tons were set for the Georges Bank; Gulf of Maine; and Nova Scotia adult fisheries, respectively, for 1972 (Tables 4, 12, and 13). These quotas were further allocated to each country which assured each country of a specified catch which could be harvested according to its own economic timetable. This represented the first instance of national allocations of a total quota in the North Atlantic. Within several years, total quotas and national allocations were implemented for most fish stocks in the Northwest Atlantic.

The allocation procedure was based mainly on historical performance (both short- and long-term), interests of possible new entrants, and the special needs of the coastal states. A nine-inch minimum size was also instituted for herring in 1972, with exceptions in Canadian waters, together with a 10 percent annual weight exemption. Since ICNAF jurisdiction applied only to waters beyond three miles of the coast, the inshore juvenile herring fisheries were not subject to management under ICNAF.

The Georges Bank quota of 150,000 tons in 1972 was exceeded because the German Democratic Republic, a non-member of ICNAF, took 40,000 tons which was not a part of that allocated to member nations. The US, Canada, and the "others" category did not take all of the 18,000 tons allotted to them; the total catch in 1972 was 174,000 tons (Table 3). The instantaneous fishing mortality rate during 1972 was 1.35 on herring age 4 and older, the highest observed in the Georges Bank fishery from 1961 to 1976. This decreased the stock size of age 4 and older herring by 42 percent during 1972 to 137,000 tons (Table 4), the lowest ever observed in this fishery.

The Gulf of Maine quota of 30,000 tons was also exceeded as both Canada and the Federal Republic of Germany exceeded their allocations and GDR caught 9,300 tons. The abundance of this stock also reached an all-time low at the beginning of 1973. Canada also exceeded its quota off Nova Scotia with a resultant catch of 75,000 tons or 16 percent in excess of the TAC. No assessment was available for the Nova Scotia stock in 1973 so that the effect on stock size was unknown.

The situation in 1973 was one of very low stock abundance and recruitment of a very good year class (1970). The abundance of the stock in 1973-1974 was, thus, due in large part to the 1970 year class. The resulting wider range of allowable catches in 1973 designed to rebuild stock size at a given rate led to significant and very important changes in the management of herring in the Northwest Atlantic. A suggestion was made by the Chairman of the ICNAF ad hoc Committee on Herring Quotas and their Allocation on January 23, 1973, that regardless of the quotas, a commitment

Table 12. Management Scenario - 5Y adult fishery - Gulf of Maine

Year	Recruitment Age 3 (year class)	Recruitment Age 3 (000 tons)	TAC (000 tons) Recommended by Scientists	TAC (000 tons) Accepted by ICNAF	Catch Age 3 and Older (000 tons)	Stock Size at Beginning of Year Age 4 and Older (000 tons)
1967	1964	24.0	-		8	144
1968	1965	27.7	-		32	155
1969	1966	32.3	-		32	141
1970	1967	18.3	-		40	136
1971	1968	14.0	-		39	101
1972	1969	8.8	15-28	30	41	66
1973	1970	64.4	21-30	25	16	31
1974	1971	9.4	18-25	25	18	88
1975	1972	9.3	15-25	16	22	83
1976	1973	14.0	April 75- 9 June 75- 9 Jan. 76- 4-7	7	20	63
1977	1974	8.8	April 76- 0 June 76- 0	7	20	57
1978*	1975	14.0	8		19	41
1979*	1976	64.0	13		23	37

Optimum stock level - 80-120,000 MT
Optimum catch level - 20-40,000 MT
Mainimum stock level constraint - 60,000 MT
Maximum TAC unless stock size at optimum level - 25,000 MT

*Management under the jurisdiction of the NERFMC.

Table 13. Management Scenario - SW Nova Scotia stock

Year	Year Class	Recruitment[2] Age 2 (000 tons)		TAC (000 tons) Recommended by Scientist		TAC (000 tons) Accepted[2] by ICNAF	Catch[2] Age 2 and Older (000 tons)	Stock Size at end[2] of Year-Age 4 and Older (000 tons)
			4XW(b)	4W(a)[1]	4WX			
1965	1963	77	-	-	-			
1966	1964	46	-	-	-			
1967	1965	38	-	-	-		136	531
1968	1966	71	-	-	-		177	543
1969	1967	19	-	-	-		161	511
1970	1968	24	-	-	-		195	489
1971	1969	27	-	-	-		152	329
1972	1970	156	65	-	-	65	148	230
1973	1971	22	90	-	-	90	125	170
1974	1972	35	90	30	-	120	147	522
1975	1973	41	90	35	-	120	149	464
1976	1974	3	84	34	-	118	125	419
1977	1975	6	-	-	109[3]	109	118	440
1978	1976	82	-	-	111[3]	111	89	304

(1) TACs were set for 4XW(b) and 4VW(a). The 4W(a) area was proportioned out.
(2) Includes 4XW(b) and 4W(a).
(3) Management under Canadian jurisdiction.

should be included in the proposals for the 1973 TACs, to the effect that, in setting the 1974 TACs, ICNAF would take action to insure substantial restoration of the stocks and that the commitment be honored. Most member countries of ICNAF agreed in principle to the commitment proposal but wanted to have "substantial restoration" quantified. The US suggested that the commitment in the 1973 proposals be stock-size objectives of 300,000 tons in the Georges Bank stock and 62,000 tons in the Gulf of Maine stock by the end of 1974. These values were about three-fifths of the optimum size for each stock as reported by the Herring Working Group at that time.

The member countries of ICNAF agreed in January 1973 to establish objectives which would require rebuilding the Georges Bank and Gulf of Maine stocks to at least 225,000 tons and 60,000 tons, respectively, by the end of 1974. This became known as the minimum stock size constraint which later proved to be a very useful management tool. Although the minimum stock sizes selected were arbitrary, they were chosen from the best scientific evidence available to represent levels below which recruitment failure might occur.

Recruitment failure has occurred in many herring stocks, and the minimum stock size constraint provided a management procedure for preventing what appeared to be the inevitable fate of these stocks. This, however, placed added pressure on the assessments for precise estimates of recruitment and spawning stock sizes.

A second significant management procedure which was achieved in January 1973 was the implementation of maximum TAC levels. The member countries agreed to set allowable catches in 1973 to 150,000 tons (same as for 1972) for Georges Bank and 25,000 tons (30,000 tons in 1972) for the Gulf of Maine, which would be reduced in 1974 if the assessments indicated that the objectives of rebuilding the stock sizes to at least the minimum stock sizes could not be reached by the end of 1974. In any event, the TACs of 150,000 tons and 25,000 tons could not be increased until the stocks reached the levels which would provide their MSYs.

These constraints of minimum stock size and maximum allowable catch simplified management decisions considerably in the following years, but increased the need for greater precision in the assessments. However, the constraints established clearer guidelines to the scientists as to the type of assessment advice to provide. These constraints remained in effect until January 1976.

These management procedures did not apply to the Nova Scotia stock. Canadian scientists determined that the 1969 year class was proportionally larger in that stock than in the Georges Bank and Gulf of Maine stocks where it was the smallest yet observed. On that basis, the TAC for the Nova Scotia stock was increased from 65,000 tons in 1972 to 90,000 tons in 1973, with no stock size commitment for 1974.

The abundance of herring increased in all areas in 1973 due to the recruitment of the very good 1970 year class. The TACs recommended by the scientists and those agreed by ICNAF remained the same in 1974 as in 1973. The German Democratic Republic became a member of ICNAF in 1971, which greatly improved the management procedures.

In 1975 and 1976, the very good 1970 year class declined under heavy fishing and recruitment from the 1971, 1972, and 1973 year classes was very poor. It became necessary to exercise the minimum stock size constraints (Figure 15), and the TACs were reluctantly reduced for Georges Bank and the Gulf of Maine (Tables 4 and 12).

US fishermen requested a TAC reduction for the Gulf of Maine fishery in 1975, and it was reduced from 25,000 to 16,000 tons. ICNAF agreed to maintain the Georges Bank TAC at the 1974 level of 150,000 tons in 1975 taking "note of the cautionary statements of the scientists." The Nova Scotia TAC remained at 90,000 tons in 1975 in spite of scientific advice to reduce the TAC.

Based on the results of tagging studies conducted along Southwest Nova Scotia, the Division 4W(a) fishery (Chedabucto Bay, Nova Scotia) was combined with Division 4XW(b) for assessment purposes after 1975. Previous assessments considered all herring in 4V and 4W(a) to constitute one stock (Figure 4) which was separate from the Division 4XW(b) stock. The size of the recruiting year classes was readjusted to account for combining the Division 4W(a) and 4XW(b) fisheries, and the management period was changed from a calendar year basis to July 1 through June 30. The Chedabucto Bay fishery occurs from November to February. This change in assessment advice was so confusing that ICNAF was not able to adopt the new system of management. The Nova Scotia TAC was reduced slightly in 1976, and the spawning stock (age 4 and older) declined by 42 percent during 1976.

The 1976 reductions in stock sizes prompted ICNAF to set new TAC constraints for the Georges Bank fishery. In 1976 and thereafter, the TAC would be 60,000 tons or less (instead of 150,000 tons) each year until the adult stock reached the level providing MSY.

Because the Georges Bank TAC was so small in 1976 and because one country wished to re-examine the TAC in June 1976, the accepted 60,000 ton TAC for Georges Bank was halved with 30,000 tons allocated to the first six months of the year on incidental catch basis except for the US and

Canada. Purse seines were allowed to take herring during this period in a directed fishery as were all vessels less than 33.5 meters in length.

Because the herring stocks had declined so greatly in spite of the strong attempts to rebuild them, the US was committed in 1977 to the principle of completely eliminating directed fishing for herring if the recovery of the stock did not progress in a satisfactory manner. A TAC of 33,000 tons was proposed for 1977 for Georges Bank on the basis of a projected 10 percent recovery of the stock. This TAC as well as limiting the fishery to a "window" (Figure 19) area during August 15 to September 30, 1977 was agreed. This "window" area was the area in which the majority of herring had been caught in the previous two years.

The catch of herring in 1977 was only about 2,000 tons on Georges Bank (Table 4). It was calculated that the 1970 year class decreased in abundance from 48,000 tons in 1976 to about 10,000 tons in 1977 (Anthony and Waring, 1980), and all older year classes were essentially gone from the stock. The TAC, therefore, would have to come from the 1971 to 1974 year classes. The 1974 year class was only 12 percent recruited and the 1971 and 1972 year classes were known to be very poor. The bulk of the 1977 TAC of 33,000 tons, therefore, depended on the 1973 year class. Extensive surveys were conducted during the fall of 1977 throughout the "window" area and Georges Bank by vessels from the USSR, Poland, and FRG. Very few herring were found except near the Nantucket Shoals area. The lowest larval production recorded from 1968 to 1977 occurred in 1976 and 1977. While the 1973 and 1974 year classes may not have recruited to the "window" area, or were distributed differently than in prior years for these two age groups, the Georges Bank herring stock was probably at its lowest level in 1977 and would not support a fishery of any significance until the recruitment of another good year class.

Under the auspicies of the New England Regional Fishery Management Council (NERFMC), a management body formed by the US Fishery Conservation and Management Act of 1976, a management plan for regulating the adult herring fisheries of the Gulf of Maine and Georges Bank went into effect in July 1978. Whereas calendar year TACs had been set for the Gulf of Maine and Georges Bank stocks under ICNAF, the NERFMC began regulating the stocks on a fishing season basis. Seasonal fishing periods of July to November and December to June were established. The rationale for this management regime was to shift some of the effort away from the autumn spawning fish and onto herring which were felt to be migrating during winter-spring from the larger Nova Scotia stock. The seasonal/area allocations for 1978-1979 are presented in Table 14; there was no allocation for distant water fleets.

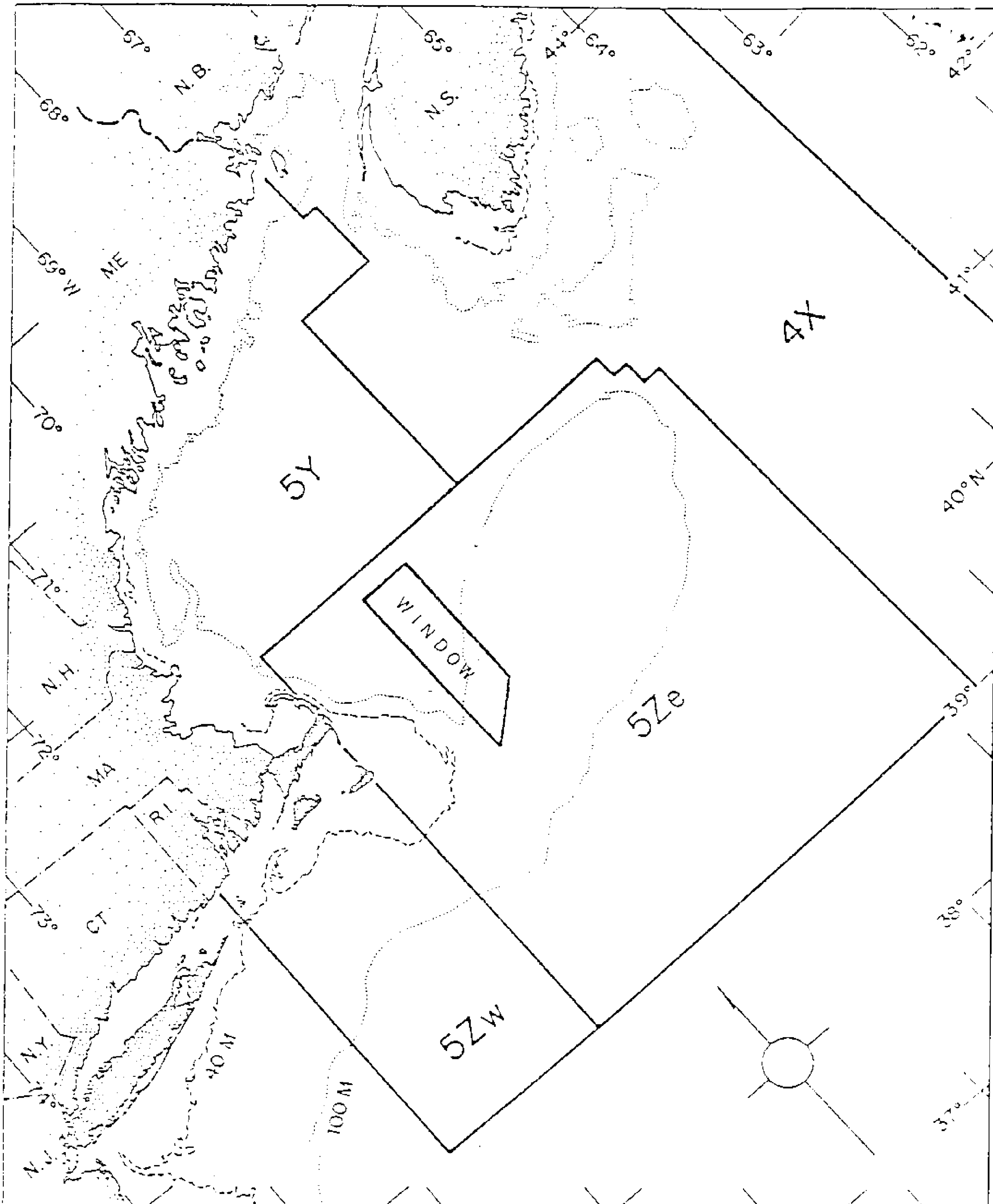

Figure 19. The "window" area in 1977 on Georges Bank that was opened for fishing for herring during August 15 - September 30.

Table 14. Summary of the U.S. catch allocations (tons) set for the northwest Atlantic herring fisheries under U.S. jurisdiction by the New England Regional Fisheries Management Council

Seasonal Period	Stock/Allocation Gulf of Maine (Jeffreys Ledge)	Georges Bank
July-November 1978	4,000	7,500
December 1978-June 1979	4,000	2,500
July-November 1979*	8,850	
December 1979-June 1980*	1,620	
July-November 1979	9,000	
April-June 1980	1,530	
December 1979-March 1980**		12,000
July-November 1979***		
December 1979-March 1980***		
April-June 1980***		(12,000)

* Recommended for adults (age 3 and older) taken in Maine coastal fishery.
** Western Gulf of Maine adult fishery and Georges Bank east of 71°50.
*** All areas (Jul. 79-No. 79, Apr. 80-Jun. 80) west of 71°50 (Dec. 79-Mar. 80); 2,000 tons allocated to Canada pending certification of US/Canadian fisheries agreement).

In February 1979, scientists from the NERFMC, the Northeast Fisheries Center, and the Maine Department of Marine Resources conducted a pooled assessment for all herring stocks between Chedabucto Bay, Nova Scotia and Cape Hatteras, North Carolina. Tagging results had indicated a considerable mixture of herring stocks during non-spawning periods in various areas, which implied, therefore, that catches from a particular area do not always come from the same stock mixture each year. In some years, catches are greater in certain months than in others, and differing amounts of a given stock are available in a given area depending on the timing of migrations, stock sizes, and environmental factors. Assessments were traditionally based on assumptions easily violated under such conditions. Calculation of mortality rates, for example, on a year-class basis assumes that the catch at age 5 is partially a function of the catch of that year class at age 4. If the stock composition varies from year to year, catches of successive ages of the same year class may not be related. Combining catches from all of the fisheries avoids these problems, but creates new ones in the final allocation of catch quotas among areas.

The pooled assessment was completed and surplus production determined for 1979. The projected Canadian catch, based on stated intent and past performance, was subtracted from the overall surplus production. An estimate of the Georges Bank share of the stock was subtracted, and the remainder of the surplus production was apportioned to the various fisheries based on recent performance. This amount was further divided by season, consistent with past fishing practices, so as to be fair to all user groups (Table 14).

Canada also continued to manage herring off Nova Scotia after 1977 as had been done in ICNAF except that it finally was able to combine the management of the Chedabucto Bay fishery with the southwest Nova Scotia fishery (Div. 4XW(b)).

In 1978 and 1979, Maine enacted management plans for adult herring taken in the coastal herring fishery (inside three miles). The principal objectives of both Maine plans were to rebuild the herring stocks consistent with the preservation of the Maine herring industry by 1) the prevention of overfishing and expansion of the fishery for large herring, and 2) the protection of spawning herring through seasonal and area closures.

In the 1978 plan, a catch quota of 3,500 tons was applied to herring age 4 and older (10 inch and larger). In 1979, to be consistent with the management plan developed by the NERFMC, the Maine plan applied to age 3 and older herring (9 inch and larger). The total 1979 Maine allocation was 10,470 tons, of which 8,000 tons was allocated to the mobile gear fishery and 2,470 tons was allocated to the fixed gear fishery (weirs and stop seines). The allocations were further divided into directed and non-directed amounts to allow fishing for small fish to continue after the quotas for large herring were reached. A tolerance of 25 percent by volume was allowed except when spawning restrictions applied. Restrictions were not placed on the juvenile fishery; it was assumed that the exploitation rate would not increase, and that the juvenile catch would be proportional to abundance. If these assumptions became invalid, quotas were recommended to control the mortality. Spawning closures were in effect during both 1978 and 1979. The Maine coast was divided into two sections, with the eastern section closed to the taking of herring (9 inches and larger) by mobile gear for a six-week period during August to October. The western section of the state was also closed to mobile gear for six weeks during September and October. A tolerance of 10 percent by volume of an entire lot (boat load) was allowed.

Other management restrictions in Maine waters currently in force are:

1) Minimum size (4.5 inches) and human consumption only.

2) Prohibition of the scaling and dumping of fish.

3) Prohibition of the taking of herring with artificial lights.

4) Laws governing vessel capacity measurements and reporting of landings data.

5) Gear conflict regulations.

6) A closure of Washington County to purse seine fishing from April 10 to October 15 each year.

SUMMARY OF HERRING ASSESSMENTS AND MANAGEMENT

Assessments failed to detect the magnitude of recruitment decline in the Georges Bank fishery from 1974 to 1976. The estimates of recruitment that were made in other years were very good, and even during 1974 to 1976, the estimates of recruitment for the Gulf of Maine fishery were surprisingly close to the levels accepted in 1980. The 1971 and 1972 year classes were known to be poor and were assumed to be equal in size to the poorest recruitment observed in the fishery, the 1969 year class at age 3. This was the case for the Nova Scotia and Gulf of Maine fisheries, but apparently not so for the Georges Bank fishery. There had previously been good agreement in relative year class size among the three adult fisheries (Figure 8). Large, unreported catches would have explained the sudden decline in stock abundance, but this seems unlikely to have occurred. Very few pre-recruit herring were caught in the juvenile herring surveys during 1974 to 1976, but it was felt by some scientists that bottom trawling for herring could not provide an accurate estimate of abundance since so few were being caught. This was especially true when survey catches appeared to conflict with each country's commercial catch per effort.

In 1972, some countries could not agree with the majority report of the Herring Working Group, and an independent assessment was produced (Draganik, 1973) which recommended a catch of 140,000 tons in 1972 and projected a stock of 706,000 tons at the beginning of 1973. The Working Group, on the other hand, recommended a TAC of between 50,000 and 95,000 tons. A 150,000 ton TAC was accepted by ICNAF, 172,000 tons were caught, and the stock size (age 4 and older) was reduced to 137,000 tons at the beginning of 1973 (Table 4). The disagreements among scientists undoubtedly affected the management decision to accept 150,000 tons for the 1972 TAC. Disagreements among the scientists in November 1974 probably also contributed to the failure of ICNAF to address the consequences of stock decline in 1975.

In 1972 and 1973, fishing mortality (age 4 and older) averaged 1.35 and 1.00, respectively. If the very strong 1970 year class had not recruited in 1973, the Georges Bank fishery would have ended by 1974. Fishing at $F_{0.1}$ (0.33-0.38) would have been acceptable, given average recruitment.

With recruitment less than average, F should be less than 0.35. During 1968 to 1975, the lowest average F for age 4 and older was 0.53. Although managing the Georges Bank herring fishery according to some arbitrary F level is probably not the best management procedure, fishing mortality should have been more carefully controlled.

Although ICNAF addressed the proper issues (i.e., rebuilding and maintenance of stock size, an F less than F_{max}) and set constraints to achieve these goals, the TACs were set more for economic rather than for conservation reasons. The 1972 TAC was three times higher than the lower recommendation made by the scientists (Table 4). The 1974 TAC was from 11 to 18 percent greater than that recommended, and in 1975, attempts to reduce the already-accepted TAC of 150,000 to 90,000 tons failed although new information indicated that the 1973 year class had been overestimated. In general, when a range of TACs was advised, indicating some uncertainty in the assessments, the largest TAC was accepted by ICNAF. The TACs were set on the basis of maintaining abundance, although the goal of rebuilding was agreed. In 1976, despite warnings of a collapse of the fishery, that recruitment had been poor since the 1970 year class, and that a TAC of 40,000 would only allow slight rebuilding of the stock, several countries still recommended a TAC of 60,000 tons. In view of the general reluctance of managers to heed scientific advice, even if accurate estimates of recruitment had been known in the period 1974 to 1976, the recommended level probably would not have been accepted.

One possible explanation for the collapse of the Georges Bank herring stock is the way overfishing occurred. Fishing was excessive during the spawning period, with spawning area after spawning area, moving from east to west, successively depleted. The fisheries appeared to shift in this fashion until the catches in the westernmost spawning area on Georges Bank finally failed. The distribution of larvae also indicated the shift in larval production from east to west. By February 1978, the only larvae present appeared to come from the Nantucket Shoals area.

In addition to the demise of spawning stocks because of fishing, the indirect effects of fishing may also have been important in the Georges Bank decline. When recruitment fails, scientists usually look at the size of the spawning stock for the reason of failure. Often, one finds that the spawning stock appears to be sufficient in size, but recruitment fails as the fishery develops. For Georges Bank, recruitment declines may have been due to the act of fishing rather than the decline of the spawning stock. Heavy fishing directly on the spawning grounds may have interfered with the spawning process. It is well known that herring are easily broken up by fishing vessels, and the number of vessels fishing the Georges Bank spawning grounds was very great in the late 1960s and early 1970s. As indicated earlier, the estimated decline in the spawning population, as indicated by the number of eggs laid (Figure 13), was greater than the decline in the stock itself. Realizing that the decline in spawning populations from egg counts may have been overestimated, the difference in the decline rates, still, may have been partially due to a reduction in spawning efficiency due to the act of fishing.

LITERATURE CITED

Anthony, V. C. 1971. The density dependence of growth of the Atlantic herring in Maine. Rapp, P.-v. Réun. Cons. Int. Explor. Mer, 160: 197-205.

__________. 1972. Population dynamics of the Atlantic herring in the Gulf of Maine. Ph.D. Thesis, Univ. Wash., 266 pp. (unpublished).

Anthony, V. C., and H. C. Boyar. 1968. Comparison of meristic characters of adult Atlantic herring from the Gulf of Maine and adjacent waters. Int. Comm. Northw. Atlant. Fish., Res. Bull. No. 5: 91-98.

Anthony, V. C., and B. E. Brown. 1972. Herring assessment for the Gulf of Maine (ICNAF Division 5Y) stock. Int. Comm. Northw. Atlant. Fish., Res. Doc. 72/13, Ser. No. 2696.

Anthony, V. C., C. W. Davis, G. Waring, M. Grosslein, and T. Burns. 1975. Size distribution and recruitment estimates for sea herring of the Georges Bank-Gulf of Maine region, based on trawl surveys by research vessels. Int. Comm. Northw. Atlant. Fish., Res. Doc. 75/110, Ser. No. 3603 (mimeo): 45 p.

Anthony, V. C., and G. Waring. 1980. The assessment and management of the Georges Bank herring fishery. Rapp. P.-v. Réun. Cons. Int. Explor. Mer, 177: 72-111.

Boyar, H. C. 1966. Distribution and abundance of larval herring on Georges Bank. Int. Comm. Northw. Atlant. Fish., Res. Doc. 66/62: 4 pp.

__________. 1968. Age, length, and gonadal stages of herring from Georges Bank and the Gulf of Maine. Int. Comm. Northw. Atlant. Fish., Res. Bull. No. 5: 49-61.

Boyar, H. C., R. R. Marak, F. E. Perkins, and R. A. Clifford. 1973. Seasonal distribtuion and growth of larval herring (Clupea harengus L.) in the Georges Bank-Gulf of Maine area from 1962 to 1970. J. Cons. Int. Explor. Mer, 35(1): 36-51.

Colton, J. B., and R. F. Temple. 1961. The enigma of Georges Bank spawning. Limnol. Oceanogr. 6(3): 280-291.

Das, N. 1968. Spawning, distribution, survival, and growth of larval herring (Clupea harengus L.) in relation to hydrographic conditions in the Bay of Fundy. J. Fish. Res. Bd. Can., Tech. Rep. 88: 129 pp.

Davis, C. W., and T. L. Morris. 1976. Preliminary report on the distribution, catches, and sizes of age 1 herring in the Gulf of Maine and Nantucket Shoals during the spring of 1976. Int. Comm. Northw. Atlant. Fish., Res. Doc. 76/114, Ser. No. 3937: 8 p.

Draganik, B. 1973. Estimates of fishing mortality and stock size of herring-Georges Bank. Int. Comm. Northw. Atlant. Fish., 73/17, Ser. No. 2919.

Graham, J. J., S. B. Chenoweth, and C. W. Davis. 1972 Abundance, distribution, movements and lengths of larval herring along the western coast of the Gulf of Maine. Fish. Bull. 70(2): 307-321.

Graham, J. J., and P. M. W. Venno. 1968. Sampling larval herring from tidewaters with buoyed and anchored nets. J. Fish. Res. Bd. Can. 25: 1169-79.

Grosslein, M. D. 1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Mass., U.S.A. Int. Comm. Northw. Atlant. Fish., Res. Doc. 74/96, Ser. No. 3332 (mimeo).

Gulland, J. A., and L. K. Boerema. 1973. Scientific advice on catch levels. U.S. Fish. Bull. 71(2): 325-335.

ICNAF. 1975. Reprot of second meeting of environmental working group. ICNAF Redbook, 1975 (App. V, Annex 1): 95-104.

__________. 1976. Report of Ad Hoc working group on planning for international herring tagging program. Int. Comm. Northw. Atlant. Fish., Redbook 1976 (App. VI): 153-156.

__________. 1977. Report of standing committee on research and statistics, May 1977. App. IV. Report of the Environmental Studies Working Group. ICNAF Redbook, 1977, Part B: 43-44.

Iles, T. D. 1971. The retention inside the Bay of Fundy of herring larvae spawned off the southwest coast of Nova Scotia. Int. Comm. Northw. Atlant. Fish., Res. Doc. 71/98, Ser. No. 2575: 93-103.

Lough, R. G. 1976. The distribution and abundance, growth and mortality of Georges Bank-Nantucket Shoals herring larvae, during the 1975-76 winter period. Int. Comm. Northw. Atlant. Fish., Res. Doc. 76/123, Ser. No. 4004: 30 p.

McKenzie, R. A. 1950. A new celluloid opercular tag. Trans. Amer. Fish. Soc. for 1948, 78: 114-116.

McKenzie, R. A., and B. E. Skud. 1958. Herring migrations in the Passamaquoddy region. J. Fish. Res. Bd. Can. 15(6): 1329-1343.

Miller, D. S., and R. G. Halliday. 1974. An assessment of the 4X-4w(b) herring stock. Int. Comm. Northw. Atlant. Fish., Res. Doc. 74/13, Ser. No. 3159.

Miller, D. S., and T. D. Iles. MS 1975. Catch statistics for the Bay of Fundy herring fisheries 1963-1974. MFS Technical Report No. 594.

Noskov, A. S., and V. N. Zinkevich. 1967. Abundance and mortality of herring (Clupea harengus L.) on Geroges Bank according to the results of egg calculation in spawning areas in 1964-1966. Int. Comm. Northw. Atlant. Fish., Res. Doc. 67/98, Ser. No. 1897: 16 p.

Parrish, B. B., and A. Saville. 1965. The biology of the Northeast Atlantic herring populations. In: Oceanogr. Mar. Biol. Ann. Rev. 3: 323-373.

Perkins, F. E., and V. C. Anthony. 1969. A note on the fecundity of herring (Clupea harengus L.) from Georges Bank, the Gulf of Maine and Nova Scotia. Int. Comm. Northw. Atlant. Fish., Redbook, Part III: 33-38.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northw. Atlant. Fish., Res. Bull. 9: 65-74.

Ridgway, G. J., R. D. Lewis, and S. Sherburne. 1969. Serological and biochemical studies of herring populations in the Gulf of Maine. Int. Council for Explor. of the Sea, Committee Memorandum No. 24.

Scattergood, L. W. 1952. The maturity of the Maine herring (Clupea harengus). Maine Dept. Sea and Shore Fish., No. 7: 1-11.

Schnack, D. 1975. Summary of the ICNAF joint larval herring survey in Georges Bank-Gulf of Maine areas, September-December 1974. Int. Comm. Northw. Atlant. Fish., Res. Doc. 75/112, Ser. No. 3605: 23 p.

Schultz, H. 1974. The fecundity of Georges Bank herring in 1971. Int. Comm. Northw. Atlant. Fish., Res. Doc. 74/119, Ser. No. 3372: 8 p.

Schumacher, A., and H. Dornheim. 1971. Estimation of fishing mortality in the Georges Bank herring stock. Int. Comm. Northw. Atlant. Fish., Res. Doc. 71/126, Ser. No. 2625.

Sindermann, C. J. 1957. Diseases of fishes of the Western North Atlantic. V. Parasites as indicators of herring movements. Maine Dept. Sea and Shore Fish., Res. Bull. No. 27: 1-30.

__________. 1962. Serology of Atlantic clupeoid fishes. Amer. Nat., Vol. 96(889): 225-231.

Sindermann, C. J., and D. F. Mairs. 1959. A major blood group system in Atlantic sea herring. Copeia, No. 3: 228-232.

Speirs, G. D. 1978. Personal communication. Maine Dept. of Marine Resources, West Boothbay Harbor, Maine.

Stobo, W. T. 1974. The Canadian 4VWa herring fishery: analysis of the 1973-1974 catch, and the distribution of fishing activity and catch per unit effort from 1971-1974. Int. Comm. Northw. Atlant. Fish., Res. Doc. 74/95, Ser. No. 3331.

Stobo, W. T. 1975. The 1974-75 Canadian Cape Breton (4VWa) herring fishery. Int. Comm. Northw. Atlant. Fish., Res. Doc. 75/39, Ser. No. 3518.

Stobo, W. T. 1976. Movements of herring tagged in the Bay of Fundy-Update. Int. Comm. Northw. Atlant. Fish., Res. Doc 76/48, Ser. No. 3834.

Stobo, W. T. 1976. Some techniques and procedures used to tag herring in ICNAF Subarea 4. Int. Comm. Northw. Atlant. Fish., Res. Doc. 76/101, Ser. No. 3924: 12 p.

Stobo, W. T., D. F. Gray and K. Metrizala. 1978. Herring assessment on Div. 4WX. CAF SAC Research Document 78/25, 17 pp.

Stobo, W. T., J. S. Scott, and J. J. Hunt. 1975. Movements of herring tagged in the Bay of Fundy. Int. Comm. Northw. Atlant. Fish., Res. Doc. 75/38, Ser. No. 3517.

Tibbo, S. N., and L. M. Lauzier. 1970. Seasonal distribution of larval herring in the Bay of Fundy and Gulf of Maine. Int. Comm. Northw. Atlant. Fish., Res. Doc. 70/52.

Tibbo, S. N., and J. E. H. Legaré. 1960. Further study of larval herring (Clupea harengus L.) in the Bay of Fundy and Gulf of Maine. J. Fish. Res. Bd. Can., 17(6): 933-942.

Tibbo, S. N., J. E. H. Legaré, L. W. Scattergood, and R. F. Temple. 1958. On the occurrence and distribution of larval herring (Clupea harengus L.) in the Bay of Fundy and the Gulf of Maine. J. Fish. Res. Bd. Can., 15(6): 1451-1469.

Watson, J. E. 1963. A method for tagging immature herring. U.S. Dept. Interior, Fish and Wildlife Serv., Spec. Sci. Rep. Fish. No. 451, 7 p.

Zinkevich, V. N. 1967. Observations on the distribution of herring. Clupea harengus L. on Georges Bank and in adjacent waters in 1962-1965. Int. Comm. Northw. Atlant. Fish., Res. Bull. 4: 101-115.

THE HERRING RESOURCE OF EASTERN CANADA

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ABSTRACT

Herring fisheries have existed along the Atlantic coast of Canada since native times and now consti tute one of the major commercial fisheries. Two spawning types, autumn spawners and spring spawners, have been identified with autumn spawners being dominant in the southern stocks and spring spawners in the northern and eastern stocks. Ten herring stock areas have been defined, based primarily on the results of tagging experiments. Two additional areas remain in which the stock relationships are not yet well known. The general migratory patterns of each of these stocks is discussed.

Catches from these stocks have been as large as 500,000 mt but since the late 1970s have stabilized at the 250,000 mt level. Many gear types are utilized and can be classed generally into two categories: mobile gear and fixed gear. The purse seine is the main mobile gear with fixed gear including traps, gillnets and weirs.

One of the most significant factors in the popula tion dynamics of these stocks is the variation in year-class strength which affects catch compo- sition and biomass levels. The recruitment problem has been examined in terms of stocks and recruit relationships, multispecies interactions and density- dependent and independent effects.

Since 1973, a management process has been in place for regulating the herring fishery particularly through such bodies as ICNAF, CAFSAC and the Atlantic Herring Management Committee. While all ten stocks are now under quota regulation, many problems remain particularly with regard to obtaining estimates of recruitment and independent estimates of abundance.

INTRODUCTION

Atlantic herring (<u>Clupea harengus harengus</u>) occurs throughout the Northwest Atlantic from West Greenland south to Cape Hatteras (Leim and Scott, 1966). Herring stocks have been exploited in North America for centuries, initially by native races and subsequently by Europeans, as a source of food and bait (Scattergood and Tibbo, 1959). Herring catches from the Canadian Atlantic (this corresponds roughly to NAFO (formerly ICNAF) areas 2-4) averaged 98,000 mt during the period 1920-1954 with peak catches being recorded during the post World War II period (Scattergood and Tibbo, 1959). These peak catches resulted from improved market conditions relating to aid programs created by the United Nations Relief Association (UNRA). The increased world demand for protein and the decline in European and West Pacific herring stocks during the 1960s resulted in a rapid expansion in Northwest Atlantic herring catches to peak levels of 568,000 mt in 1969; during the 1970s, with the imposition of catch quotas, landings have averaged 250,000 mt.

In the past, catch levels were greatly influenced by market conditions. With recent developments in the concepts of "fisheries management" this has changed to the situation where catch levels are controlled by government decree, with the aim of optimizing yield while conserving the resource. The role of the fisheries biologist has also changed from that of collecting biological data without specific time constraints for their analyses to one of examining the population dynamics of fish stocks on a real-time basis while attempting to assess the impact of various management strategies. To meet the demand for advice, research has expanded to include definition of stock boundaries, estimation of population parameters, such as mortality rates, in addition to continuing research on basic biological topics including species interactions.

HERRING STOCKS OF THE CANADIAN ATLANTIC

On the basis of present information, ten herring stock areas have been defined with two areas in which the stock relationships have yet to be established (Figure 1). These stock areas represent management zones containing stock complexes. The stock areas are:

1) Eastern and Southeast Newfoundland:

   a) White Bay-Notre Dame Bay (Area 2)
   b) Bonavista Bay (Area 3)
   c) Trinity Bay (Area 4)
   d) Conception Bay-Southern Shore (Area 5)
   e) Placentia Bay-St. Mary's Bay (Area 6)
   f) Fortune Bay (Area 7)

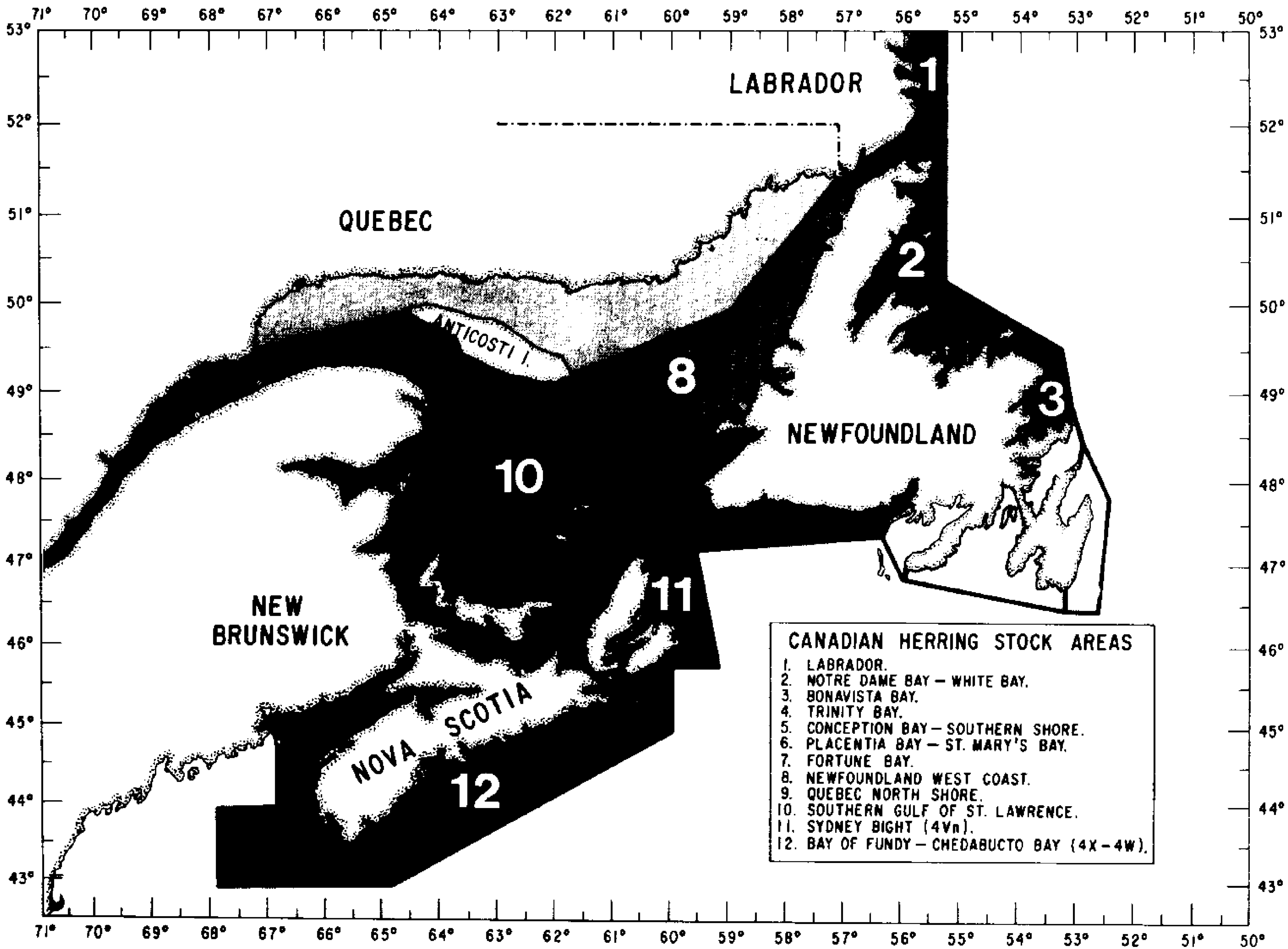


Figure 1. Herring stock areas in the Canadian Atlantic.

2) Gulf:

   a) Newfoundland west coast (Area 8)
   b) Southern Gulf of St. Lawrence (Area 10)

3) Southern Nova Scotia and New Brunswick:

   a) Sydney Bight (ICNAF/NAFO Div. 4V) (Area 11)
   b) Bay of Fundy-Chedabucto Bay (ICNAF/NAFO Div. 4W+4X) (Area 12)

The remaining two areas (Labrador (Area 1) and the Quebec North Shore (Area 9)) are lightly exploited and have yet to be studied in sufficient depth to ascertain whether they are separate stock areas or are related to adjacent areas.

SPAWNING TYPES

Two spawning types of herring have been identified in the Northwest Atlantic; spring spawners and autumn spawners. The spawning season for spring spawners occurs between mid-April and mid-June and for fall spawners between mid-August and mid-October. The proportion of each spawning type varies from stock to stock and from year to year within stocks. At present, a general north-south cline exists with spring spawners being dominant in the north and autumn spawners dominant in the southern stocks (Table 1).

Variability in spawning type within a stock results primarily from variation in the success of the two components in producing strong year-classes. This can be clearly seen in the case of the southern Gulf of St. Lawrence herring stock (Area 10). During the early 1950s, this stock was characterized as a spring spawning stock (Leim, 1957). In the mid-1950s, the stock was decimated by a fungus disease, *Icthyosporidium hoferii* (Tibbo and Graham, 1963; Sinderman, 1966) but rebounded quickly with the production of two large year-classes in 1958 and 1959 (Winters and Hodder, 1975). The largest of these was the 1958 year-class of autumn spawners and effectively resulted in the stock being predominantly autumn spawners (Figure 2a). Autumn spawners remained dominant during the 1960s and early 1970s until the recruitment of the 1974 year-class which shifted the stock to predominantly spring spawners (Winters and Moores, 1979a). This shift can also be seen in the Newfoundland West Coast stock where the recruitment of the 1968 year-class of spring spawners completely reversed the spawning type (Moores, 1979) (Figure 2b).

The two spawning types show marked differences in selections of spawning sites and spawning temperatures. The spring spawners spawn in an increasing temperature regime

Table 1. Approximate levels of the two spawning components in the Canadian sub-areas in 1978.

Areas	% Autumn spawners	% Spring spawners
Newfoundland	2	98
Gulf of St. Lawrence	35	65
Nova Scotia and New Brunswick	99	1

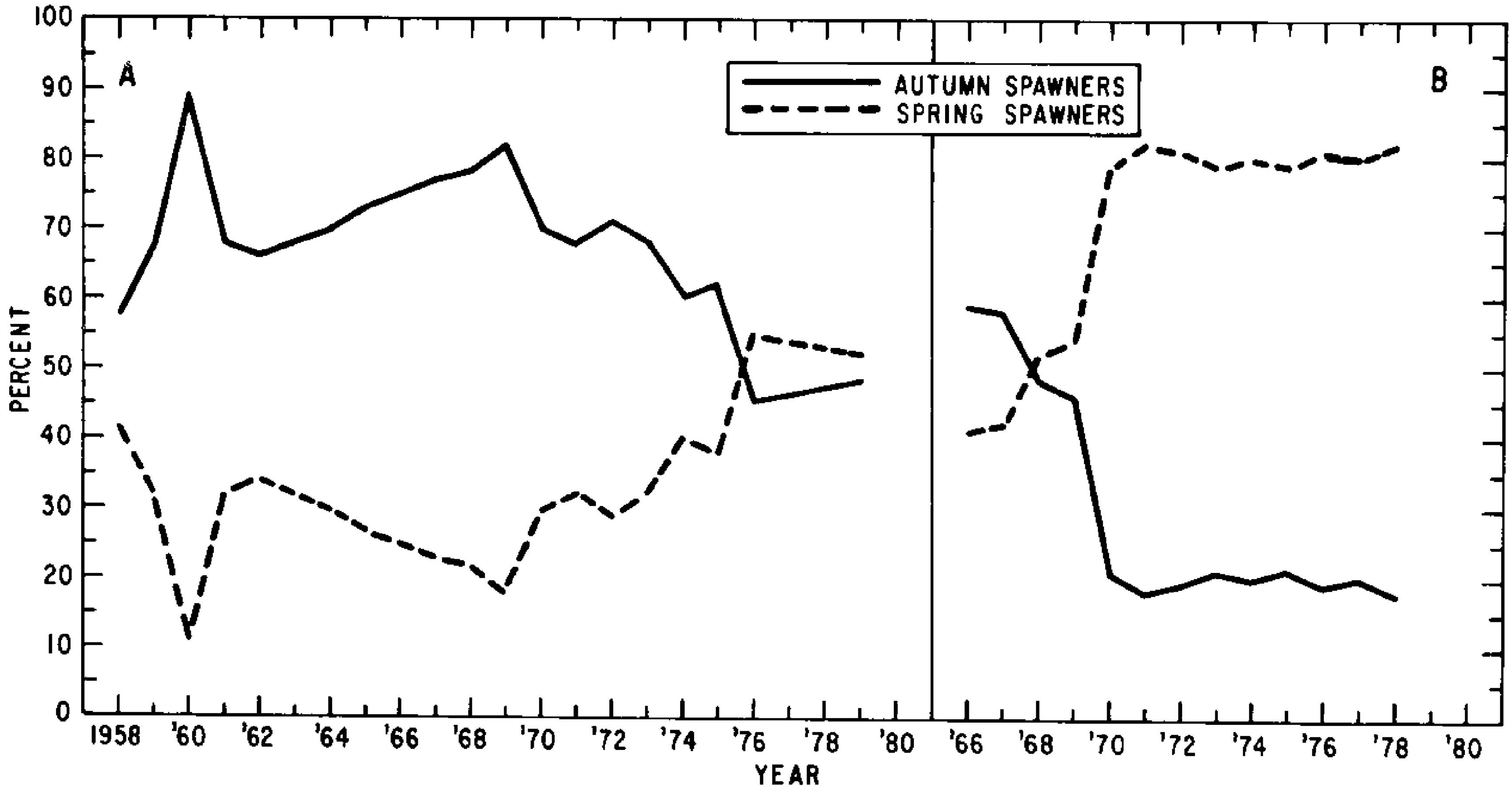


Figure 2a & b. Percent spawning type by year in (A) Southern Gulf of St. Lawrence stock and (B) Newfoundland west coast stock.

and close to shore with eggs often being laid in the intertidal zone, while autumn spawners spawn in a decreasing temperature regime and in water depths generally exceeding 50 meters. Mean water temperatures during spring spawning range from 2° to $12^{\circ}C$ and during autumn spawning from 8° to $19^{\circ}C$ (Parsons, 1973). Both types produce adhesive eggs which become attached to the available substrate, primarily seaweed and eelgrass.

Assignation of an individual herring to a particular spawning type is based primarily on the maturity stage of that fish in relation to the maturity cycles of the two spawning types. For immature fish, the otolith type is used to assign spawning type. The differences in otoliths result from differences in the fist year growth. Fish born in the late spring grow rapidly during the summer resulting in a small nucleus and a complete annulus being formed in the first year. Autumn spawners grow slowly during the winter resulting in a large nucleus with the first annulus not being completed until the year after birth.

The discretions of the two spawning types and whether or not the characteristic is genetically determined is a matter of some debate. Recent studies by Ware and Henriksen (1978) in the southern Gulf of St. Lawrence have suggested that each spawning component can be further subdivided into two spawning groups. From their data on peak fixed gear catches, larval data and growth rates, they conclude that these groups or "spawning runs" are discrete with the offspring returning to the parental spawning grounds. Winters et al., (1977) hypothesized that when population size is severely reduced, such as in the Gulf of St. Lawrence in the late 1950s, growth rates may increase sufficiently to permit spring spawned year-classes to mature early enough to spawn (at least partially) in the summer and fall rather than the spring. This would result in an extended spawning season.

STOCK SEPARATION

Several approaches have been examined for separating herring stocks. These include tagging (Winters and Beckett, 1978; Stobo et al., 1975) meristics and morphometrics (Hodder and Parsons, 1971a, 1971b; Messieh and Longmuir, 1978) biochemical systematics (Odense and Allen, 1971) and parasites (Parsons and Hodder, 1971). By far the most successful has been tagging with the indirect means at best providing corroborating results.

The tagging studies have generally been designed for determining migration patterns and, particularly for external tags, ancillary data on population parameters have not been thoroughly examined, mainly because of problems associated with initial and sustained tagging mortalities.

In the 1960s and early 1970s, the main market for herring was as herring meal. Under these circumstances of bulk processing, an internal tag was found to be most useful (Winters, 1975). The small metal tag was inserted in the abdominal cavity and recovered from the magnets in the separation plants. By accurately recording where the fish being processed had been captured and frequent cleaning of the magnets, an accurate picture of migration could be constructed. This technique proved highly successful in evaluating the seasonal migration patterns of the southern Gulf stock and, in addition, provided reliable estimates of stock sizes and mortality rates (Winters and Beckett, 1978).

With improved markets for food herring since the early 1970s, the processing system changed with only about 5 percent of the catch presently being processed for meal. This reduces the value of internal tags and tagging studies now utilize external tags. Of the many types of tags tested, the spaghetti type anchor tag (Floy FT-2) has been found to be most effective. This tag, however, does not provide as many long-term recaptures as the internal tag and highly variable initial and sustained tagging mortalities substantially reduce its value as an estimator of population parameters. A streamer tag (Floy FTSL-B) is currently being tested for small herring.

MIGRATION PATTERNS

1) Notre Dame-White Bay (Area 2)

Spawning concentrations are found in the spring of the year (May-June) in the bays and arms. After spawning, the schools undergo a feeding migration moving northward and become dispersed over the area. In late August large schools reform in the north and move southward in overwintering concentrations (Winters and Moores, 1979b).

2) Bonavista Bay and Trinity Bay (Areas 3 and 4)

These stocks are considered to be confined to each coastal bay with marginal interchanges in contiguous areas. Spawning concentrations are found in the spring with overwintering schools in the fall. The schools are dispersed during the summer (Winters and Moores, 1979b).

3) Conception Bay-Southern Shore (Area 5)

There is a fair degree of interchange between these two areas with a pattern of pre-spawning and overwintering concentrations with schools dispersed in the summer (Winters and Moores, 1979b).

4) Placentia-St. Mary's Bays (Area 6)

Both areas have spawning stocks with a large degree of intermix mainly during the overwintering period in Placentia Bay with schools of adult fish moving to St. Mary's Bay during the spring. Schools are dispersed in the summer and reform in Placentia Bay to overwinter (Winters and Moores, 1979c).

5) Fortune Bay (Area 7)

Similar pattern to Areas 3 and 4 (Moores and Winters, 1979).

6) Newfoundland West Coast (Area 8)

The spring spawning component is thought to overwinter in the southern extreme of the area. In the spring, the stock undergoes a northward migration with the spawning population branching off to different bays. After spawning, the schools disperse into the Northern Gulf for feeding. In October, schools reform and undergo a southward migration. The autumn spawners have an east-west migration pattern moving in from the Esquiman Channel to spawn in the early fall, then moving back after spawning (Moores and Winters, 1977). In earlier studies (Winters and Parsons, 1972) recoveries from this area were reported from southwest Newfoundland and the southern Gulf of St. Lawrence. This is probably attributable to an expansion of the range of both Gulf stocks due to the large stock size in this period.

7) Southern Gulf of St. Lawrence (Area 10)

The pattern in this area is more complex. The autumn and spring spawners spawn in numerous areas of the Gulf; spring spawners mainly in the more southern areas such as the Magdalen Shallows, Chaleur Bay and Northumberland Strait, and autumn spawners around Gaspe. Movement is basically east-west with fish being found in the area of the Laurentian Channel during the spring and progress westward as time passes. In the fall they appear to move southwest toward the Laurentian Channel again. When the stock is large as in the 1960s there is an expanded overwintering migration with adults (>5-year-old) moving to southwest Newfoundland (Winters, 1975; Winters and Beckett, 1978).

8) Sydney Bight (Area 11)

The definition of this stock is at present imprecise. The main fishery occurs during the late fall on overwintering concentrations. Tag recoveries have been reported from both the southern Gulf stock (Area 10) and the 4WX stock (Area 12) and suggests intermix from these areas, however, the pattern of returns has been highly variable. It is also possible that this stock is related to the stock exploited in ICNAF area 4Vs in the early 1970s (Sinclair et al., 1979b). Until the migration can be adequately characterized the stock is assumed to be a spearate entity with a variable degree of intermix with adjacent stocks.

9) Bay of Fundy-Chedabucto Bay (Area 12)

This stock complex is primarily autumn spawners. Large schools occur in the Bay of Fundy during the summer with movement out of the bay during spawning to Lurcher Shoals and southwest Nova Scotia. Overwintering schools are found in Chedabucto Bay (Stobo et al., 1975; Sinclair et al., 1979a). This migration and possible stock intermix with ICNAF area 5 stock is dealt with more fully by Anthony (preceeding paper).

10) Labrador (Area 1) - Quebec North Shore (Area 9)

The migration patterns in these areas are not fully understood, however, Tibbo (1956) postulated that part of the Labrador fishery may be based on fish migrating from Notre Dame Bay (Area 2).

CATCH DATA

The catch data can best be examined by dividing the area into three components: 1) east and southeast Newfoundland (Areas 1-7); 2) Gulf stocks (Areas 8-10; and 3) Nova Scotia-New Brunswick (Areas 11-12). An examination of the recent period (1961-1978) shows that the total catch has been highly variable from a low of 85,000 mt in 1961 to a high of 568,000 mt in 1969 (Figure 3).

1) East and southeast Newfoundland

Historically the major herring fishing areas were Fortune and Placentia Bays (Areas 6 and 7) (Templeman, 1966; Pinhorn, 1976) but since 1975, the fishery on the east coast (Areas 2-5) has been expanding and, due to increased fishing effort, as can be seen in Figure 3, the catch from the area has been increasing gradually up to 30,000 mt.

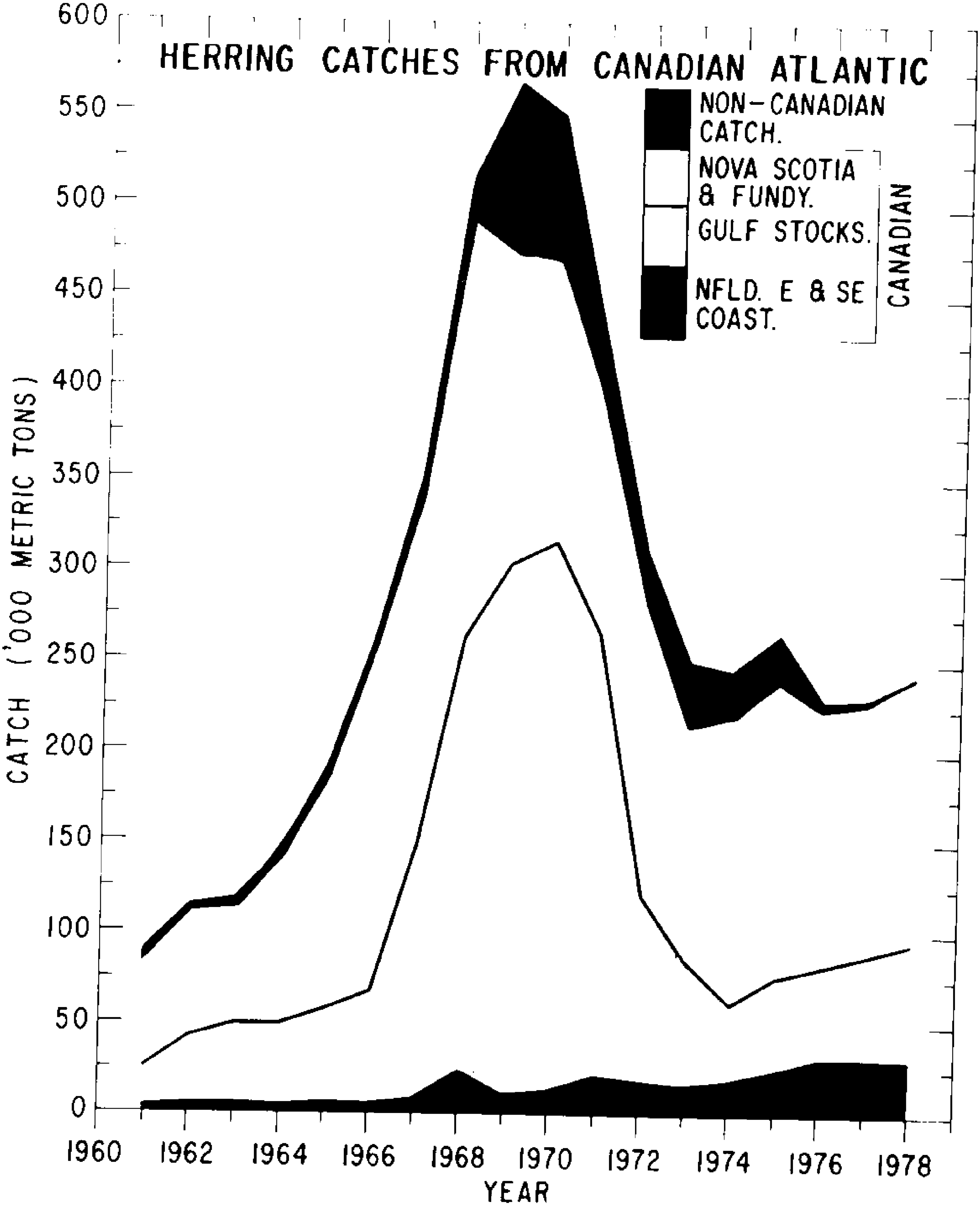


Figure 3. Herring catches from the Canadian Atlantic.

2) Gulf Stocks

Catches from these stocks were low in the early 1960s primarily due to reduced abundance of adult fish as a result of the fungus disease in the late 1950s, and to low effort levels. With the recruitment of the large 1958 and 1959 year-classes and the discovery of the major overwintering area off southwest Newfoundland, catches increased dramatically from 21,000 mt in 1961 to 304,000 mt in 1970. With the passage of these year-classes through the fishery, catches declined, reaching a low of 43,000 mt in 1974. Recruitment of these stocks has shown some improvement with slight increases in catches since then.

3) Nova Scotia-New Brunswick

The Bay of Fundy has historically been a major herring fishing area particularly for sardine herring. In the 1960s, effort expanded throughout the area with total catches increasing from 60,000 mt in 1961 to 265,000 mt in 1969. This area has also seen the greatest activity by non-Canadian countries with international catch reaching a peak of 94,000 mt in 1969, with most of the catch being reported from NAFO 4Vs. With the implementation of quotas and later the extension of jurisdiction, the catch is now taken almost exclusively by Canadian vessels.

GEAR TYPES USED

A variety of gear is used in the herring fishery and can be broadly categorized into two types: mobile gear and fixed gear. The major mobile gear is the purse seine. In the Canadian region purse seines are generally classified into two types according to size, ie., those boats in excess of 65 feet LOA (length overall) and boats under 65 feet LOA. Both fleets operate under either separate quotas as in Areas 6 and 7 or under a single quota as in Area 12. Each vessel is individually licensed with the license specifying which stock areas can be fished. Licenses for vessels in excess of 65 feet have been frozen since 1972, while in the recently developed fishery in eastern Newfoundland, the vessel size has been restricted to under 65 feet. While vessel size is regulated, no restrictions have been placed on the size of seine operated.

In some areas bar seines (beach seine or stop seine) are also classed as mobile gear depending on the vessel size and mobility. In areas where large vessels are traditionally used the gear is classed as mobile, while in areas where small open boats are used the bar seine is nominally classed with fixed gear.

Fixed gear includes traps, gillnets, and weirs. These gear types are generally used by inshore fishermen within a localized area. The manner of use and rigging of these gear types is highly variable depending on local custom. Traps may be constructed of seine twine (1-1/8") or be converted cod traps with a small meshed "herring back" for retaining the catch while the trap is being hauled. Gillnets may be fished at the surface, sunk close to the bottom or utilized as drift nets. Weirs are used predominantly in the Bay of Fundy in the sardine fishery.

ASPECTS OF THE POPULATION DYNAMICS

Many of the general characteristics ascribed to pelagic fish stocks can be seen in the herring stocks of the Canadian Atlantic. These characteristics include a wide variation in the strength of year-classes, dominance of year-classes in the catch and variation in biomass and catch. In the case of the southern Gulf stock (Area 10), year-class strength has varied by up to 80 times (Figure 4) (Winters and Moores, 1979a). The largest year-classes observed were the 1958 year-class of autumn spawners and the 1959 year-class of spring spawners. The influence of these two year-classes on the composition of the stock can be seen in the age frequency of the catch (Figure 5) where they are dominant from 1965 to 1970 (Winters, 1975). Fisheries tend to exploit predominantly one year-class. The production of large year-classes also strongly influences the biomass of the stock. The 1958 and 1959 year-classes built the biomass from low levels to the highest levels observed (Figure 6). Once these year-classes peaked, the stock declined with subsequent recruitment levels being insufficient to maintain the high biomass. Peak catch levels tend to lag peak biomass levels (Figure 6), and accelerate the decline. Management of this stock began in 1973 and has acted to bring catch levels in phase with biomass levels.

An understanding of the variation in the size of year-classes is critical to a complete understanding of the population dynamics of a pelagic stock. When the herring stocks in the western Atlantic are examined for possible stock-recurit relationship, no such relationship is apparent with the points being widely scattered as in Figure 7. As the data base has improved, the recruitment problem has been analyzed in greater depth including both abiotic and biotic factors (Winters, 1976; Lett and Kohler, 1976).

Lett and Kohler (1976) postulated that year-class size of herring in the Gulf of St. Lawrence was controlled by temperature and density-dependent effects of mackerel.

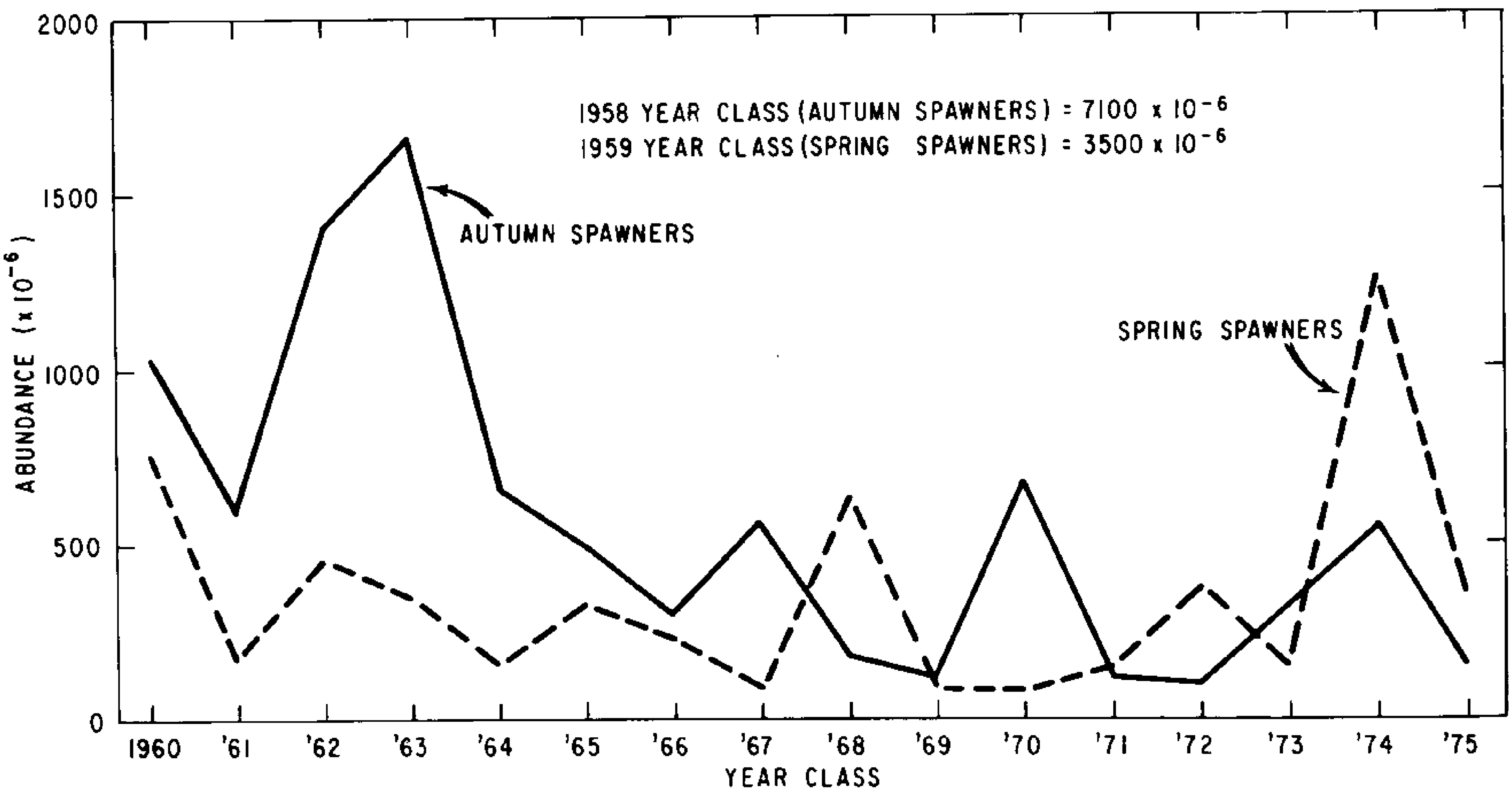


Figure 4. Trends in year-class size of spring- and autumn-spawning herring in the Southern Gulf of St. Lawrence herring stock complex.

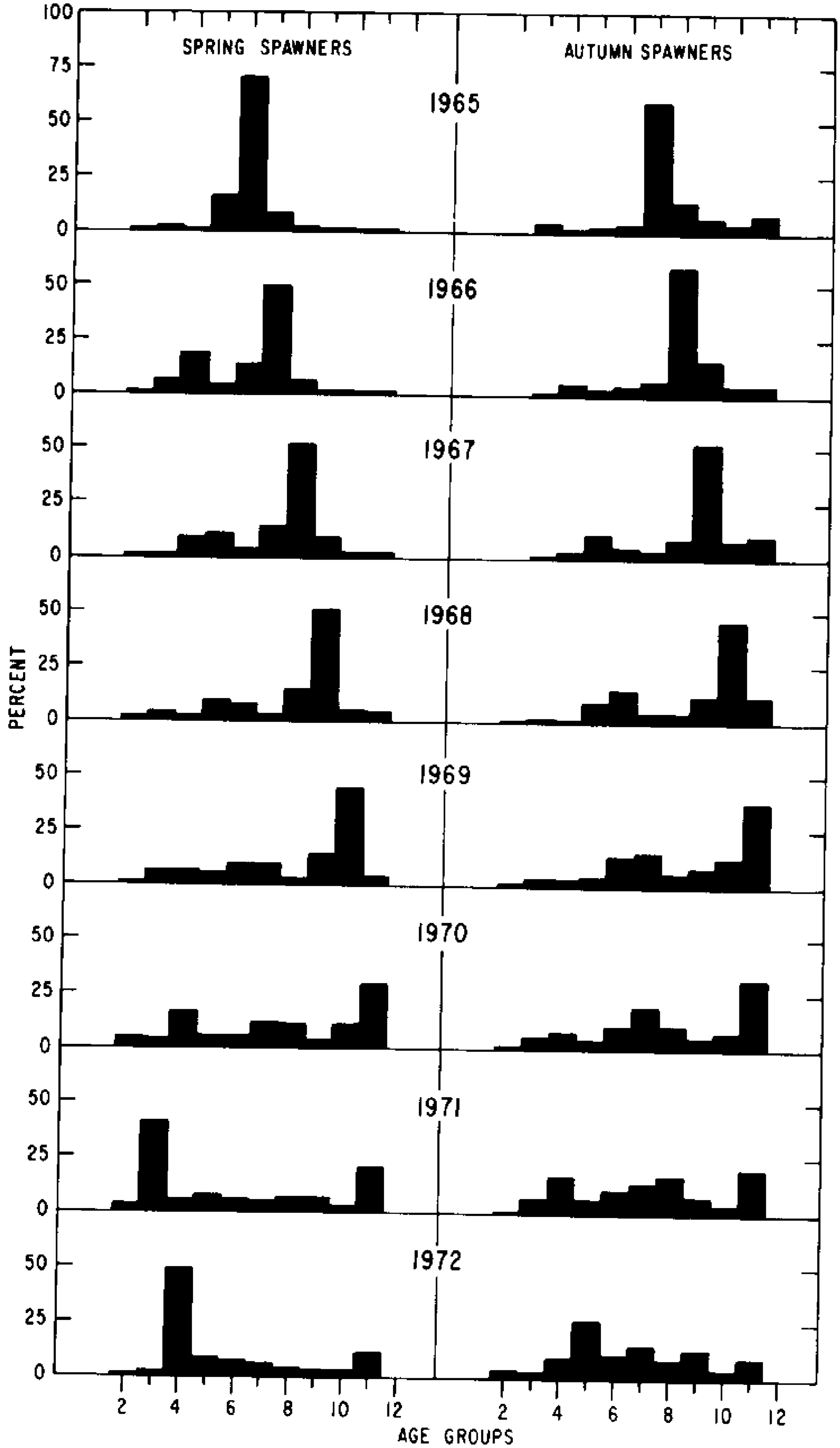


Figure 5. Age frequency of the herring catch from the Southern Gulf of St. Lawrence stock for the period 1965-1972.

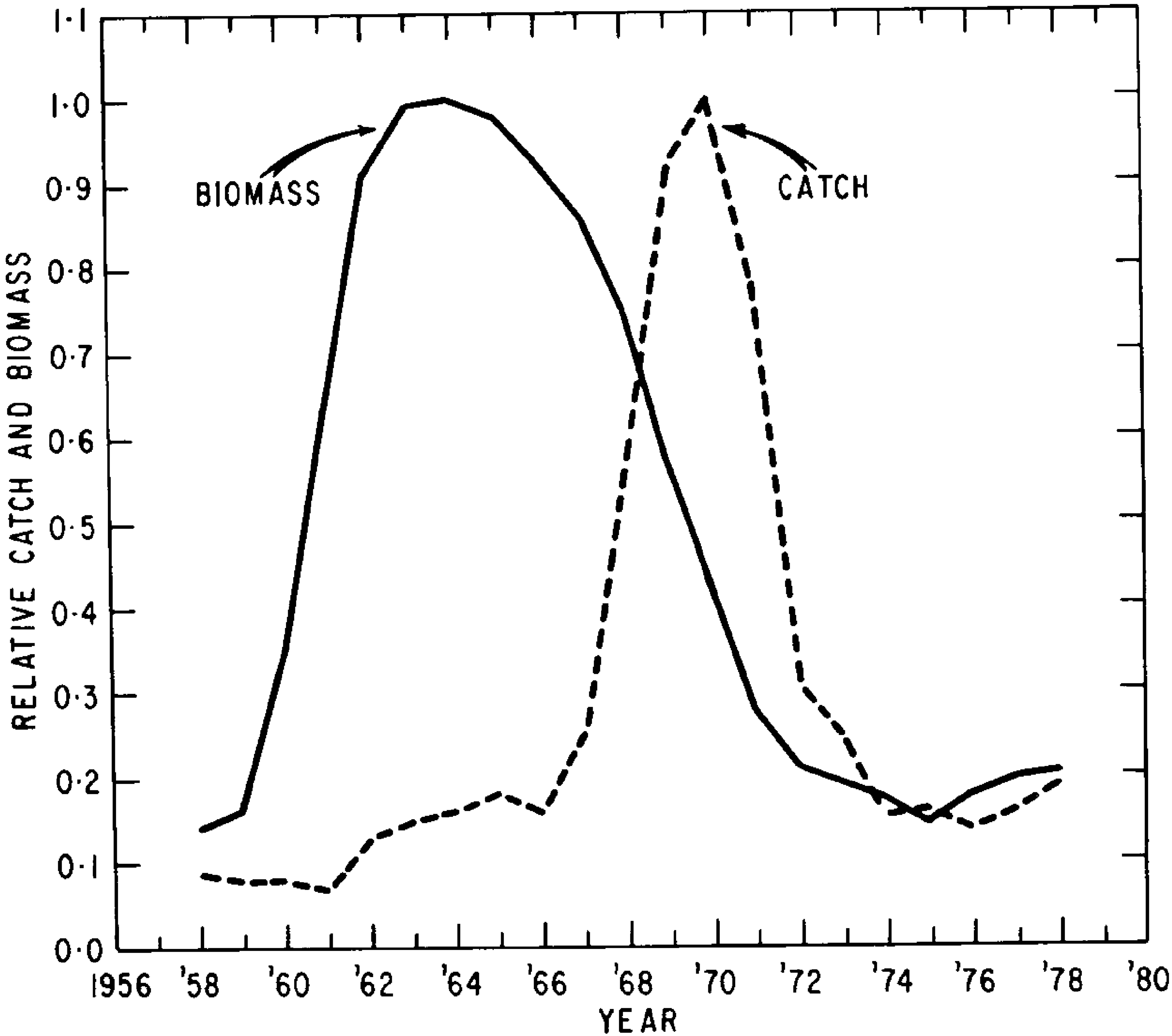


Figure 6. Relative catch and biomass levels for the Southern Gulf of St. Lawrence stock for the period 1958-1978 (Catch 1 = 275 x 10^3 mt, biomass 1 = 1.9 x 10^9 mt).

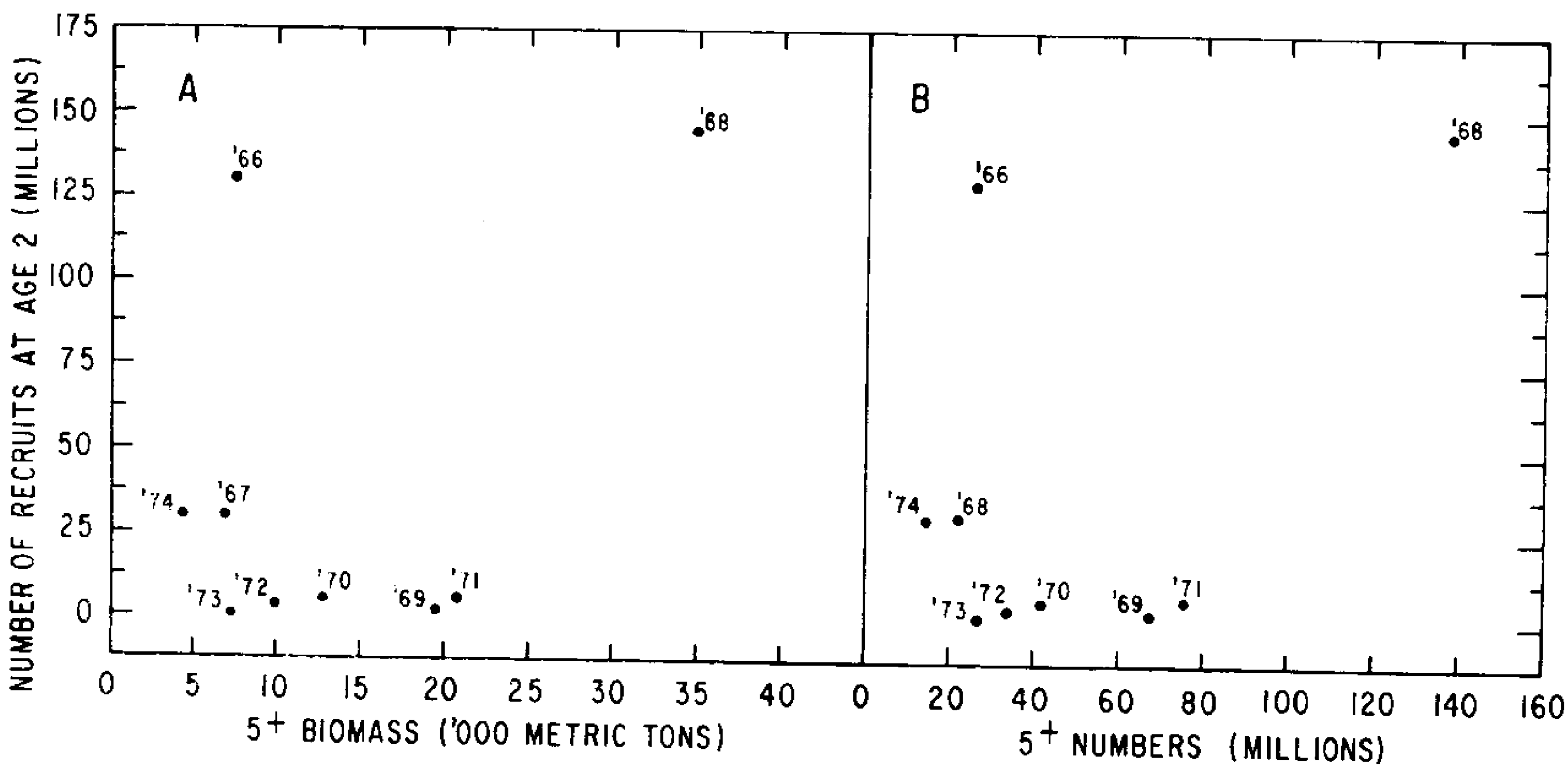


Figure 7. Stock and recruit relationship as seen in Fortune Bay. Recruits at age 2 against (A) age 5+ and (B) 5+ numbers.

Winters (1976), in examining the same stock, found a relationship between herring and mackerel biomass levels which indicated a pelagic (herring and mackerel) carrying capacity in the Gulf of St. Lawrence (Figure 8).

Lett and Kohler (1976) also postulated that recruitment was also influenced by growth in the first year. They hypothesized that growth was density-dependent during the first year and thereby controlled subsequent growth and hence age-specific maturity. However, it was found that Lett and Kohler (1976) had misinterpreted the conventions for aging used in the data source (Winters et al., 1977); their hypothesis was then re-tested using the simplified case of the Fortune Bay herring stock (Moores and Winters, 1978). From this analysis, it was apparent that growth in Fortune Bay herring was most influenced by temperature (Figure 9) with no demonstrable density-dependent effects either in regard to growth or maturation rates. Using multiple regression techniques for the southern Gulf of St. Lawrence stock it was found that temperature explained 68 percent of the variation in herring growth. With the addition of herring biomass and juvenile mackerel biomass to the analysis, the explained variation increased to 77 percent indicating that a logistic growth pattern in this stock would only be evident under stable environmental conditions.

The role of a general environmental factor influencing recruitment would also explain the common pattern of strong year-classes observed in different Canadian stocks. For example, among spring spawning stocks the 1959 and 1968 year-classes have been strong throughout Newfoundland and the Gulf of St. Lawrence and in fall spawners the 1970 year-class has been dominant from Georges Bank to the Gulf of St. Lawrence.

If indeed recruitment is controlled by environmental factors rather than by the stock size, it becomes exceedinly difficult to maintain stock size through stopping fishing at a proscribed level. Indeed, the net result may be a loss in yield with no apparent benefit to the stock.

MANAGEMENT PRACTICES AND THEIR EVOLUTION

All herring stocks in the Canadian zone, with the exception of Labrador and the Quebec north shore, are assessed using cohort analysis (Pope, 1972). The two non-assessed areas have low catch levels ($\leq$500 mt) and are regulated by a precautionary TAC in the case of Labrador and in conjunction with the adjacent stocks in the case of the Quebec north shore.

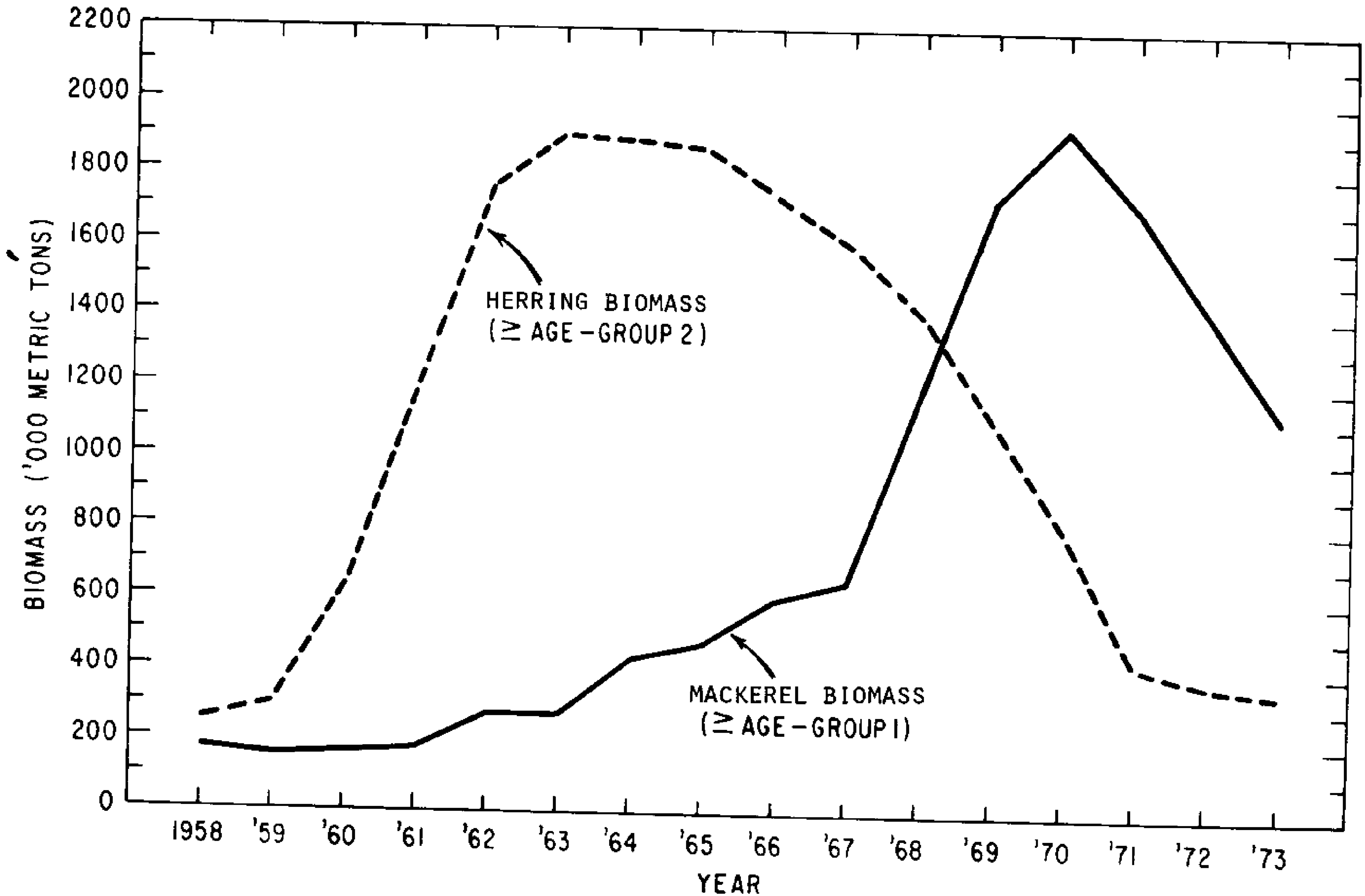


Figure 8. Trends in herring and mackerel abundance in the Southern Gulf of St. Lawrence, 1958-1973.

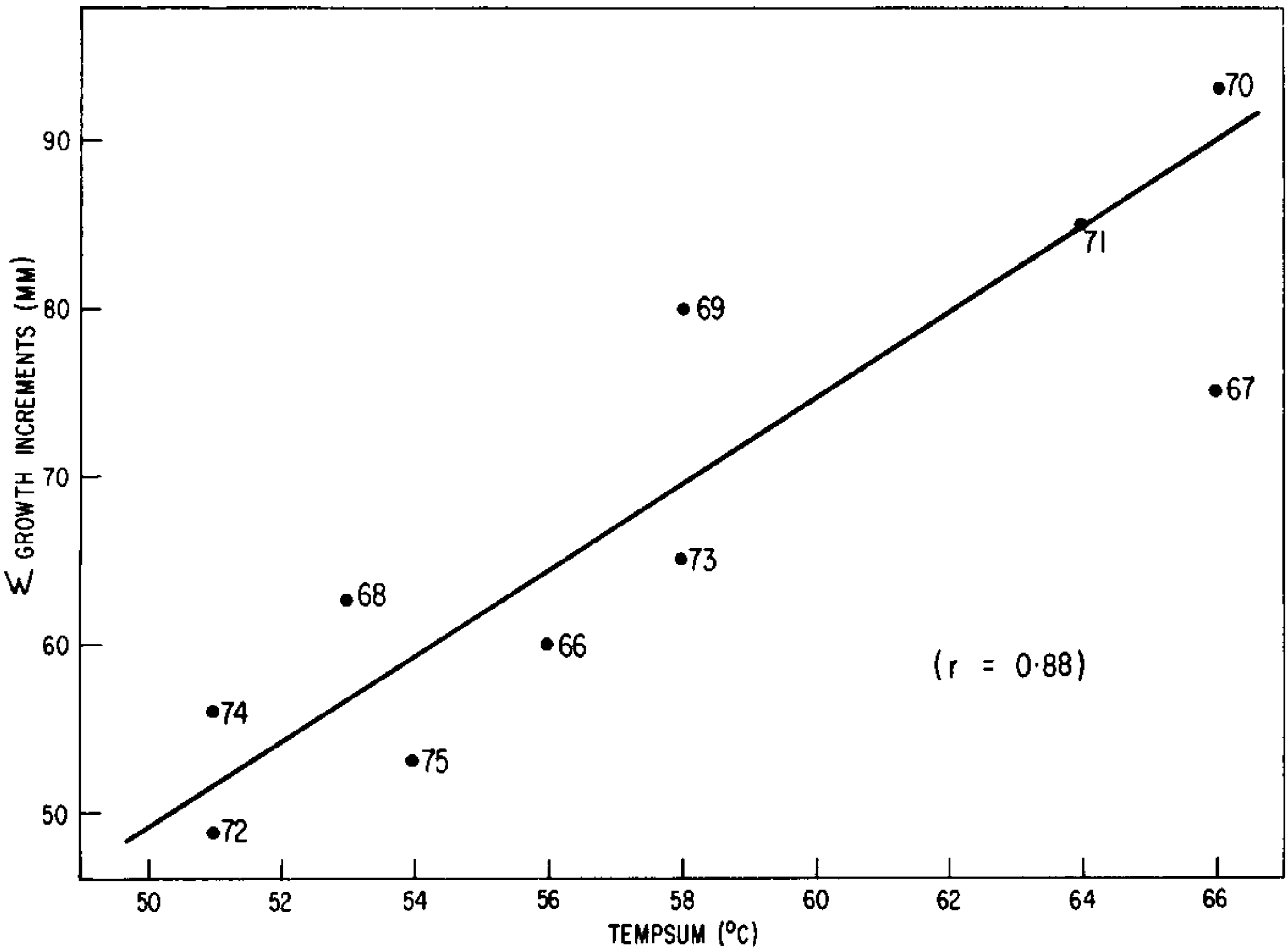


Figure 9. Growth increments of Fortune Bay herring versus Tempsum (May-Dec.) for Station 27. (Σ growth increments = 2.21 Tempsum - 59.47).

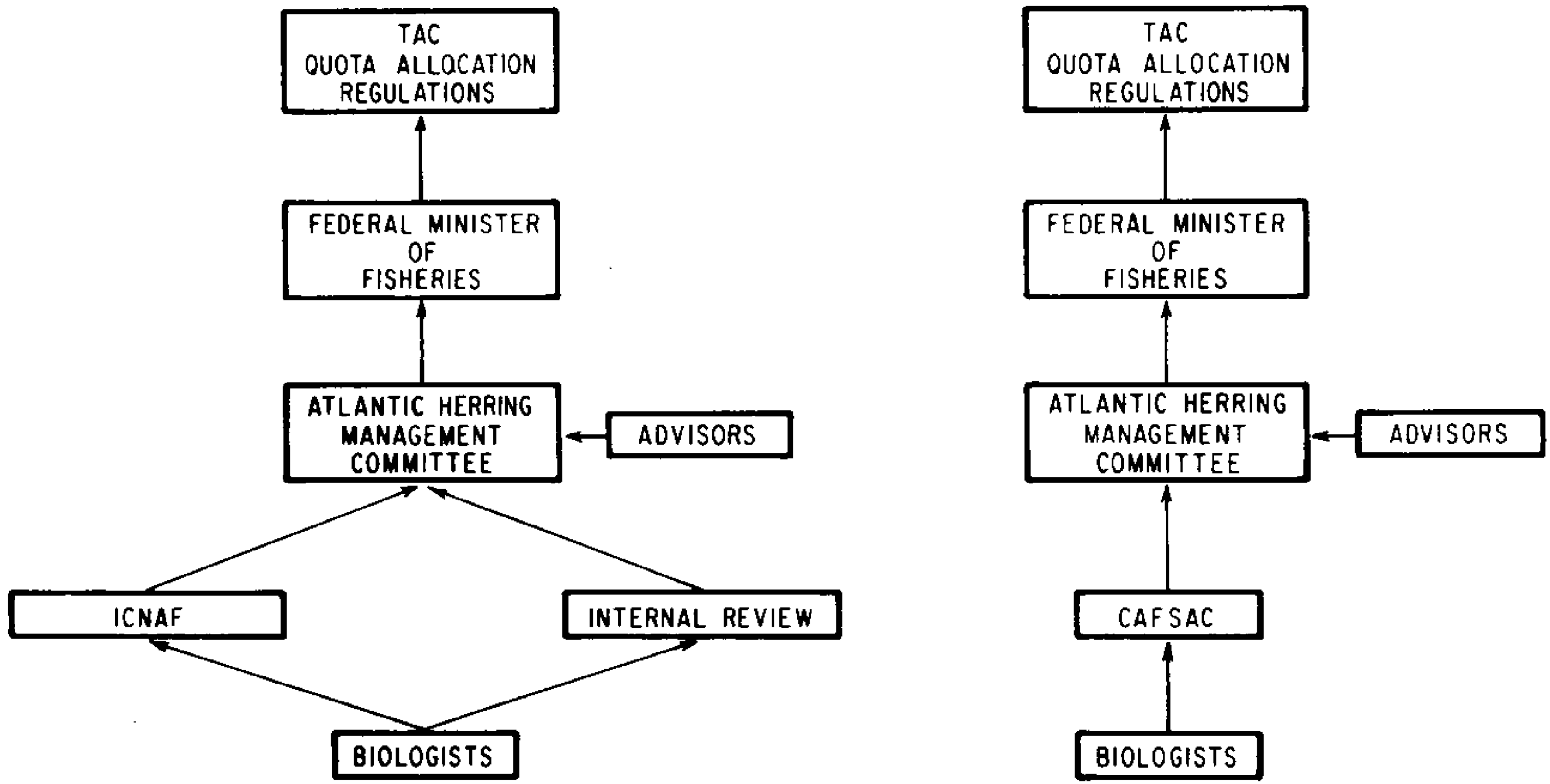
The use of analytical models for assessing the status of herring stocks in Canada essentially began in 1973 with data being presented for the southern Gulf, Fortune Bay and Placentia-St. Mary's Bays herring stocks. All this time two management systems were in place. For stocks within Canadian jurisdiction (Gulf of St. Lawrence and Newfoundland) the assessment process was internal, while for stocks in ICNAF/NAFO Areas 4V, 4W, and 4X where international fisheries occurred the assessment process was handled by ICNAF. Since 1977, with the implementation of the 200 mile limit, all these stocks are under Canadian control and assessments are conducted under the auspicies of the Pelagic Sub-Committee of CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee).

Although the forum for considering the biological aspects of the stocks has changed, the management scheme has not. Once agreement has been reached as to the status of the stock and catch projections made, with $F_{0.1}$ as a reference point, the information is passed along to the Atlantic Herring Management Committee (AHMC). The AHMC is composed of a chairman and the three federal regional director-generals for fisheries (Newfoundland, Quebec and the Maritimes). The AHMC appoints advisors from all sectors of the fishery including processors, fishermen, economists and biologists. After discussion with the advisors, the AHMC makes recommendations to the federal minister of fisheries and oceans as to the appropriate catch levels, restrictions on seasons and gears, and any additional management considerations. The minister is the final authority on all management plans and can either accept the recommendations of the AHMC or reject or vary the recommendations as he deems appropriate (Figure 10). All regulations are enforced by the Conservation and Protection Branch of Fisheries and Oceans.

Traditionally, the TAC has been allocated in a two-tier system with the mobile sector having a quota while fixed gear catches have been estimated but no quota is enforced. This system operated well when the fixed gear effort was relatively stable, but with increased prices for herring, fixed gear effort has been expanding rapidly. To create more stability in the fishery, two approaches are being considered to place all gear components under quota control or to implement gear limitations. Both approaches are aimed at protecting the rights of all the components of the fishery such that they all benefit from the resource.

PROBLEM AREAS AND CURRENT RESEARCH

Much time and effort is currently expended in the collection and preparation of data for inclusion into the



PRIOR TO 200 MILE LIMIT

POST 200 MILE LIMIT

Figure 10. Schematic diagram of the herring management procedure in the Canadian Atlantic.

sequential population models. In cohort analysis the potential error in estimates of N_t is greatest in the terminal year since these are directly dependent on the input parameters; this error, however, is sequentially reduced as the analyses proceeds back through a cohort (Pope, 1972). While this provides a good historical picture in terms of fisheries management, population size estimates in the terminal year are the basis for setting catch levels in the future. Critical to the analysis is the establishment of the level of fishing mortality for the terminal year and the strength of incoming year-classes. The more accurate these are, the more closely the analysis will resemble the real situation. Terminal F has been calculated using effort or catch per unit effort of the purse seine fleet as an index of stock abundance. Effort data are derived primarily from log records. The provision of accurate log records is a condition of licensing. Although this regulation has not been enforced, cooperation by the fishermen has been excellent. However, changes in fishing pattern, gear types, and efficiences have increased the degree of difficulty in interpreting the data. It is also impossible to determine the effect of quota regulations and changes in migration patterns resulting from changes in stock size on the effort data. These problems clearly indicate the need for having independent measures of stock abundance. For some stocks, such as the southern Gulf of St. Lawrence, the catch of herring in groundfish surveys can be used, but in other areas different methods must be developed. Research is currently being conducted into standardized research gillnet catches and acoustic techniques. Two approaches are being used for acoustics; one method is to cover a standard cruise track using sounders and sonar, thereby estimating the number of schools encountered to obtain rough biomass estimates. The second is that consideration being given to developing an echo integration system for use on herring similar to the method currently employed on capelin (*Mallotus villosus*) (Miller and Carscadden, 1979).

Once the best estimate of current stock size has been calculated, it remains to refine the parameters of the projection. Of importance are the values used for recruitment. At present we are restricted to using arbitrary or average values (geometric mean) as estimates of those year-classes which have not yet entered the commercial fishery. To provide improved information on year-class size and the mechanism controlling reproductive success, a long-term project has been established in Fortune Bay. The program includes study of egg production, seasonal sampling of larvae for distribtuion and growth, and measurement of physical parameters.

Another area of concern is changes in migration routes with changing stock size as has been noted in the southern

Gulf stock. The implications of these changes with regard to stock boundaries, and hence management zones, and also the planning of fishing strategies are important. This variability indicates the need for continuing tagging programs to monitor possible changes.

CONCLUSION

The Canadian Atlantic herring stocks display a high degree of variation both in terms of their biological characteristics and their population dynamics and in their manner of exploitation. The fisheries have passed from subsistance level to unrestricted exploitation to the present situation of a high degree of management control and regulation. As we try to unravel the population dynamics of these stocks we are constantly faced with major gaps in our knowledge, and indeed as one question is answered, two more are raised.

ACKNOWLEDGEMENT

I would like to acknowledge the scientific and technical staffs, involved in herring research, at the Northwest Atlantic Fisheries Center, St. John's, the Marine Fish Division, Halifax. and the St. Andrews Biological Station, St. Andrews, who over the years have built the broad basis of knowledge regarding the herring stocks of the Canadian Atlantic.

REFERENCES

Hodder, V. M. and L. S. Parsons. 1971a. Comparison of certain biological characteristics of herring from Magdalen Islands and southwest Newfoundland. ICNAF Res. Bull. 8: 5965.

__________. 1971b. Some biological features of southwest Newfoundland and northern Scotian Shelf herring stocks. ICNAF Res. Bull. 8: 6773.

Leim, A. H. 1957. Summary of results under the Atlantic Herring Investigation Committee. Bull. Fish. Res. Bd. Can. 111: 116.

Leim, A. H. and W. B. Scott. 1966. Fishes of the Atlantic Coast of Canada. Bull. Fish. Res. Bd. Can. 155, 485 pp.

Lett, P. F. and A. C. Kohler. 1976. Recruitment: a problem of multispecies interactions and environmental perterbations, with special reference to Gulf of St. Lawrence Atlantic herring (*Clupea harengus harengus*). J. Fish. Res. Bd. Can. 33: 13531371.

Messieh, S. N. and J. Longmuir. 1978. The interrelationships between herring stocks in the Canadian Atlantic fisheries as revealed by multivariate analysis of their meristic characters. CAFSAC Res. Doc. 78/45.

Miller, D. S. and J. E. Carscadden. 1979. An acoustic estimate of capelin biomass in ICNAF Divisions 2J and 3K, October 1978. ICNAF Res. Doc. 79/II/34.

Moores, J. A. 1979. Analysis of the status of the west coast herring stock. CAFSAC Res. Doc. 79/5.

Moores, J. A. and G. H. Winters. 1977. Production and yield of western Newfoundland herring stocks. CAFSAC Res. Doc. 77/3.

__________. 1978. Growth patterns in a Newfoundland herring stock. CAFSAC Res. Doc. 78/43.

__________. 1979. Analysis of the current status of the Fortune Bay herring stock. CAFSAC Res. Doc. 79/35.

Odense, P. H. and T. M. Allen. 1971. A biochemical comparison of some Atlantic herring populations (Abstract). ICES Proc.Verb. 161: 26.

Parsons, L. S. 1973. Meristic characteristics of Atlantic herring, Clupea harengus harengus L., stocks in Newfoundland and adjacent waters. ICNAF Res. Bull. 10: 37-52.

Parsons, L. S. and V. M. Hodder. 1971. Variation in the incidence of larval nematodes in herring from Canadian Atlantic waters. ICNAF Res. Bull. 8: 5-14.

Pinhorn, A. T. 1976. Living marine resource of Newfoundland-Labrador: Status and potential. Bull. Fish. Res. Bd. Can. 194, 64 pp.

Pope, J. G. 1972. An investigation of the accuracy of virtual population analysis. ICNAF Res. Bull. 9: 65-74.

Scattergood, L. N. and S. N. Tibbo. 1959. The herring fishery of the northwest Atlantic. Bull. Fish. Res. Bd. Can. 121, 42 pp.

Sinclair, M., K. Metuzals and W. T. Stobo. 1979a. 1978 4WX herring assessment. CAFSAC Res. Doc. 79/19.

Sinclair, M., W. Stobo and A. Sinclair. 1979b. Status of the 4Vn herring fishery. CAFSAC Res. Doc. 79/40.

Sinderman, C. J. 1966. Diseases of Marine fishes. Advances in Mar. Biol. (Russell ed.) Vol. 4: 1-91.

Stobo, W. T., J. S. Scott and J. J. Hunt. 1975. Movements of herring tagged in the Bay of Fundy. ICNAF Res. Doc. 75/38. 24 pp.

Templeman, W. 1966. Marine resources of Newfoundland. Bull. Fish. Res. Bd. Can. 154, 170 pp.

Tibbo, S. N. 1956. Populations of herring (*Clupea harengus* L.) in Newfoundland waters. *J. Fish. Res. Bd. Can.* 13(4): 449-466.

Tibbo, S. N. and T. R. Graham. 1963. Biological changes in herring stocks following an epizootic. J. Fish. Res. Bd. Can. 20: 435-449.

Ware, D. M. and B. L. Henriksen. 1978. On the dynamics and structure of the southern Gulf of St. Lawrence herring stocks. Fish. and Mar. Ser. Tech. Rept. 800, 83 pp.

Winters, G. H. 1975. Population dynamics of the southern Gulf of St. Lawrence herring stock complex and implications concerning its future management. Ph.D. Thesis, Dalhousie University, 142 pp.

__________. 1976. Recruitment mechanisms of southern Gulf of St. Lawrence Atlantic herring (*Clupea harengus harengus*). J. Fish. Res. Bd. Can. 33: 1751-1763.

Winters, G. H. and J. S. Beckett. 1978. Migrations, biomass and stock interrelationships of southwest Newfoundland-southern Gulf herring from mark-recapture experiments. ICNAF Res. Bull. 13: 67-79.

Winters, G. H. and V. M. Hodder. 1975. Analysis of the southern Gulf of St. Lawrence herring stock and implications concerning its future management. ICNAF Res. Bull. 11: 43-59.

Winters, G. H. and J. A. Moores. 1979a. An evaluation of recent changes in the population dynamics of southern Gulf herring. CAFSAC Res. Doc. 79/28.

Winters, G. H., D. S. Miller and J. A. Moores. 1979. Analysis of stock size and yield of southern Gulf herring. CAFSAC Res. Doc. 77/2.

__________. 1979c. Estimation of biomass and yield of the St. Mary's-Placentia herring stock complex. CAFSAC Res. Doc. 79/36.

Sinderman, C. J. 1966. Diseases of Marine fishes. Advances in Mar. Biol. (Russell ed.) Vol. 4: 1-91.

Stobo, W. T., J. S. Scott and J. J. Hunt. 1975. Movements of herring tagged in the Bay of Fundy. ICNAF Res. Doc. 75/38. 24 pp.

Templeman, W. 1966. Marine resources of Newfoundland. Bull. Fish. Res. Bd. Can. 154, 170 pp.

Tibbo, S. N. 1956. Populations of herring (*Clupea harengus* L.) in Newfoundland waters. *J. Fish. Res. Bd. Can.* 13(4): 449-466.

Tibbo, S. N. and T. R. Graham. 1963. Biological changes in herring stocks following an epizootic. J. Fish. Res. Bd. Can. 20: 435-449.

Ware, D. M. and B. L. Henriksen. 1978. On the dynamics and structure of the southern Gulf of St. Lawrence herring stocks. Fish. and Mar. Ser. Tech. Rept. 800, 83 pp.

Winters, G. H. 1975. Population dynamics of the southern Gulf of St. Lawrence herring stock complex and implications concerning its future management. Ph.D. Thesis, Dalhousie University, 142 pp.

__________. 1976. Recruitment mechanisms of southern Gulf of St. Lawrence Atlantic herring (*Clupea harengus harengus*). J. Fish. Res. Bd. Can. 33: 1751-1763.

Winters, G. H. and J. S. Beckett. 1978. Migrations, biomass and stock interrelationships of southwest Newfoundland-southern Gulf herring from mark-recapture experiments. ICNAF Res. Bull. 13: 67-79.

Winters, G. H. and V. M. Hodder. 1975. Analysis of the southern Gulf of St. Lawrence herring stock and implications concerning its future management. ICNAF Res. Bull. 11: 43-59.

Winters, G. H. and J. A. Moores. 1979a. An evaluation of recent changes in the population dynamics of southern Gulf herring. CAFSAC Res. Doc. 79/28.

__________. 1979b. Prognosis of abundance and yield of eastern Newfoundland herring stocks. CAFSAC Res. Doc. 79/16.

__________. 1979c. Estimation of biomass and yield of the St. Mary's-Placentia herring stock complex. CAFSAC Res. Doc. 79/36.

Winters, G. H., D. S. Miller and J. A. Moores. 1979. Analysis of stock size and yield of southern Gulf herring. CAFSAC Res. Doc. 77/2.

Winters, G. H. and L. S. Parsons. 1972. Interrelationships among Hawke's Bay, southwest Newfoundland and southern Gulf of St. Lawrence herring stocks. ICNAF Res. Doc. 72/100.

A REVIEW OF MANAGEMENT PRACTICES AND RESEARCH ACTIVITIES ON NORWEGIAN SPRING SPAWNING HERRING

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INTRODUCTION

A review of our knowledge of the Atlanto-Scandian herring must be based on the work of numerous scientists in several countries over many years. The earlier workers at the Institute of Marine Research, Bergen, included Lea (1910, 1929, 1930), Runnstrøm (1936, 1941a, 1941b), Devold (1963, 1968), Aasen (1958, 1962), Østvedt (1958, 1963) and Dragesund (1970a, 1970b). The present work is being directed by Hamre (Anon., 1979). The earlier workers in Iceland included Fridriksson (1944, 1958) and Einarsson (1958). The present work is being directed by Jakobsson (1963, 1968, 1971, 1980). The earlier workers in the Soviet Union included Marti (1956), Marti and Fedorov (1963) and Yudanov (1966). The present work is directed by Seliverstov (Benko and Seliverstov 1971). Much information also resides in reports of limited circulation prepared for the International Council for the Exploration of the Sea, ICES (1964a, 1965, 1970, 1972, 1977, 1979).

The term Atlanto-Scandian herring is frequently used as a synonym for Norwegian spring spawning herring. This can give rise to misunderstandings, as the Atlanto-Scandian herring is now considered to include three stocks: Norwegian spring spawners, Icelandic spring spawners, and Icelandic summer spawners. According to Johansen (1919), spawners near the Faroes and the northern edge of the North Sea plateau also belong to the Atlanto-Scandian herring.

The Norwegian spring spawners, potentially the largest stock within the Atlanto-Scandian herring, are the subject of this review. The management practices and research activities discussed here are largely based on recent work of Dragesund and Ulltang (1978) and Dragesund, Hamre, and Ulltang (1980).

DISTRIBUTION AND MIGRATION

ADULT HERRING

The spawning grounds are located in Norwegian coastal waters (Figure 1). The spawning depths range from 50 to 200 m; the temperature varies between 5° and 7°C. The main feeding of the adult stock takes place from May to August

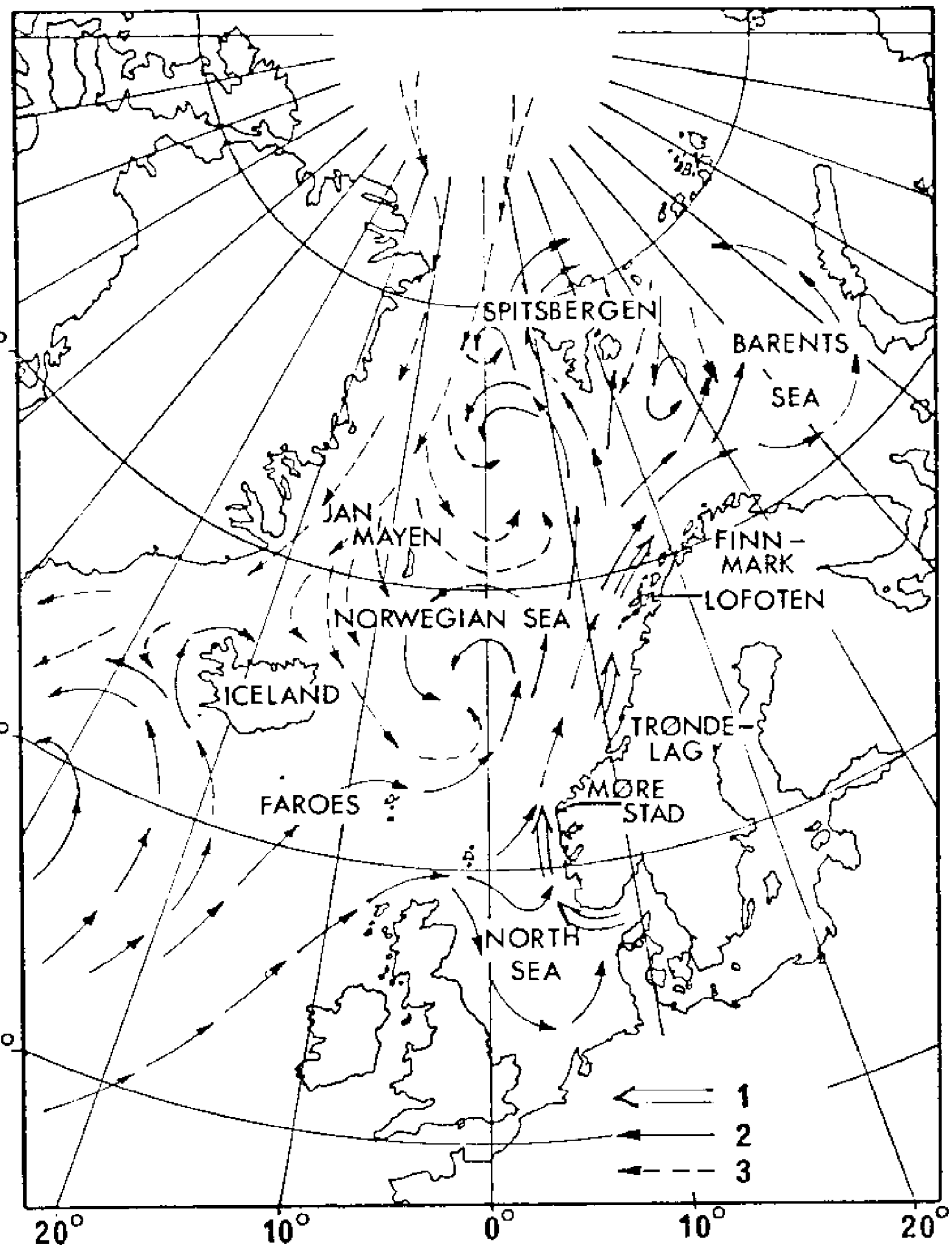

Figure 1. Surface currents of the Northwest Atlantic Ocean: 1) Norwegian Coastal Current, 2) Atlantic Water, 3) Arctic Water.

along the Polar Front in the Norwegian Sea where the herring feed heavily on zooplankton (ICES, 1964b). The limit of the summer feeding migration extends from the Spitsbergen-Jan Mayen area in the north to the western border of the cold East Icelandic Current in the south.

During the feeding season, some of the Norwegian spring spawners mix with the adults of the Icelandic spring spawners and in August some mix with the Icelandic summer spawners (Figure 2). The feeding area contracts during the autumn. The Norwegian spring spawning herring gradually concentrate into an area in the southwestern part of the Norwegian Sea along the borders of the East Icelandic Current. Those ripening herring winter east of Iceland. In December and January, prespawning concentrations move towards the Norwegian coast. Spawning takes place mainly in the first half of March (Devold, 1963; Fridriksson, 1963).

This description of the distribution and migration of the adult stock was probably the pattern when the stock size was relatively high. However, from 1950 to 1969 changes occurred in the migration pattern. From 1950 to 1962, the spawning grounds of the stock gradually shifted northward, and after 1959, spawning south of Stad was negligible (Devold, 1963; Dragesund, 1970a). From 1960 to 1968, the spawning was concentrated off Møre-Trøndelag. From 1963 to 1966, much spawning also took place at Lofoten (Figure 3).

From 1952 to 1962, the main feeding grounds were in the Iceland-Jan Mayen area. However, in autumn 1962, a stock component of maturing herring was found off the coast of northern Norway (Figure 3). In spring 1963, this component migrated to the Lofoten area for spawning. Most of these herring moved to the feeding area southwest of Spitsbergen after spawning. They wintered off the coast of northern Norway with maturing herring and spawned at Lofoten the following spring. From 1963 to 1966 some exchange took place between the component feeding southwest of Bear Island and the main component feeding between Iceland and Jan Mayen. Almost no mixing took place between spawning herring at Lofoten and those spawning farther south.

In the autumn of 1966, the northern component migrated from the Bear Island feeding grounds to the wintering area off East Iceland and mixed with the main component of the stock in that area (Figure 4). From 1967 to 1969, the stock migrated as a single unit to the main spawning grounds off Møre-Trøndelag, with no spawning at Lofoten. After spawning, the stock moved to the summer feeding grounds in the Spitsbergen-Bear Island area. During late autumn, the herring again concentrated in the traditional wintering area east of Iceland.

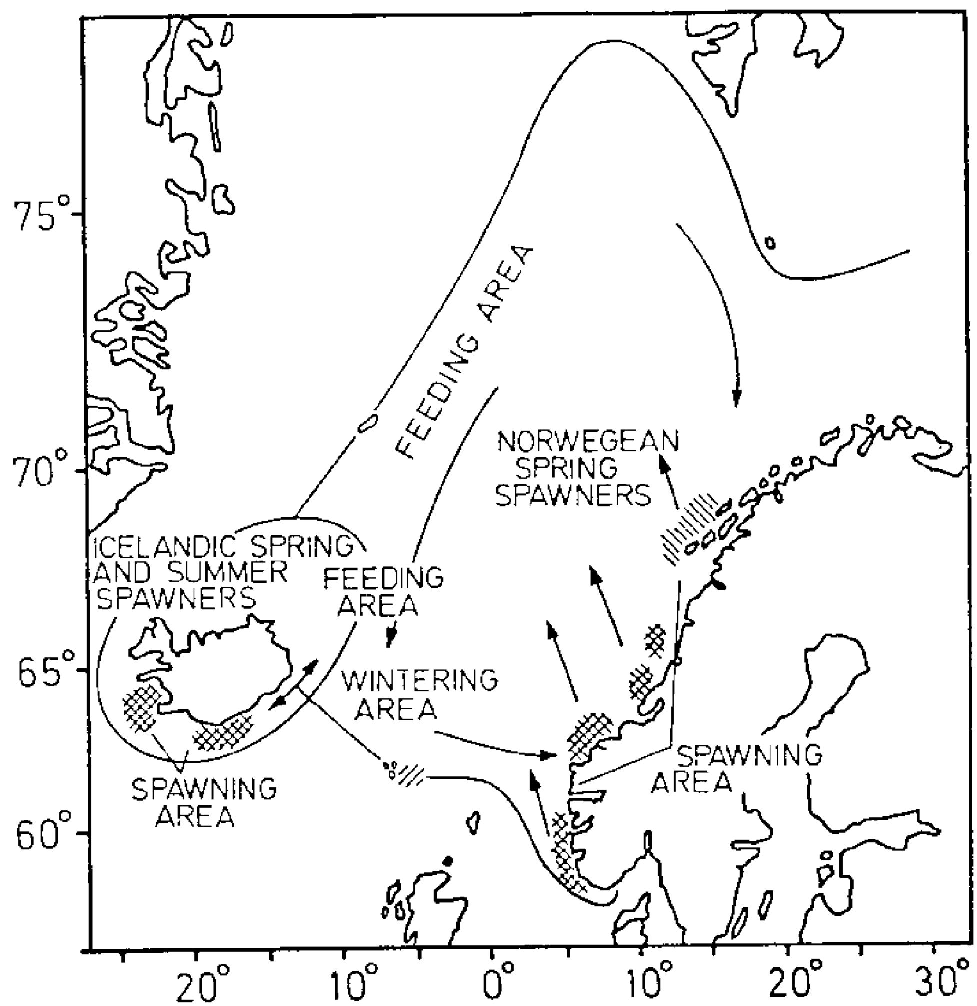

Figure 2. Distributions of the three spawning stocks of the Atlanto-Scandian herring group.

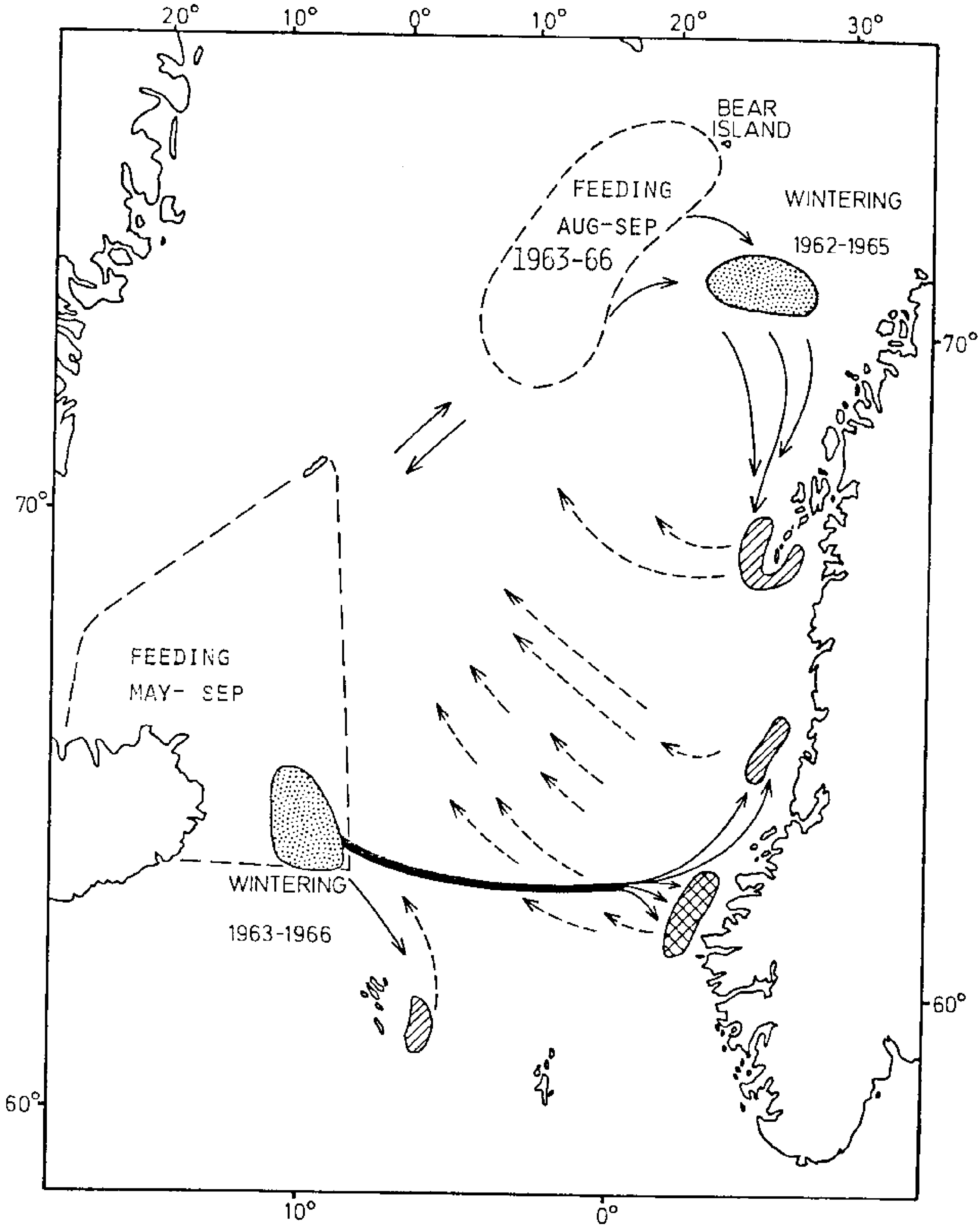

Figure 3. Migration routes of Norwegian spring spawning herring between feeding, spawning, and wintering areas from 1963 to 1966 (modified from ICES 1970).

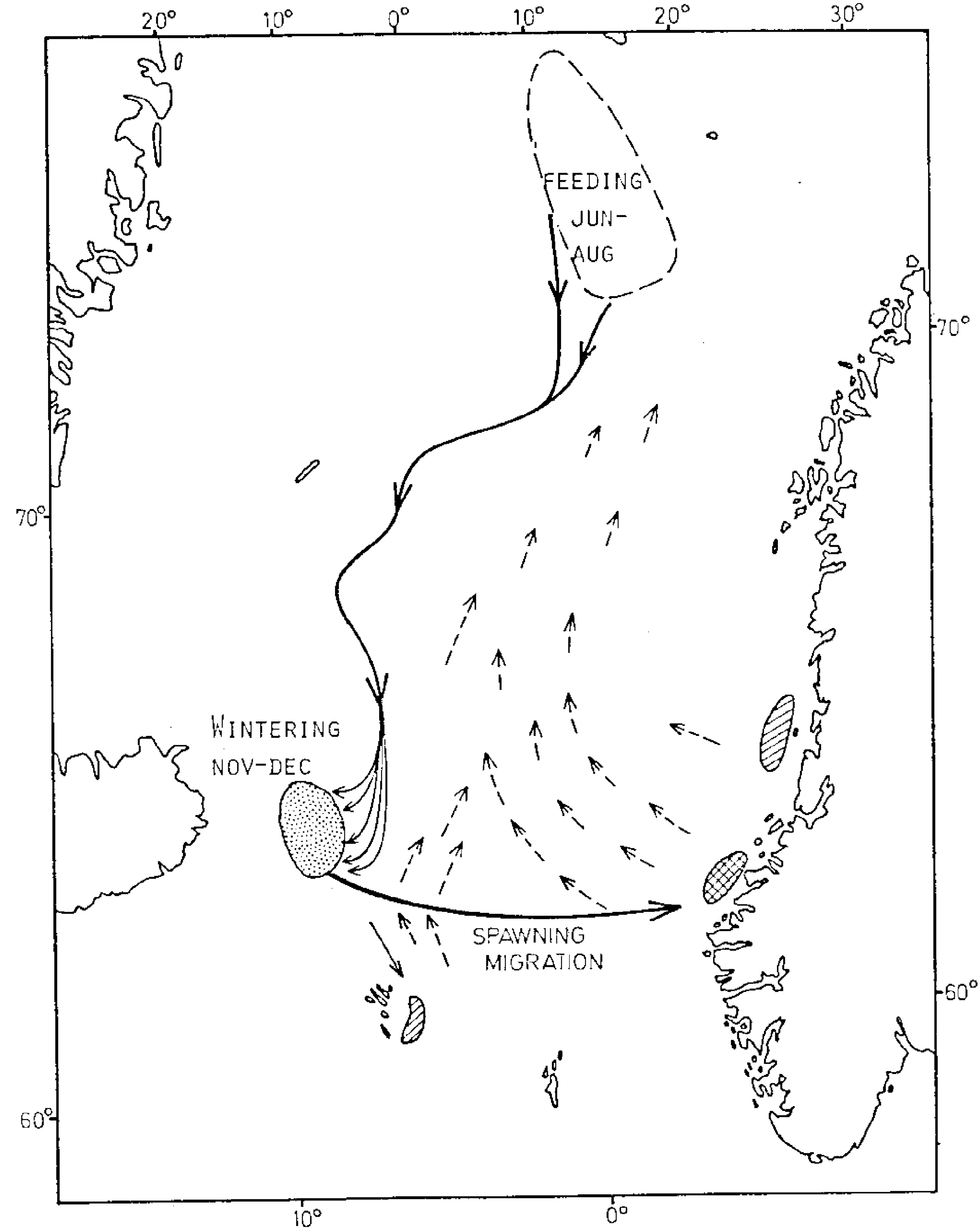

Figure 4. Migration routes of Norwegian spring spawning herring in 1967 and 1968 (modified from ICES 1970).

From 1967 to 1969, the spawning stock decreased sharply, and since the summer of 1969 no herring have been recorded on the usual feeding area in the Norwegian Sea. A fishery continued on the depleted stock on the spawning grounds until 1971, when the collapse of the stock was almost complete. Although a small recovery of the stock took place during the late 1970s, the spent herring did not leave the coast as in previous years, but remained in coastal waters for feeding. In late autumn the herring migrated into the fjords for wintering and were found in dense concentrations from October to February. The fjords of Lofoten were the main wintering area for a northern component, while a southern component seemed to stay at Møre throughout the year. During February and March, there was a spawning migration from the fjords to the spawning grounds just off the coast (Anon., 1979).

YOUNG HERRING

The larvae from the Norwegian spawning grounds are transported northward with the coastal current. The larval stage lasts for about two months. During the northward drift, some larvae accumulate at the entrance of the fjords along the Norwegian coast and others drift farther northward and offshore into the northeastern Norwegian Sea and the Barents Sea (Figure 5). The 0-group herring in the coastal areas migrate into the fjords during autumn. Those herring stay in the fjords through the autumn and the following winter. In late autumn, a major part of the 0-group herring in offshore waters is concentrated along the oceanic fronts between the cold Arctic water and the warmer water masses which cover the areas west of Spitsbergen and Bear Island and the central and southeastern parts of the Barents Sea (Figures 2 and 5). The herring remain in those areas during the following winter and spring. They live in colder water than the 0-group herring along the coast, especially those south of Finnmark (Dragesund, 1970b). The abundance of the offshore distribution of 0-group herring is quite variable and appears closely related to the year class strength at that stage. In the last 10 years, oceanic 0-group herring have not been observed in large numbers relative to earlier years. The Norwegian coastal waters have become the main nursery area of the young herring.

A gradual emigration of 1-group herring takes place from the fjords in April and May. These herring remain in coastal waters for one to two years. The 1-group herring distributed in offshore waters move southward toward the southern parts of the Barents Sea and coastal waters off northern Norway (Figure 6). The 1- and 2-groups feed in these areas. During periods of exceptionally high abundance, these age-groups have a much wider distribution than in years when the young herring stock is at a low level, as in the 1970s.

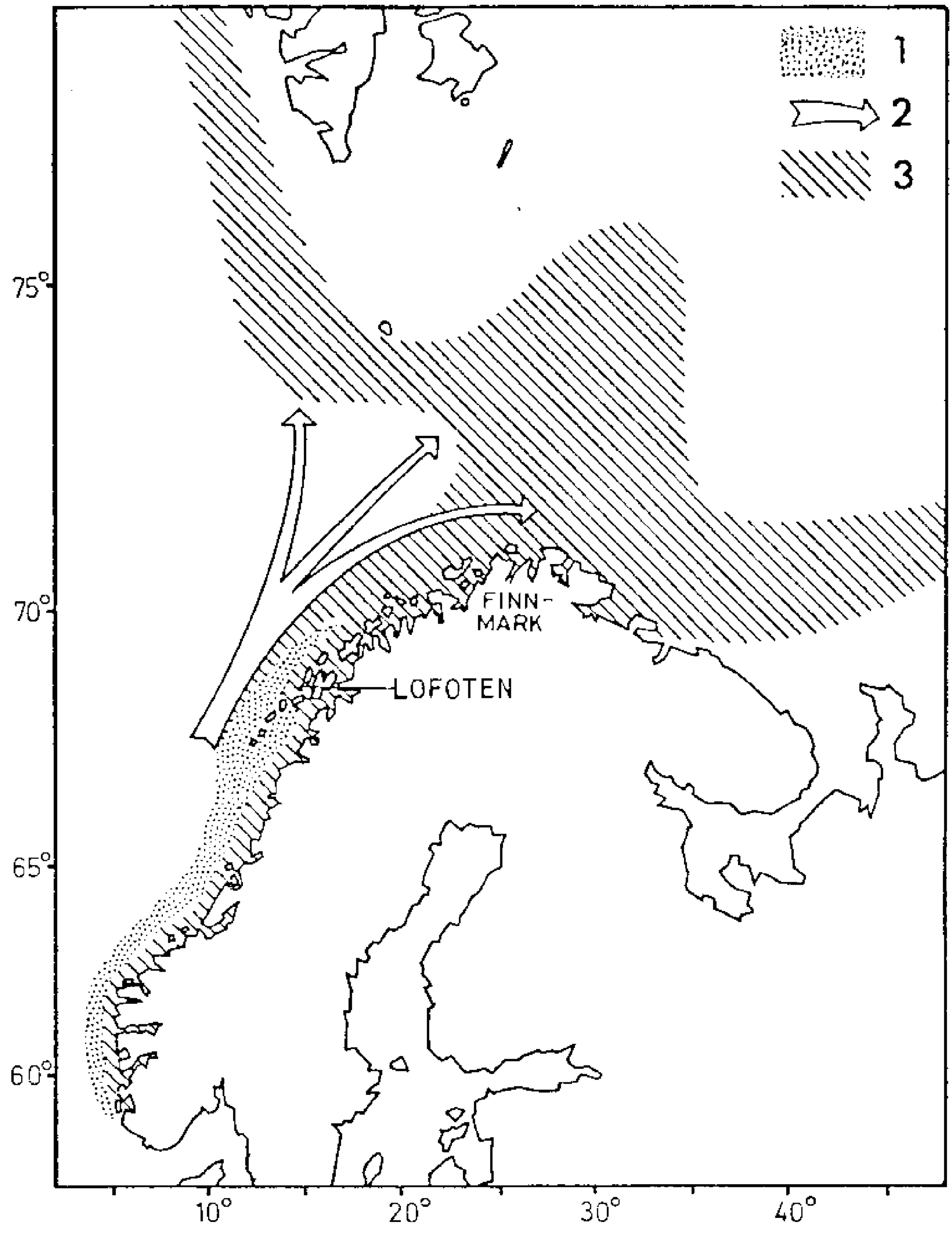

Figure 5. Distribution of young herring:
1) larval distribution, 2) postlarval drift, and 3) nursery area.

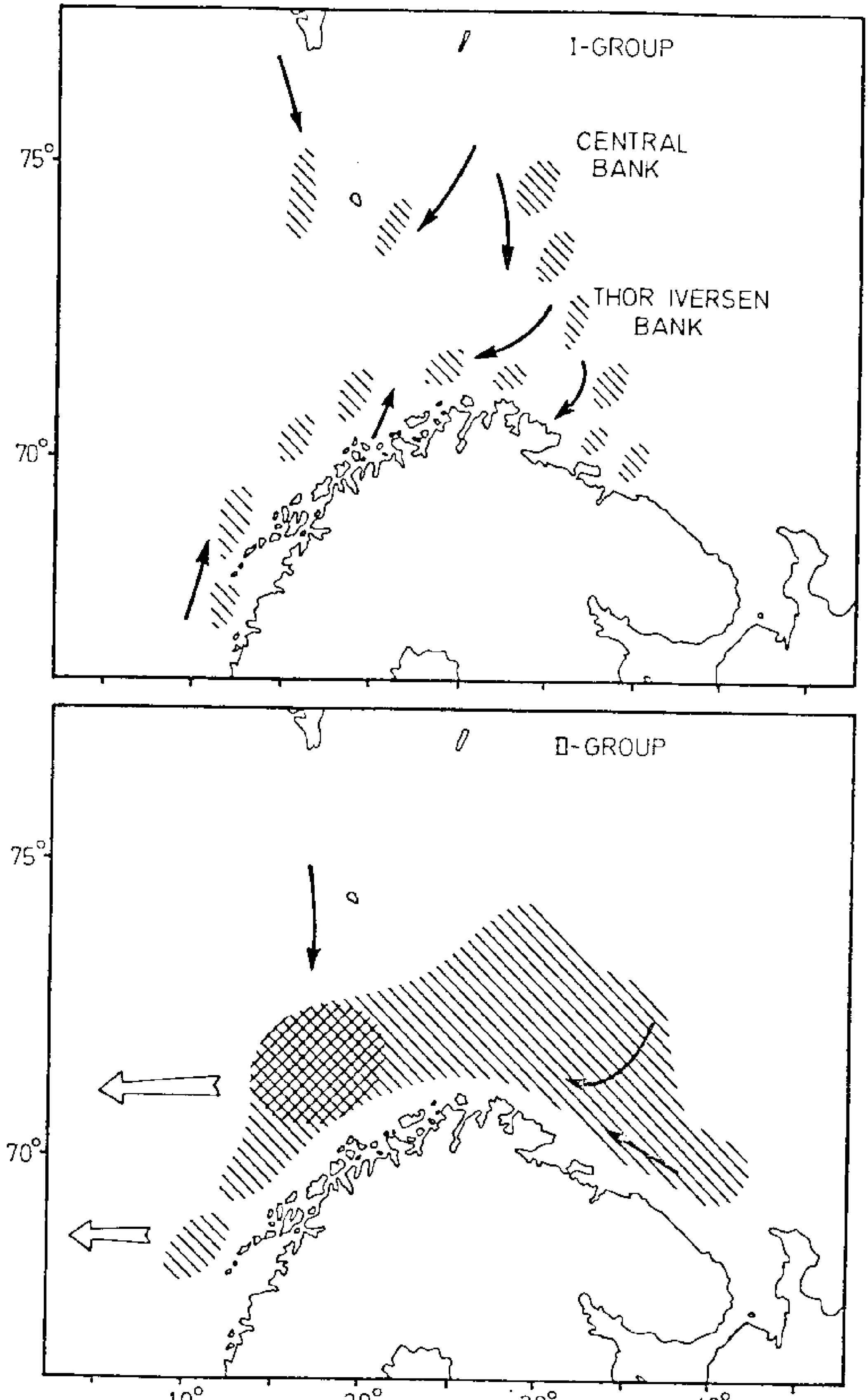

Figure 6. Distribution of 1 and 2 group young and adolescent herring in summer. The arrows indicate migration routes during the summer.

Young herring from the southern coastal area from Møre to Lofoten usually grow faster than those distributed farther north. They start their westward migration into the Norwegian Sea to join the adult sotck as 2-group fish. Those distributed off north Norway used to remain one or two years more in the nursery area before they began their migration to the Norwegian Sea. However, throughout the 1970s no such westward migration of maturing herring into the Norwegian Sea took place.

EXPLOITATION AND MANAGEMENT

THE FISHERIES

Traditionally the main fishery on the adult stock has been on winter herring along the Norwegian west coast prior to and during the spawning season. Another important fishery, the summer-and-autumn herring fishery took place on the feeding grounds north and east of Iceland and Jan Mayen. In addition to the fishery on adults, there has been a fishery for young and adolescent herring in Norwegian coastal areas and in the fjords, mainly in northern Norway. This fishery was based on 0- to 4-group herring.

The annual catches from the winter herring fishery fluctuated widely from 1925 to 1970 (Figure 7). Beginning in 1947, the catches rose steadily to a peak of about 1.2 million tons in 1956. The age distribution of the winter herring from 1950 to 1962 suggests that the strong year class of 1950 supported the high catches in the mid-1950s (Table 1). The catches then fell steadily to 1963. The high catches from 1964 to 1967 were associated with the strong 1959 and 1960 year classes (Table 2). From 1964 to 1967, a sharp increase in fishing effort took place. Then from 1968 to 1971, the catches in the winter herring fisheries were negligible compared with earlier years. Later in the 1970s there was practically no winter herring fishery.

The annual catches of the summer-and-autumn herring fishery from 1925 to 1970 also fluctuated (Figure 8). From 1925 to 1950 the catches fluctuated around 100,000 tons. Until 1950, mainly Icelandic and Norwegian boats participated in this fishery. The Soviet fishery on feeding herring in the Norwegian Sea started in 1950 and the total catches gradually increased during the 1950s and reached a peak on 420,000 tons in 1960. From 1962 to 1966, there was a sharp increase in the total catch, mainly due to the Icelandic fishermen.

The drastic change in the migration pattern of the adult stock during the 1960s strongly influenced the location of the summer-and-autumn fishery. The fishery off Iceland gradually became negligible and at the end of the 1960s most of the summer fishery took place in the northeastern part of

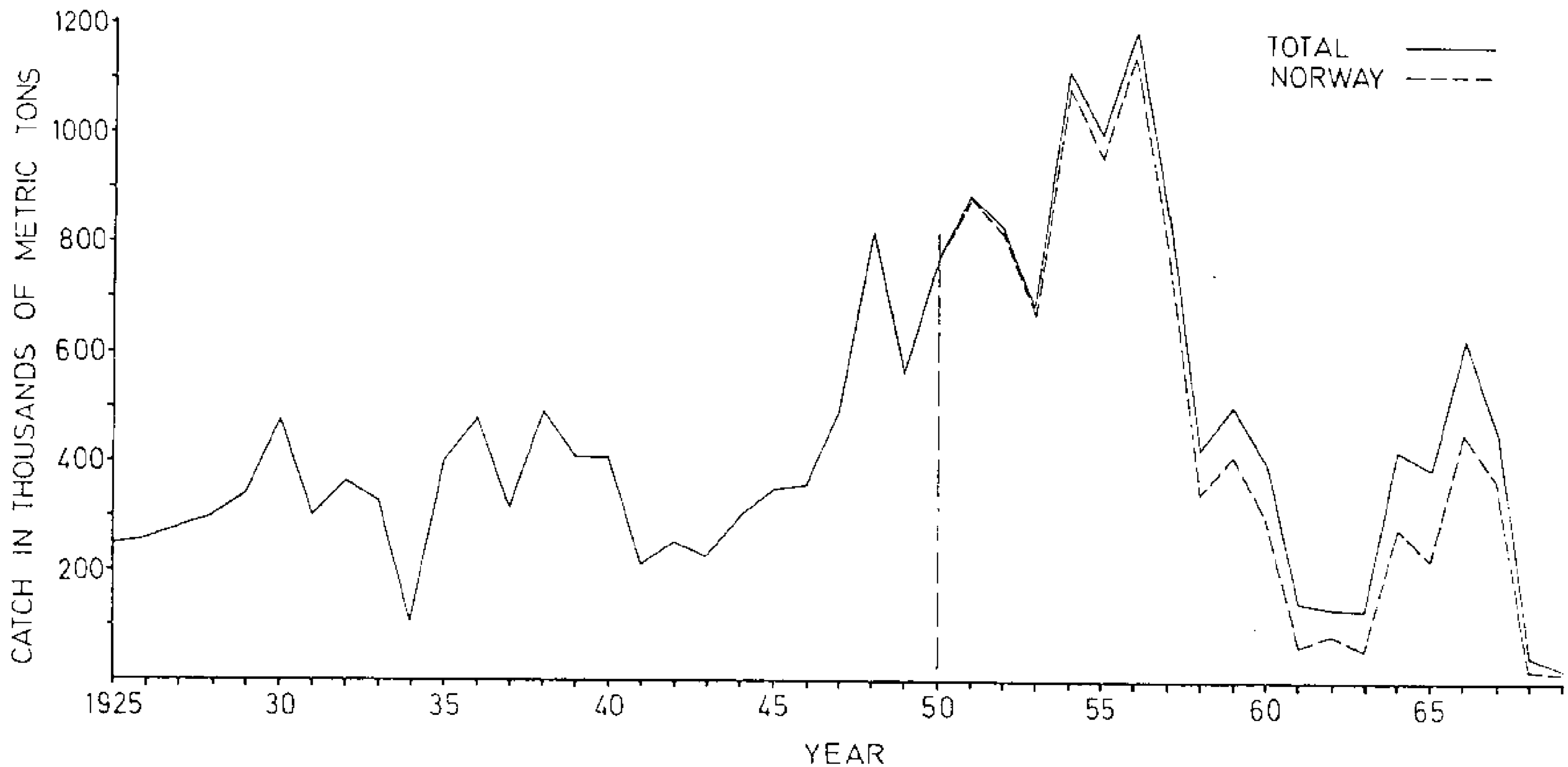

Figure 7. Catches of Norwegian spring spawning herring by the winter fishery from 1925 to 1970.

Table 1. Percentage age composition of Norwegian spring spawning herring caught by the Norwegian winter fishery from 1950 to 1962. Catches from the 1950 year class are underlined.

Age	Year												
	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
2	0.1	-	0.1	0.1	0.1	-	-	0.2	-	-	-	-	-
3	8.3	0.2	1.3	4.0	1.3	1.5	0.6	0.4	0.5	0.4	-	-	0.1
4	5.5	11.6	2.0	1.9	25.2	6.3	5.0	7.4	1.0	1.3	0.3	0.4	-
5	5.5	5.2	19.9	4.1	3.3	45.9	5.9	4.3	6.1	1.4	1.6	0.9	0.5
6	16.3	4.8	4.5	14.4	5.4	2.7	50.6	5.6	4.7	7.5	1.2	3.3	0.9
7	18.7	15.2	6.7	3.2	11.0	4.3	2.3	56.5	6.6	5.1	6.5	2.9	2.5
8	2.3	17.7	17.4	4.2	2.8	5.6	3.9	1.8	50.5	7.3	3.5	7.7	1.5
9	2.5	2.0	12.2	12.0	4.2	1.7	4.6	2.6	2.6	47.3	5.0	4.8	5.0
10	3.1	2.2	2.4	14.4	9.2	4.0	2.2	2.4	3.5	2.2	[illegible]	6.5	4.0
11	2.4	2.6	2.5	2.0	9.5	5.5	3.5	1.6	3.4	3.3	1.6	59.0	6.0
12	5.4	2.7	3.1	2.8	1.7	3.3	4.1	2.2	2.3	4.5	3.3	4.4	63.8
13	10.4	6.7	3.0	2.9	1.9	1.0	1.9	2.7	2.2	1.9	4.1	3.0	2.1
14	1.6	9.1	5.0	3.0	2.5	1.4	0.9	1.5	1.8	2.3	1.5	2.3	3.4
15	2.7	1.5	7.0	6.6	2.2	1.3	1.2	0.5	1.1	2.2	1.0	1.8	3.4
16	4.8	3.0	1.6	7.0	3.4	1.9	1.4	0.6	0.6	0.9	1.3	1.4	0.7
17	1.1	4.0	2.2	2.2	4.3	2.2	1.7	0.8	0.7	0.5	0.9	0.9	1.0
18	0.5	0.4	3.4	2.9	1.7	1.3	1.6	1.0	0.7	0.7	0.5	0.3	1.0
19	-	0.2	0.8	2.9	1.4	1.5	0.6	0.7	0.5	0.4	0.3	0.4	0.3
20	0.1	-	0.1	0.7	1.0	0.7	0.6	0.3	0.3	0.3	0.5	0.1	-
21	-	0.1	-	0.1	0.1	0.2	0.3	0.2	0.2	0.2	0.3	0.1	0.2
22	-	-	-	-	0.1	0.1	0.1	-	-	0.1	0.1	0.1	-
23	-	-	-	-	-	-	-	-	-	0.1	0.1	-	0.1
?	8.6	10.8	9.8	8.6	7.8	5.9	7.0	6.6	10.6	10.0	7.8	-	-
n	3973	3841	3336	2796	4839	4174	4988	2779	972	1116	1155	452	396

Table 2. Percentage year class composition of Norwegian spring spawning herring caught by purse seine during the spawning season from 1963 to 1968.

Year	Area	Total	Year class															Mean
			1963	1962	1961	1960	1959	1958	1957	1956	1955	1954	1953	1952	1951	1950	<1950	age
1963	Møre	923	-	-	-	-	4.0	0.3	0.4	0.7	1.8	1.7	8.7	3.6	8.3	61.1	9.4	12.2
	Lofoten	433	-	-	-	9.5	89.8	0.7	-	-	-	-	-	-	-	-	-	3.9
1964	Møre	1198	-	-	-	4.0	51.5	0.4	0.2	0.7	1.3	0.5	4.2	2.2	3.2	28.0	3.8	8.7
	Lofoten	1089	-	-	0.6	10.1	88.4	0.3	-	-	-	-	0.1	-	-	0.5	-	4.9
1965	Møre	1141	-	-	3.2	10.7	62.7	0.1	0.2	-	0.4	0.9	2.0	1.4	2.2	14.4	1.8	7.8
	Lofoten	719	-	-	5.8	19.6	74.1	0.1	-	-	-	-	0.3	-	-	-	0.1	5.7
1966	Møre	2963	-	0.1	10.3	27.7	53.4	0.2	0.2	0.1	0.2	0.3	0.7	0.7	0.4	5.2	0.5	7.2
	Lofoten	749	-	0.3	8.0	39.1	51.6	0.3	-	-	-	-	-	0.1	0.3	0.3	-	6.5
1967	Møre	2135	0.5	0.4	13.4	32.1	48.8	0.1	0.1	0.1	0.2	0.3	0.7	0.3	0.3	2.6	0.1	7.3
1968	Møre	1352	0.7	1.7	13.8	34.2	46.9	0.2	-	0.1	0.2	0.2	0.7	0.3	-	1.0	-	8.5

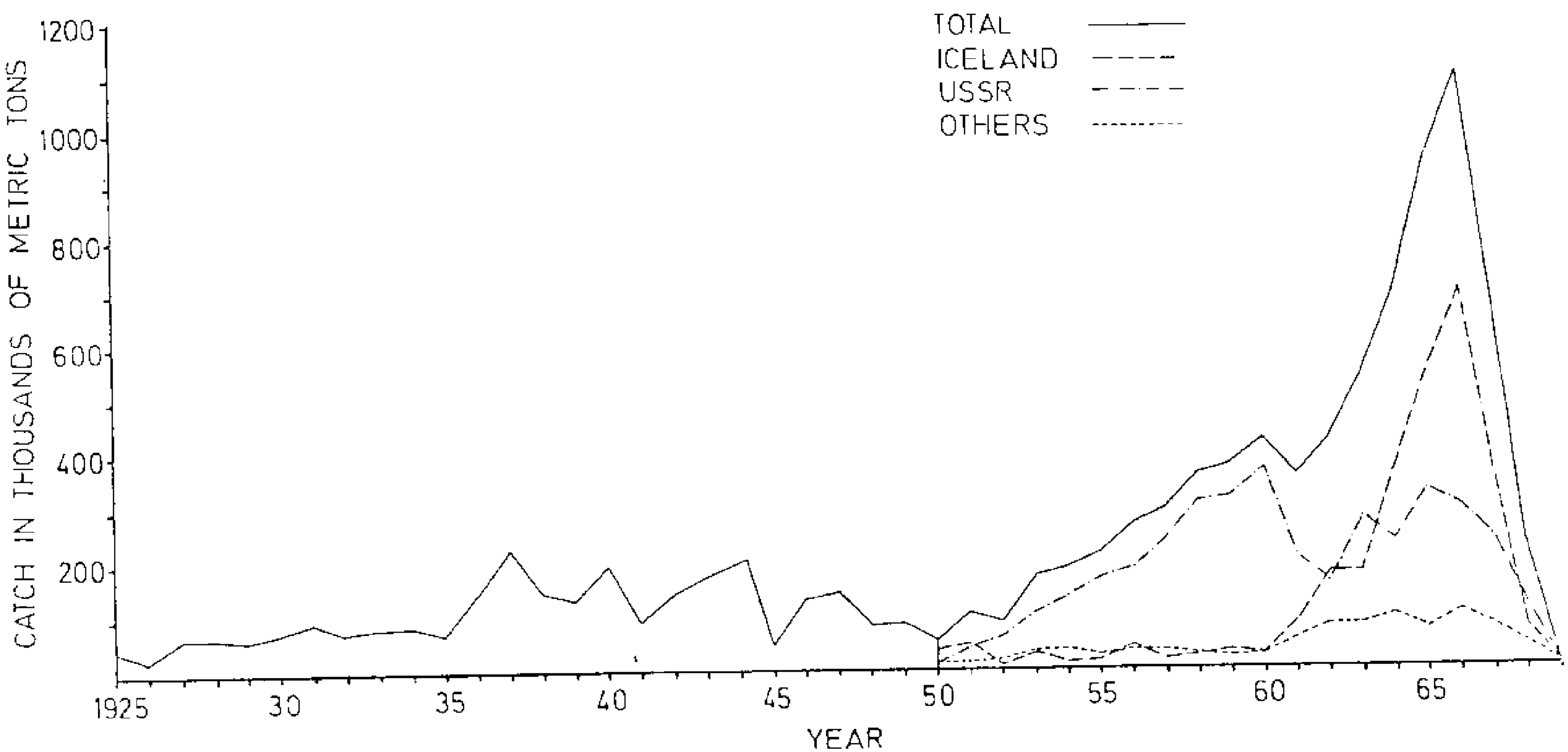

Figure 8. Catches of Norwegian spring spawning herring by the summer and autumn fishery from 1925 to 1970.

the Norwegian Sea off the shelf next to Bear Island and Spitsbergen. A sharp decline in the catch occurred from 1967 to 1968 and the fishery ended in 1969. Since then, almost no herring have been available in the Norwegian Sea during the feeding period.

The total catch of young and adolescent herring landed from 1930 to 1975 also fluctuated widely (Figure 9). The fishery on 0- and 1-group herring occurred in the fjords from late autumn to early spring. The fishery started with the immigration of 0-group herring to the fjords and continued throughout the wintering period. The most intensive fishery for adolescent herring (1- to 4-group fish), especially in the 1960s, took place offshore along the coast between Lofoten and Finnmark, with the peak in summer and early autumn. Farther south along the coast, off Møre-Trøndelag, most of the adolescent herring were landed in spring and early summer. The stock of immature herring was almost depleted in 1969, and in 1969 and 1970 the catch had declined by about 90 percent compared to 1968. In 1971 and 1972, further decreases in catch took place. About 14,000 tons were landed each year, mainly from the 1969 year class. Later in the 1970s only small catches were taken.

STOCK SIZE CHANGES AND RATE OF EXPLOITATION

The changes in spawning stock size from 1950 to 1978 were analyzed by Dragesund, Hamre, and Ulltang (1980). The stock size was estimated at 9 million tons in 1950 and decreased to about 7 million tons in 1953 (Figure 10). From 1954 to 1957, the strong 1950 year class was gradually recruited to the spawning stock, resulting in an increase in stock size to about 10 million tons in 1957. The stock then decreased again, as a result of poor recruitment, to about 2.5 million tons in 1963. From 1963 to 1966, the stock size increased somewhat, but from 1966 onwards there was another rapid decline. Fishing mortality was relatively low and constant up to 1962 (Figure 11). Thereafter, a sharp increase took place due to increased effort in both the summer-and-autumn and winter fisheries.

Around 1960, technical advances considerably improved the purse seining system in all three herring fisheries. The new techniques enabled the use of larger and deeper nets and led to an extension of the fishery seaward. Also, the use of acoustic equipment was important for the development of the herring fishery. During the 1950s the fishermen came to consider acoustic devices to be indispensible for fishing; it became common to use sonar to guide net setting.

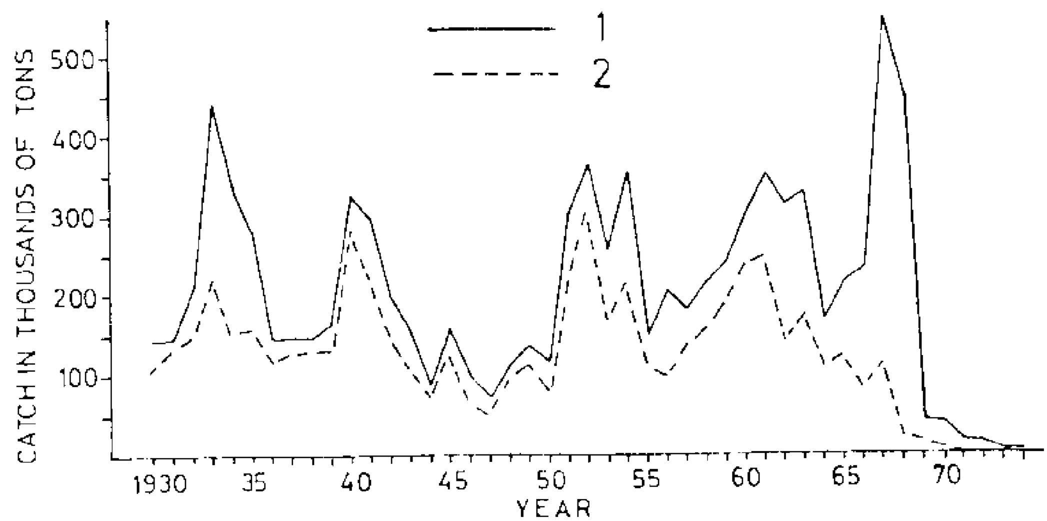

Figure 9. Catch of young and adolescent Norwegian spring spawning herring from 1930 to 1968: 1) total catch and 2) young, 0- and 1-groups.

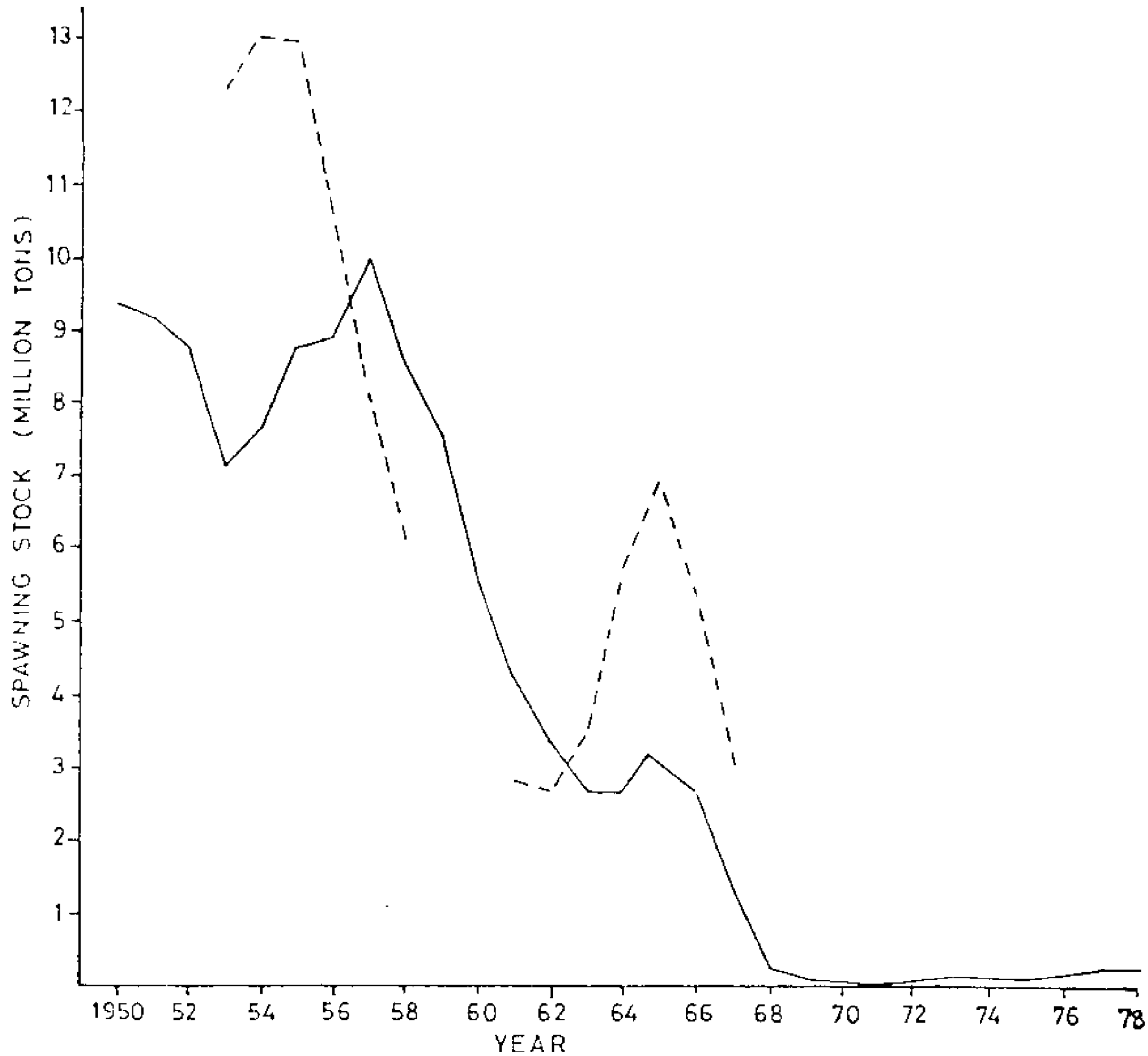

Figure 10. Estimated weight of the spawning stock size of Norwegian spring spawning herring from 1950 to 1978. The broken lines are estimates of the ICES Working Group on Atlanto-Scandian herring (ICES 1970, 1977).

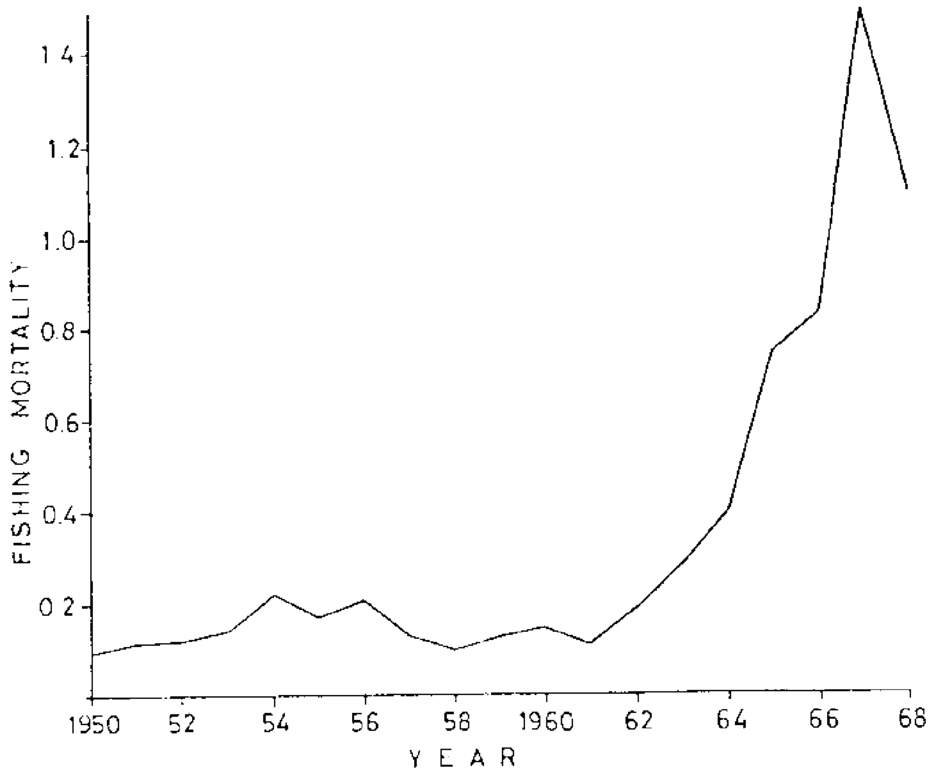

Figure 11. Fishing mortality estimates for 7-years-and-older herring from 1950 to 1968.

From 1950 to 1969, the exploitation rate on young herring was high. The purse seine fishery in Norwegian coastal waters generated much higher fishing mortalities on weak and moderate year classes than on strong ones. Weak and moderate year classes survived four years in small quantities (Figure 12). The 1961 year class was the last which gave recruits to the spawning stock in any quantity. Some of the 1963 and 1964 year classes survived to an age of four years, but those were practically fished out in the adolescent fishery in 1968. Thus, there was practically no recruitment to the adult stock after 1966, which inevitably resulted in the rapid decrease of the adult stock size. This decline was further accelerated by the increased exploitation of the adults.

RECENT MANAGEMENT

The collapse of the Norwegian spring spawning herring was the first of a fish stock in the Northeast Atlantic Ocean (Saetersdal, 1980). However, the dramatic events taking palce during the 1960s did not result in any immediate management action. The collapse of the stock was almost complete before any effective steps were taken. An assessment report dealing with the state of Atlanto-Scandian herring and their exploitation to 1963 was prepared (ICES, 1965).

The report concluded that the magnitude of the reduction of recruitment due to the young herring fishery was not yet known. Even in 1969 (ICES, 1970), when the catches had declined drastically, no firm restriction was recommended. The ICES Working Group on Atlanto-Scandian herring concluded that the fishing mortality on immature herring should be reduced and an increase in fishing rate on the adult stock be avoided. The Working Group met again in 1971, stating that there had been almost no recruitment to the adult stock since 1966 due to the heavy exploitation of young herring, and that the stock was considered to be in a critical state (ICES, 1972).

The first effective management action was taken in 1971 when the use of herring for reduction was prohibited. This regulation probably prevented total depletion of the 1969 year class in 1971 and 1972. From 1972 to 1974, the fishery was regulated by an agreement between Iceland, Norway, and the USSR. There were no commercial catches of adult herring and the catches of young and adolescent herring were limited by quotas. In 1973 the catch was limited to 6,800 tons and in 1974 to 6,300 tons. In 1975 and 1976, the fishery was regulated by a Northeast Atlantic Fisheries Commission agreement. In 1975 a total allowable catch (TAC) of 3,500 tons was set and in 1976 no commercial fishing was permitted.

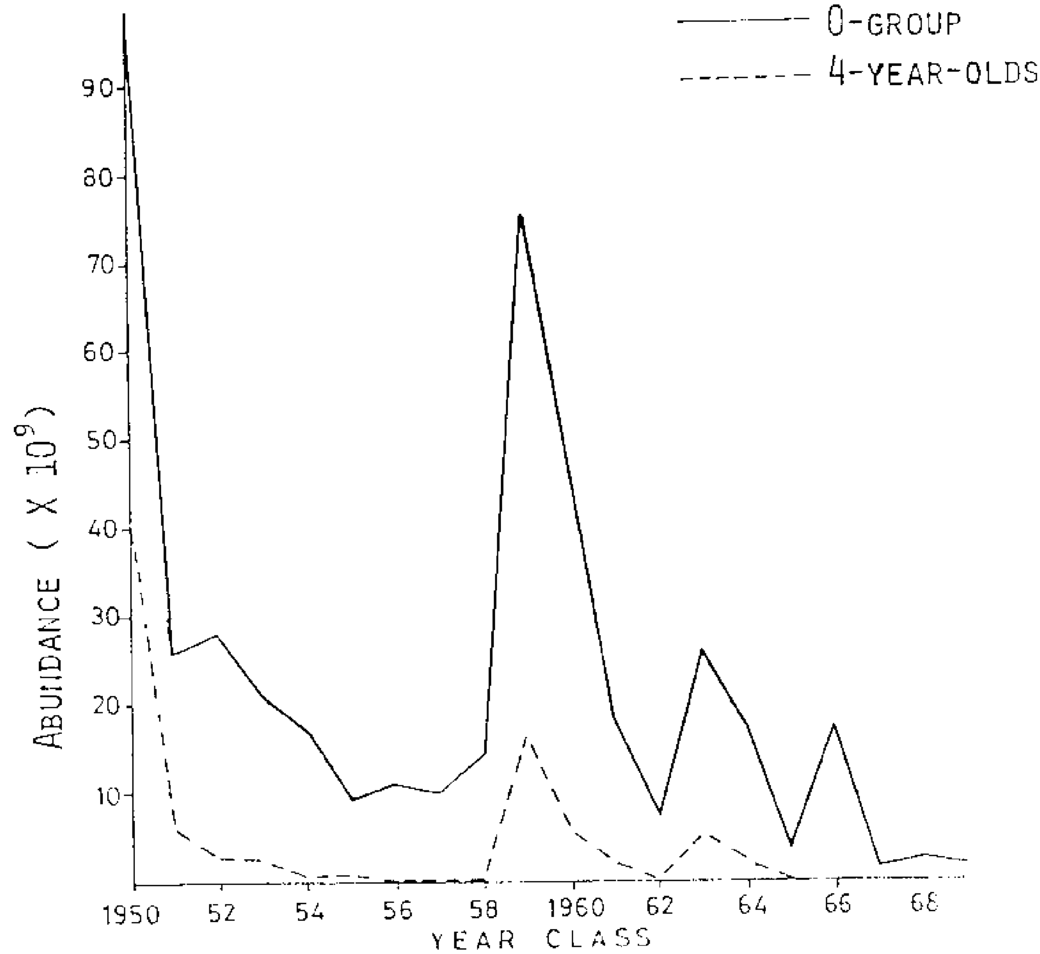

Figure 12. Year class abundance for 0-group and 4-year-old Norwegian spring spawning herring.

In 1977 and 1978 some 13,000 tons and 9,000 tons of adult and juvenile herring were caught in Norwegian coastal waters.

There has been widespread speculation on the primary reason for the disappearance of the herring--whether the collapse of the stock was caused by overfishing alone or whether it was due to natural causes. Computer simulation was used to investigate whether the collapse could have been avoided if the herring fishery had been managed by regulations in the 1960s (Dragesund, Hamre and Ulltang, 1980).

The simulation runs can conveniently be classified in two groups (Figure 13). In the first group of runs the effect of some minimal regulations (saving strategies) were studied to see whether they could have had a significant effect on the final spawning stock in 1970 and could have avoided the collapse of the stock (Figure 13A). In these runs the simulated exploitation pattern is still damaging to the stock. Run 1 is a check using the estimated fishing mortalities obtained from the virtual population analyses (VPA), where the calculated spawning stock size should be equal to that estimated from the VPA. Run 2 simulates the effects of a closing of the young herring fishery ($F_0 = F_1 = 0$). Run 3 simulates the likely effects of the restrictions on the adult fisheries from 1963 onward when the increase in F generated by these fisheries started. F for 7-years-and-older was put equal to 0.2 for the years 1963 to 1970. In run 4 a severe restriction on the heavy adolescent fishery in 1967 and 1968 on the 1963 and 1964 year classes is simulated, letting all other fisheries go on unregulated. The results of the simulation runs indicated that the collapse seemed to occur as a combined effect of increased effort in the adult fishery and the high exploitation rate on the immature stock. Regulation in either of the two fisheries would have had a pronounced effect on maintaining the spawning stock size at a reasonable level up to 1970. The fishery on 0- and 1-group herring was the most irrational strategy. A minimum legal size protecting the 0- and 1-group fish was the only regulation needed in the 1960s to prevent the depletion of the stock. With the recruitment observed in the 1960s, this regulation could have preserved a spawning stock in 1970 of 1.6 million tons (run 2).

In the second group of runs some more optimal strategies were studied (Figure 13B). If the regulation simulated had been combined with a catch quota aimed at F_{max} or $F_{0.1}$ on older fish, it is estimated that the spawning stock could have remained at a level of 2.4 to 4.7 million tons if the young herring fishery ($t_c = 2$) was prohibited. The conclusion is that the collapse of the stock in the 1970s was mainly caused by over-exploitation.

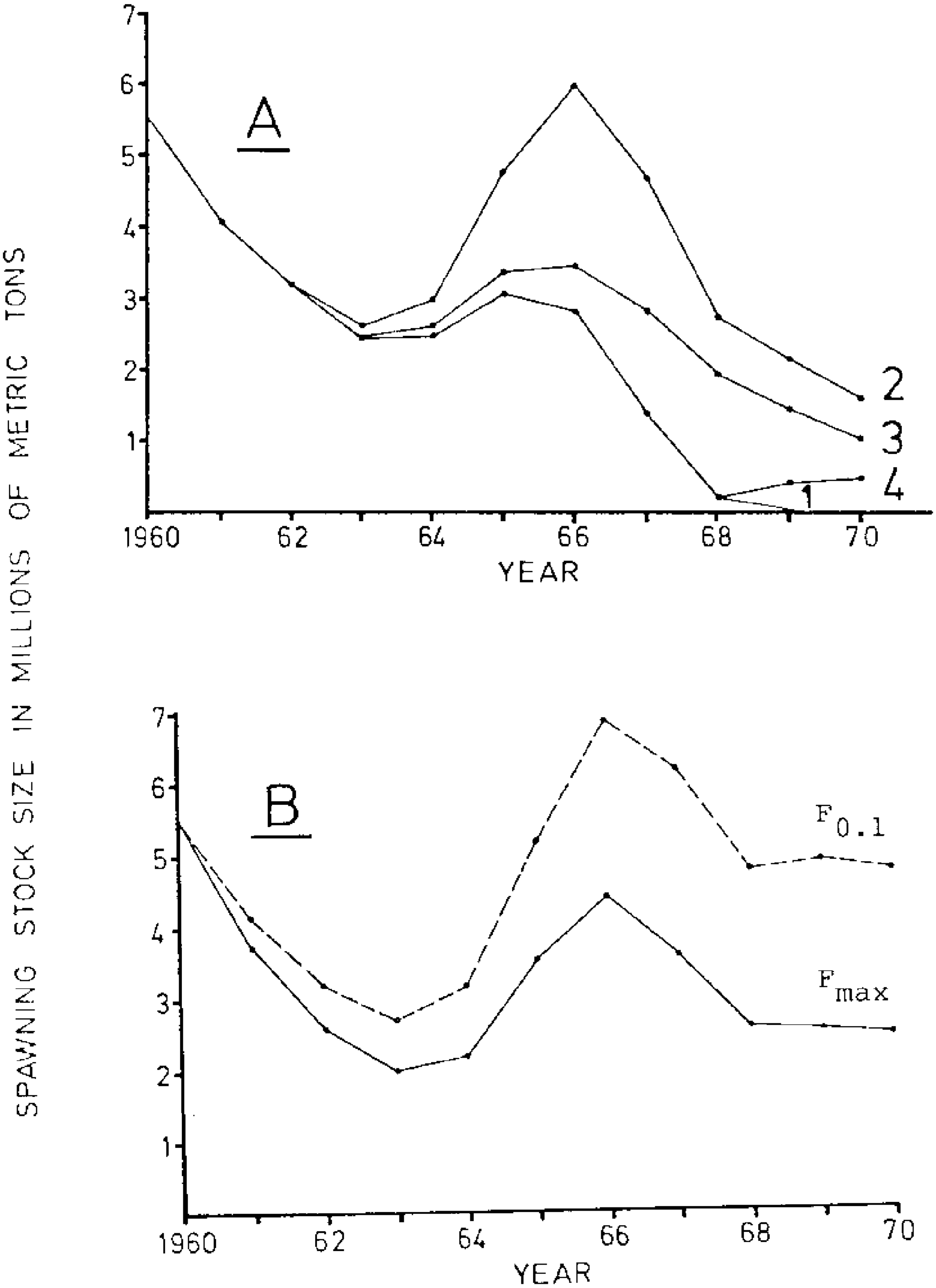

Figure 13. Simulated spawning stock sizes for Norwegian spring spawning herring. A) These runs examined the effects of some minimal regulations. B) These runs examined more optimal regulations.

RESEARCH ACTIVITIES

The present long-term aim for management is to rebuild the spawning stock to a minimum of 2.5 million tons. The research program monitoring the state of the stock during the last years has included: echo surveys and biological sampling on the spawning and feeding grounds; larval surveys; echo abundance estimates of 0-group herring in coastal areas; and tagging experiments (Dragesund, Hamre and Ulltag, 1980).

SURVEYS ON SPAWNING AND FEEDING GROUNDS

Prior to and during the spawning season, echo surveys are carried out along the coast, mainly between Stad and Lofoten, with biological sampling and fishing experiments. Similarly, surveys are made during summer and autumn in Norwegian coastal waters and into the offshore waters of northern Norway. No regular oceanic surveys were carried out during the 1970s. However, Soviet research vessels surveyed large areas of the Norwegian Sea as well as near Jan Mayen-Spitsbergen in 1977 and 1978 (ICES, 1979). During the survey in 1977 no herring concentrations were located by acoustic methods, but experimental fishing with both driftnets and pelagic trawls yielded a few samples in which the 1969 year class was dominant. In 1978, no herring were located by acoustic methods and the experimental fishing caught one herring.

Two small components of the 1969 year class, one in the Barents Sea and the other off Møre, survived the heavy exploitation during the immature stage. Both components spawned for the first time in 1973, the northern component at Lofoten and the southern at Møre. These two components did not mix later in the 1970s and the northern component spawned on traditional spawning grounds along the coast between Møre and Lofoten. The southern component spawned towards the southern part of the Møre coast.

It is likely that an increase in spawning stock size took place from 1972 to 1973 when the recurits of the 1969 year class entered the spawning grounds. However, no appreciable increase in the spawning stock size was observed from 1973 to 1976, although a fraction of the 1973 year class matured in 1976 (Table 3). A considerable increase in the abundance of spawning herring was recorded in the winter of 1977. In 1978 and 1979, no similar increase in stock strength was observed on the spawning grounds (Anon., 1979; ICES, 1979).

LARVAL SURVEYS

Larval surveys have been carried out for several years. Until 1972, the larvae were collected mainly with Clarke-

Table 3. Spawning stock of Norwegian spring spawning herring as abundance (millions) and weight (thousands of metric tons) from 1973 to 1979.

Year	Age							Weight
	3	4	5	6	7	8	9	
1973	18	289	9	14	6	3	5	93
1974	6	21	237	3	2	1	1	71
1975	44	4	6	194	1	1	1	81
1976	237	57	1	3	159	1	-	124
1977	173	413	23	-	-	130	-	200
1978	6	234	335	---------- 98 --------				200
1979	32	37	171	232	----- 65 -----			170

Bumpus plankton samplers. Since 1972, a modified version of the Gulf III sampler has been used. There has been about the same survey effort each year. The distributions of the herring larvae from 1968 to 1972 and from 1973 to 1977 can be compared (Figures 14 and 15). The distribution of abundance of the larvae is in reasonable agreement with the echo recordings of herring on the spawning grounds. The decreasing abundance of larvae from 1968 to 1972 is evident (Figure 14). The increase of the spawning stock in 1973 with the appearance of one component spawning off Møre, another off Lofoten, is also evident (Figure 14). In 1976, the abundance of larvae increased considerably related to the recruitment of the 1973 year class to the spawning stock. The failure of the increase of the stock strength in 1977 to be reflected in the larval abundance measured that year was probably because the sampling was late in relation to the time of hatching. There was no major change in the larval abundance in 1978 and 1979 compared with 1976 and 1977, indicating that no increase had taken place in the spawning stock size (Anon., 1979).

0-GROUP SURVEYS

Regular 0-group surveys with acoustic methods have been carried out in coastal waters of western and northern Norway every October to December since 1974 (ICES, 1979). In addition, 0-group surveys for species other than herring are also undertaken every year in offshore waters of northern Norway, including the whole Barents Sea and Spitsbergen area.

Anon. (1979) has given abundance estimates of 0-group herring in the coastal waters from 1974 to 1978 (Table 4). Herring recorded in the offshore surveys are not included in these estimates. 0-group herring were observed in small quantities in the Barents Sea in 1976, 1977, and 1978. The estimates of the 1974 year class are probably low due to poor geographic coverage. A marked drop in the 0-group abundance in all areas occurred in 1977, indicating unfavorable conditions for the survival of larvae.

TAGGING EXPERIMENTS

In 1975, a tagging project was initiated. Nearly 140,000 herring from an experimental fishery were tagged internally in April and May from 1975 to 1978. Catches from the experimental fishery have been analyzed for recoveries by a device retaining internally tagged fish (Gytre and Jakupsstovu, 1977). Most of the catches screened for tags were taken in the overwintering area of the mature stock or at the spawning grounds. Some samples were also obtained during autumn. The spawning stock size estimates were based on tag returns during the experimental fishery from 1977 to 1979 and the age composition of the catches (Dragesund,

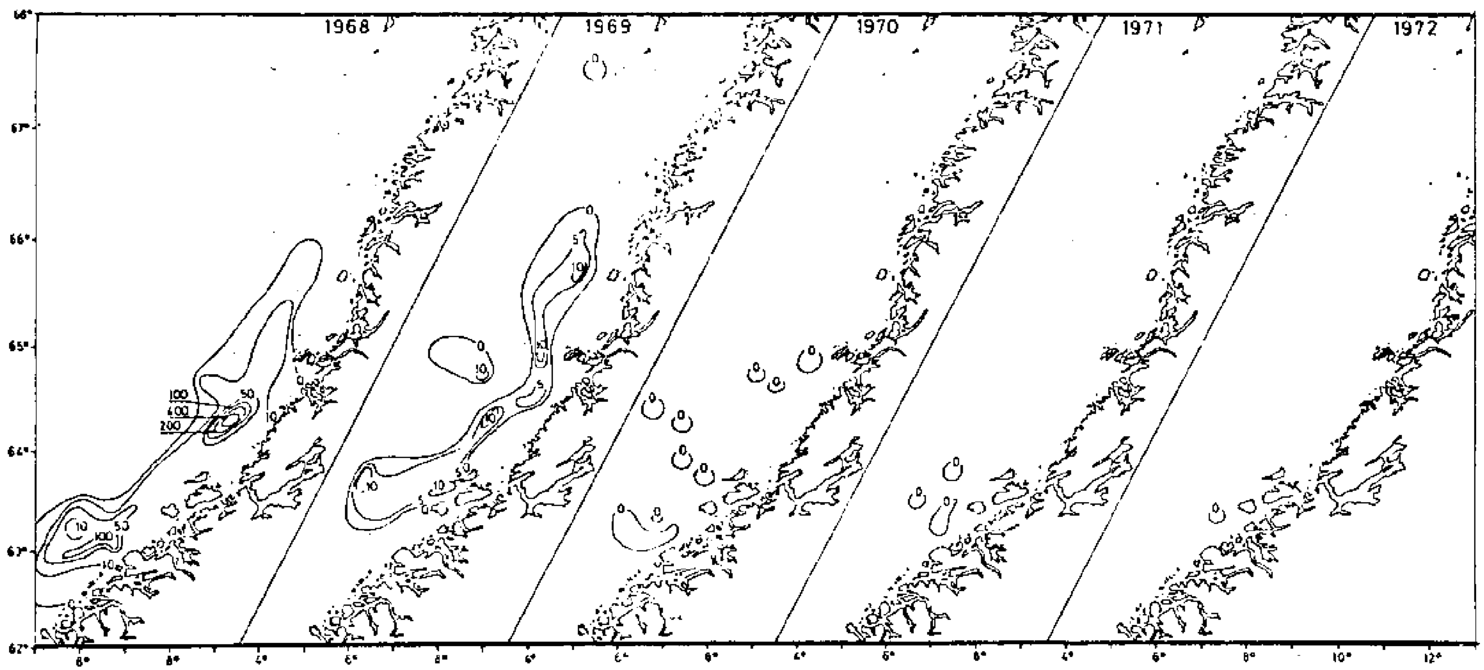

Figure 14. Distribution of larvae of the Norwegian spring spawning herring from 1968 to 1972. The isolines indicate abundance/m^2.

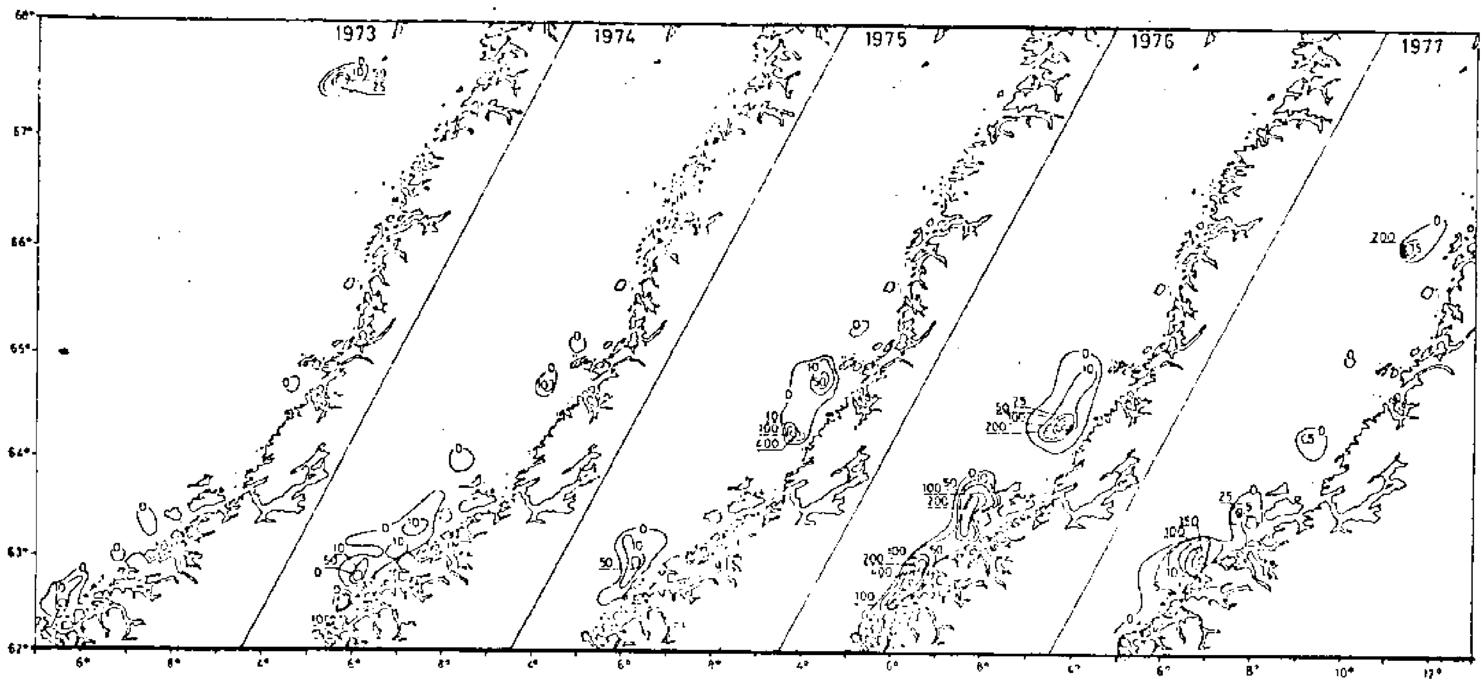

Figure 15. Distribution of larvae of the Norwegian spring spawning herring from 1973 to 1977. This isolines indicate abundance/m^2.

Table 4. Abundance (millions) of 0-group Norwegian spring spawning herring by area from 1974 to 1978.

Year	Møre-Trøndelag	Northern Norway	Total
1974	50	280	330
1975	1 933	747	2 680
1976	440	3 360	3 800
1977	72	342	414
1978	321	903	1 224

Hamre and Ulltang, 1980; Anon., 1979). Estimates are available from 1973 to 1979 (Table 4). Some increase is expected in the spawning stock size in 1980 due to greater 0-group abundance in 1976 than in the previous years. Based on the 0-group abundance estimates, recuritment from the 1977 and 1978 year classes is expected to be low.

CONCLUSIONS

The efficiency of techniques to catch schooling fishes can now endanger the survival of stocks. The adult Norwegian spring spawning herring were fished out by 1970. Regulations were probably effective in saving the immature herring from further depletion. It is not certain that the Norwegian spring spawning herring were about to be eliminated, but the most important fish resource in the Northeast Atlantic Ocean may have been saved by last-minute regulations. A slight recovery of the stock took place during the late 1970s and the critical stage is probably past.

The effects of the collapse of the herring on other populations are of great interest and difficult to assess. The Norwegian spring spawning herring compete with two other planktonfeeding stocks, the blue whiting and the capelin. There are no indications that the herring have been replaced by another species. Therefore, the consequence of the collapse of the Norwegian spring spawning herring is that the production of a rich area of the ocean is no longer harvested by fishermen.

REFERENCES

Anon. 1979. Ressursoversikt for 1979. Fisken og havet, 1979 (saernummer): 1-119.

Aasen, O. 1958. Estimation of the stock strength of the Norwegian herring. J. Cons. perm. int. Explor. Mer, 24: 95-110.

Aasen, O. 1962. On the correlation between the arrival and spawning of the Norwegian winter herring. J. Cons. perm. int. Explor. Mer, 27: 162-166.

Benko, J. Sk. and Seliverstov, A. S. 1971. Influence of some factors on the abundance of Atlanto-Scandian Herring year-classes. Rapp. P.-V. Réun. Cons. perm. int. Explor. Mer, 160: 153-157.

Devold, F. 1963. The life history of the Atlanto-Scandian herring. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 154: 98-108.

Devold, F. 1968. The formation and the disappearance of a stock unit of Norwegian herring. FiskDir. Skr. Ser. HavUnders. 15: 3-15.

Dragesund, O. 1970a. Factors influencing year-class strength of Norwegian spring spawning herring (Clupea harengus, Linné). FiskDir. Skr. Ser. HavUnders., 15: 381-450.

Dragesund, O. 1970b. Distribution, abundance and mortality of young and adolescent Norwegian spring spawning herring (Clupea harengus, Linné) in relation to subsequent year-class strength. FiskDir. Skr. Ser. HavUnders, 15: 451-556.

Dragesund, O. and Ø. Ulltang. 1978. Stock size fluctuations and rate of exploitation of the Norwegian spring spawning herring, 1950-1974. FiskDir. Skr. Ser. HavUnders., 16: 315-337.

Dragesund, O., J. Hamre, and Ø. Ulltang. 1980. Biology and population dynamics of the Norwegian spring spawning herring. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer. (In press.)

Einarsson, H. 1958. The Icelandic herring and racial problems. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 143: 45-52.

Fridriksson, A. 1944. The herring of the north coast of Iceland. Rit. Fiskideild, 1: 390 pp.

Fridriksson, A. 1958. The tribes of the north coast herring of Iceland with special reference to the period 1948-1955. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 143: 36-44.

Fridriksson, A. 1963. Recent trends in the tribal composition of the north coast herring of Iceland. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 154: 68-72.

Gytre, T. and H. Jakupsstovu. 1977. Detection of internally tagged fish with special application of the Atlanto-Scandian herring. Coun. Meet. int. Coun. Explor. Sea, 1977(H:20):1-13.

ICES. 1964a. Report of the Atlanto-Scandian Herring Working Group. Coun. Meet. int. Coun. Explor. Sea, 1964 Doc. No. 8 (Herring Committee): 1-22. (Mimeo.)

ICES. 1964b. Appendix. Report of joint investigations on the distribution of herring in relation to hydrography and plankton in the Norwegian Sea, June/July 1962. Annals biol., Copenh., 1964: 193-198.

ICES. 1965. Report of the assessment group on herring and herring fisheries in the north-eastern Atlantic. Coun. Meet. int. Coun. Explor. Sea, 1965 (1): 1-40. (Mimeo.)

ICES. 1970. Report of the Working Group on Atlanto-Scandian Herring. Copenhagen 21st-25th April 1969. ICES Coop. Res. Rep. Ser. A, 17: 1-43.

ICES. 1972. Report of the meeting of the Working Group on Atlanto-Scandian Herring. ICES Coop. Res. Rep. Ser. A, 30: 1-27.

ICES. 1977. Report of the Atlanto-Scandian Herring Working Group. Bergen 18th-22nd April 1977. Coun. Meet. int. Coun. Explor. Sea, 1977 (H:4): 1-28. (Mimeo).

ICES. 1979. Report of the Working Group on Atlanto-Scandian Herring. Bergen 21st-23rd May 1979. Coun. Meet. int. Coun. Explor. Sea, 1979 (H:8): 1-43. (Mimeo.)

Jakobsson, J. 1963. Some remarks on the distribution and availability of the Iceland north coast herring. Rapp. P.-v. Réun. Con. perm. int. Explor. Mer, 154 : 73-82.

Jakobsson, J. 1968. Appendix. Herring, migration east of Iceland during the summer and autumn 1966 and 1967. FiskDir. Skr. Ser. HavUnders., 15: 17-22.

Jakobsson, J. 1971 Icelandic Herring Search and Information Services. Pp. 2-11 in Kristjansson, H., ed. Modern Fishing Gear of the World: 3. London.

Jakobsson, J. 1980. Exploitation of the Icelandic spring and summer spawning herring in relation to Fisheries Management 1947-1977. Rapp. P.-v. Réun. cons. perm. int. Explor. Mer. (In press.)

Johansen, A. C. 1919. The large spring spawning sea herring (Clupea harengus L.) in the North-West European waters. Medd. Komm. HavUnders., Ser. Fisk., 5: 1-56.

Lea, E. 1910. On the methods used in the herring investigations. Publs. Circonst. Cons. perm. int. Explor. Mer, 53: 7-33.

Lea, E. 1929. The oceanic stage in the life history of the Norwegian herring. J. Cons. perm. int. Explor. Mer, 4: 3-42.

Lea, E. 1930. Mortality in the tribe of Norwegian herring. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 65: 100-117.

Marti, Yu. Yu. 1956. The fundamental stages of the life cycle of Atlanto-Scandian herring. Trudy polyar. nauchno-issled. Inst. morsk. ryb. Khoz. Okeanogr., 9: 5-61. (In Russian.)

Marti, Yu. Yu. and S. S. Fedorov. 1963. Features of the population dynamics of marine herring as seen from the Atlanto-Scandian stock. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 154: 91-97.

Runnstrøm, S. 1936. A study of the life history and migrations of the Norwegian spring herring based on the analysis of the winter rings and summer zones of the scale. FiskDir. Skr. Ser. HavUnders., 5(2): 1-110.

Runnstrøm, S. 1941a. Racial analysis of the herring in Norwegian waters. FiskDir. Skr. Ser. HavUnders., 6(7): 1-110.

Runnstrøm, S. 1941b. Quantitative investigations on herring spawning and its yearly fluctuations at the west coast of Norway. FiskDir. Skr. Ser. HavUnders., 6(8): 1-71.

Saetersdal, G. 1980. Review of past management of some pelagic stocks and its effectiveness. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer. (In press.)

Yudanov, J. G. 1966. Spawning efficiency and the crop of the 1964 and 1965 year-classes of Atlanto-Scandian herring. Mater ryb. Issled. Sever. bass., 7: 5-18. (In Russian.)

Østvedt, O. J. 1958. Some considerations concerning the homogeneity of the Atlanto-Scandian herring. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 143: 53-57.

Østvedt, O. J. 1963. Catch, effort and composition of the Norwegian winter herring fishery. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, 154: 109-117.

MANAGEMENT OF THE NORTH SEA HERRING FISHERIES

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THE MANAGEMENT SYSTEM OF THE NORTHEAST ATLANTIC FISHERIES

The herring fishery in the North Sea has always been a multinational fishery and, therefore, management of this fishery could only be introduced on the basis of international cooperation. The legal basis for international management of the fisheries in the Northeast Atlantic was provided by the International Fisheries Convention of 1946, followed by the Northeast Atlantic Fisheries Convention of 1959 signed by 14 European countries. The corresponding management body was the Northeast Atlantic Fisheries Commission (NEAFC). Up to 1973, the powers of the commission had been limited to measures for the regulation of mesh sizes, attachment to nets, minimum landing sizes, closed areas and seasons.

Introduction of measures for regulating the amount of total catch or the amount of fishing effort did require a proposal adopted by not less than a two-thirds majority and subsequent acception by all member countries in accordance with their respective constitutional procedures.

Extending the powers of NEAFC was a lengthy process which started in 1966 by exploring a general basis for fishing effort regulations within a study group which considered all the aspects of fishing effort regulations. There was no doubt from the beginning of the discussion about the economic advantages of a reduction in effort, that is, the possibility of obtaining current catches with a fraction of the current fishing effort. On the other hand, it was virtually impossible for the commission to settle in a uniform and sensible manner the special economic and social problems of effort regulations for all member countries, a total of 14 countries with highly divergent political, economic and social structures.

It was logical, therefore, that the commission agree to aim at a catch limit system in which the total allowable catches were apportioned among the member countries. It should then be left to each country to decide how its fleet would take the amount allocated to it. The discussions and the following ratification process were finalized in 1973 at a time when NEAFC urgently needed the new competence.

The commission, however, could not decide upon management measures directly; there was only the possibility of making recommendations to the contracting countries which were under the obligation to implement any recommendation adopted by a two-thirds majority.

However, any contracting country could object to a recommendation within 90 days and thereby escape this obligation. If objections were lodged by three or more contracting countries, the recommendation was taken as not binding on any.

In order to make sure that the regulations--which are the instruments of fisheries management--will be observed, NEAFC, in close cooperation with ICNAF, developed a scheme of joint enforcement. This again was a difficult task because the commissions were breaking new ground in international law. It had been unthinkable until then for most countries that ships flying their flags could be subject to inspection on the high seas by officials of other countries.

The scientific advice as basis for managment action was provided by the International Council for the Exploration of the Sea (ICES) through its Advisory Committee on Fisheries Management (ACFM)--the former liaison committee. The advice given by ACFM with regard to North Sea herring is based on assessments done by the Herring Assessment Working Group for the area south of 62° north. Data and information on catches and their composition are provided by national laboratories of the different member countries for the assessment work. In addition, ICES-coordinated surveys on young herring and larvae have been established with growing importance for the scientific evaluation of the state of the stocks, in particular when directed herring fishing is prohibited.

THE HISTORY OF THE HERRING FISHERY IN THE NORTH SEA

The large scale fishery for herring in the North Sea as recorded in historical documents began in the 15th century. Since 1903, when ICES started to collect and to publish catch data, the level of catch was about 500,000 to 600,000 tons per year until the First World War. In the inter-war period, total catches increased continuously from about 200,000 to 300,000 tons in the early 1920s with some fluctuations due to variations in year-class strength (Figure 1). A maximum of about 700,000 tons was reached in 1937. This development was associated with an increase in fishing effort and a gradual change in the method of fishing. The traditional method of fishing was drift-netting from sailing vessels and, in some nearshore areas, ring-netting. After the First World War, sailing vessels were replaced by vessels

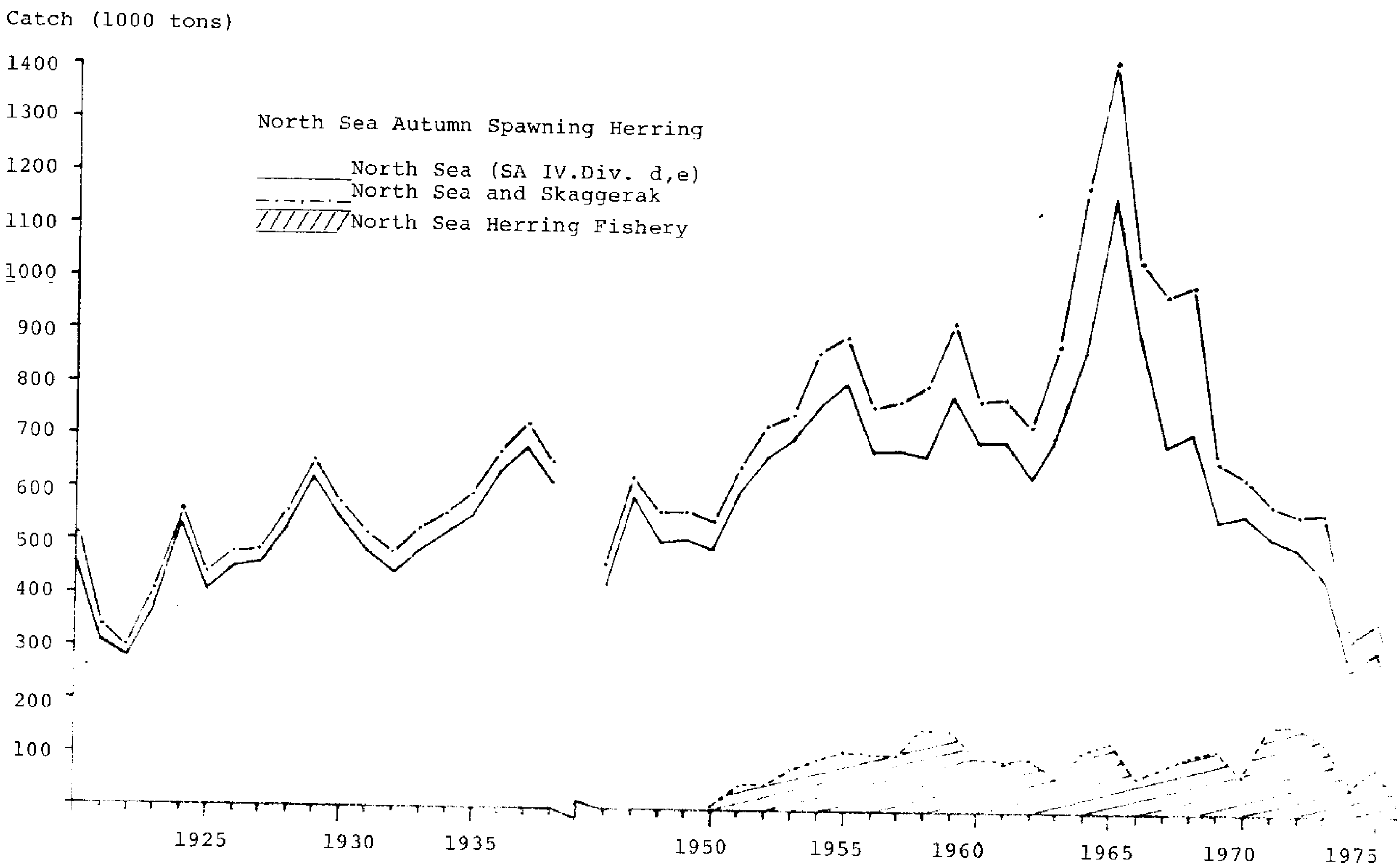

Figure 1. North Sea herring catch, 1920-1975.

with steam or motor propulsion and herring trawling was introduced, but drift-netting was still the dominating method.

Total catches of adult herring in the North Sea since 1946 maintained a level around 600,000 tons until 1963. This stable level, however, could only be maintained due to continuation of the trend toward the more efficient herring trawl and by a further increase in fishing effort. Fishing effort increased not only by simply increasing the number of vessels; there was also a remakable increase in efficiency of the vessels due to further modernization and the introduction of echosounding. In addition, the seasonality of the fishery as well as the exploited area changed. The traditional season started in May in the northwestern North Sea and the fishery was directed toward pre-spawning and spawning concentrations. During the season the fleets migrated southward along the British coast of the North Sea following the migration of herring shoals. The season ended in the Channel just before Christmas.

In the mid 1950s the southwestern North Sea became less productive and the East-Anglia driftnet fishery virtually collapsed. The more mobile part of the international herring fleet developed a new winter fishery in the northeastern part of the North Sea along the edge of the Norwegian deep and in the Skagerrak, which lasted from November to the end of February.

Since 1963, a completely new component of effort has been introduced into the North Sea herring fishery: open sea ringnetting. This method of fishing, originally developed in the fishery for atlanto-scandian herring, is very effective due to efficient use of sonar fish-detecting equipment and the powerblock technique. Due to this invasion of very efficient vessels (mainly from Norway) into the North Sea, total catch of adult herring increased to just over one million tons in 1965. The exploitation of North Sea herring by purse seiners was linked with a different fishing pattern and enlargement of the fishing area by inclusion of the waters around the Shetlands. These waters became the most productive fishing grounds after 1964, but even this expansion could not prevent the continuous decline in the catch of adult herring in the following years to about 170,000 tons in 1976.

In addition to the fishery for adult herring, a young herring fishery was developed catching one- and two-year-old herring for meal and oil production. The fishery started in 1950 in the southeastern part of the North Sea, but very soon the area of operation was enlarged to the western and northern North Sea. From the level of 5,000 tons in 1950, young herring catches increased to about 100,000 tons in 1955, fluctuating around this level in the following years according to the strength of the exploited year-classes (Figure 1). A maximum was reached in 1971-1972 as a result of the relatively good 1969 and 1970 year-classes.

The simple description of the development of catches since the mid 1960s already indicates that this decline in catch must have been associated with enormous economic difficulties in the fisheries and in the dependent industries. This fact is even more obvious in view of the dominating role of the purse seiners in the fishery on pre-spawning herring since 1965. The traditional drift-net fishery on spawning herring became totally uneconomic and virtually collapsed within two years. For example, in the Federal Republic of Germany, nearly 200 drift-netters had to be scrapped from 1966 to 1968, and the herring trawlers had to go to other fishing grounds like the west of Scotland waters and Georges Bank. In other countries, the consequences of this development have been similar or even more severe. It would, however, go beyond the limits of this paper to elaborate in more detail on this part of the problem. The most interesting question in the contex of this workshop is how the management system reacted to this long-lasting and partly foreseeable development.

SCIENTIFIC ADVICE AND REACTION OF NEAFC

From the beginning of herring investigations, attempts have been made to develop techniques which would describe the different groups of spawning fish in the North Sea with some precision (Figure 2). This type of work dominated the research activities up to the mid 1960s. A number of differences in some biological characteristics have been established indicating a grouping of the spawning populations into two or three groups, but the results could not be used for the purpose of quantitative stock assessments. One of the difficulties in agreeing upon conservation action for North Sea herring has been due to the problems in dealing with stock separation, not only at the biological level, but more particularly in the problem of allocation of catch to the stock components.

The decline of the southwestern (Downs) component of North Sea herring in the mid 1950s was carefully studied, but as late as 1971 it was concluded by the liaison committee that the decline of the Downs herring may have been caused by, or at least accelerated by, fishing. It was recommended as an experiment that the spawning areas in the southern North Sea should be closed for the months of October to March for at least six years or even longer until the effect of such a closure could be evaluated. The management objective behind this experimental closure was to increase the catch per unit effort as well as the proportion of older agegroups, and hence, to reduce year-to-year fluctuations in the size of the catches.

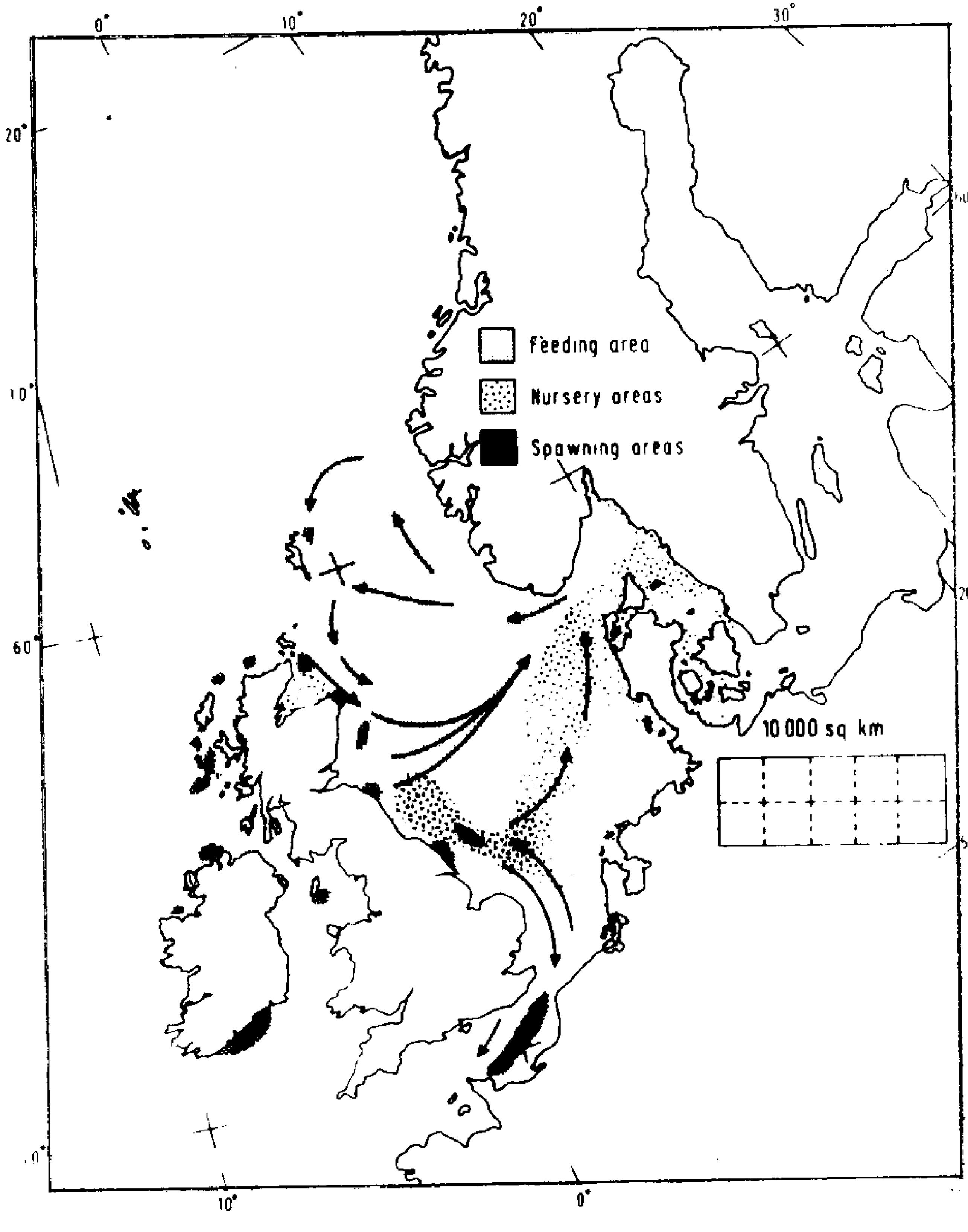

Figure 2. Distribution of herring in the North Sea and Irish Sea.

An experimental closure of the young herring fishery was also discussed, but it was recommended that such an experiment be deferred and considered later, in light of the results of the experiment on the adult fishery. The reason for this attitude was that "only if a stock-recruitment relationship is revealed by the closure of the southern North Sea adult fishery, could a significant benefit be expected from a restriction of the young herring fishery."

For the northern North Sea, attempts have been made to estimate fishing mortality on the basis of catch per unit of effort figures. The time series for the different fisheries, however, gave conflicting results so that the effect of fishing on the stock could not be assessed with convincing precision for NEAFC to introduce management measures in order to reduce fishing mortality in that fishery.

The generally accepted management objective during the 1950s and 1960s was to obtain the MSY per recruit. The high vulnerability of pelagic species as compared to demersal species for which this concept was originally developed, was not taken into account sufficiently at that time. Furthermore, there was no definite proof that a stock-recruitment relationship exists, and this part of the problem was not adequately considered. These two factors have led to insufficient reaction by the scientists as well as by administrators to the situation of the herring stocks in the North Sea. On the other hand, one has to recognize the inadequacy of both the general state of the art of our science in that period, and the particular lack of information on, and understanding of, pelagic stocks.

The situation, as far as the scientific advice is concerned, has changed drastically since 1970 compared to the preceding period. Only little attention was paid to the complicated stock-structure since the concern now applied to the North Sea herring population as a whole.

In 1970 and 1971 attention was drawn to the high proportion of juvenile herring in the catches, to the high level of fishing mortality, and decreasing stock size (Figures 3 and 4). Catch limitation to 500,000 tons was suggested in order to increase the size of the stock, and it was stated that "without a reduction in fishing effort, it is expected that the stock will not recover and that catch as well as stock size may continue to decline." This new attitude of the herring biologists was at least partly a reaction to the VPA and catch prediction techniques which were introduced into the Herring Working Group at that time. This gave a better historical record on the fishing mortality and stock size and a more realistic estimation of possible future developments under certain assumptions. The reaction of

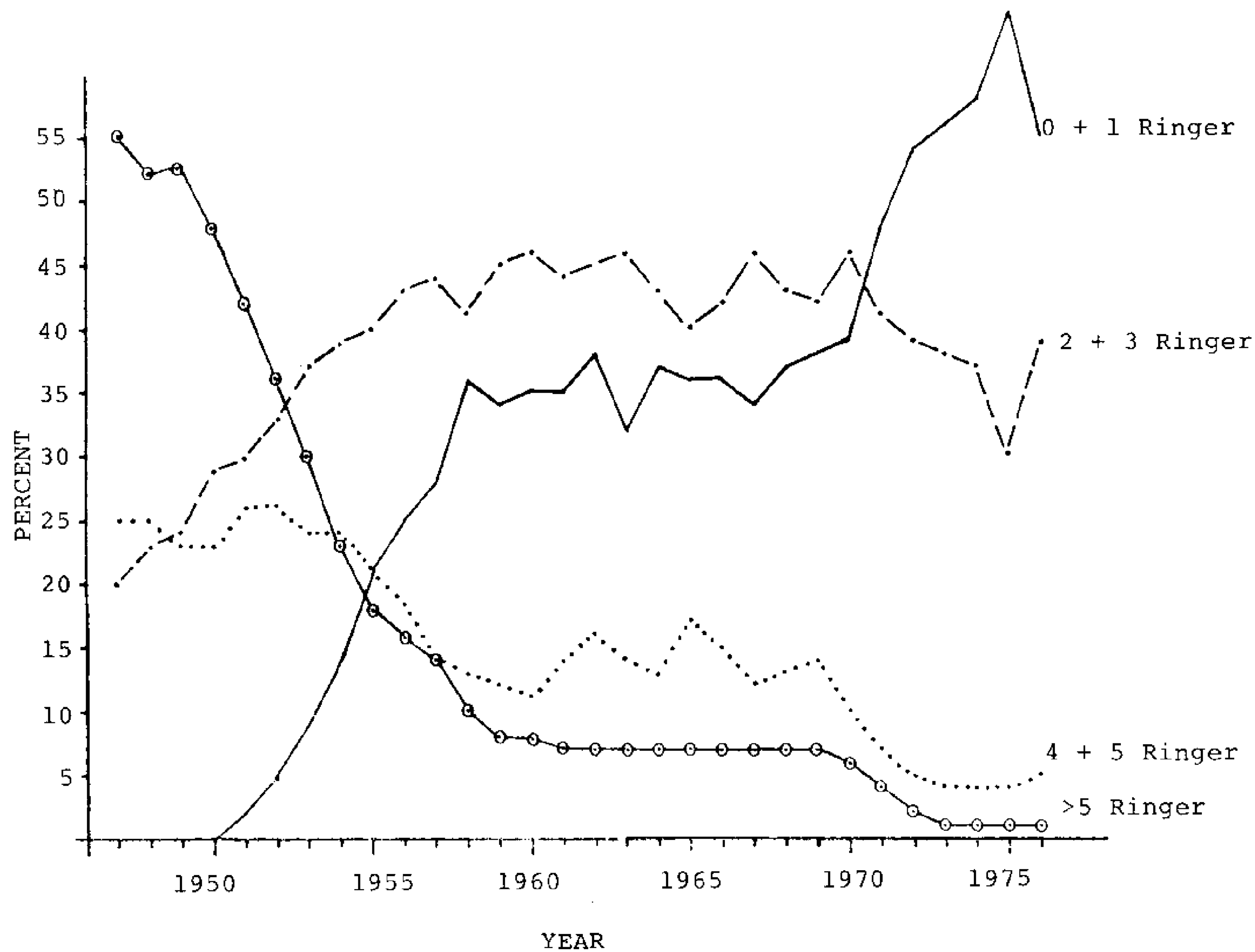

Figure 3. Trends in age structure of 1947 to 1976 North Sea herring catches in percentages. Moving average over five years.

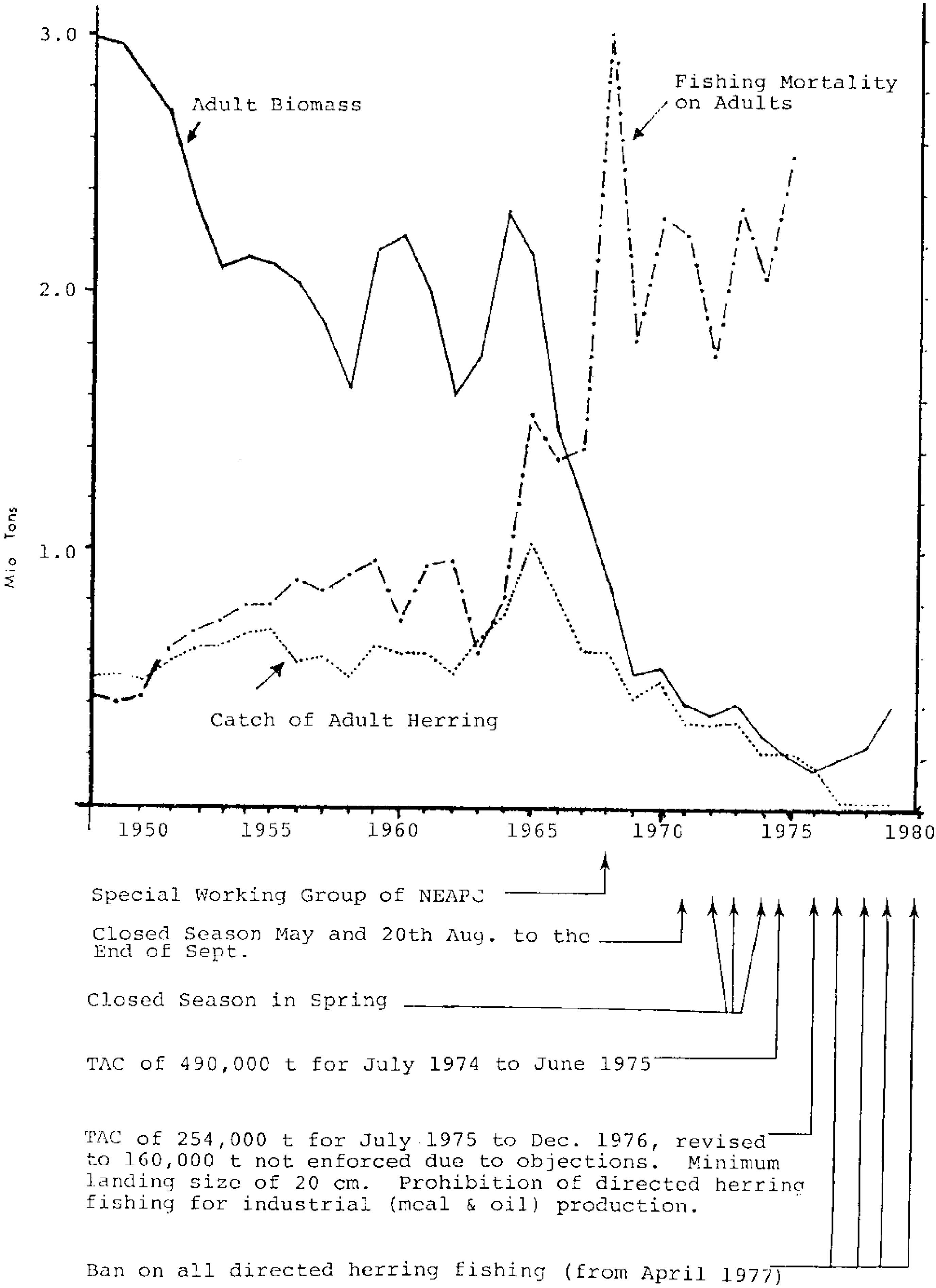

Figure 4. North Sea Herring Catch, biomass, fishing mortality and management trends.

NEAFC was that closed seasons were introduced with some exemptions for the years 1971 to 1974, which later proved to be completely ineffective in reducing fishing mortality (Figure 4).

During the following years, ICES advised that in light of the continuous reduction in spawning biomass of TAC-options, different combinations of fishing mortality on adults and juveniles be considered. For 1976, a TAC of 140,000 tons was recommended and in October 1975 this recommendation was revised to a total ban on herring fishing in the North Sea. The reaction of NEAFC was that several TACs were recommended for 1974 to 1976 but none of these survived the objection period. In 1976, only a prohibition of directed herring fishing for reduction to meal and oil with some by-catch allowance and a 20 cm minimum landing size came into force.

The advice on total prohibition of directed herring fishing for 1976 and the following years was linked with the advice to rebuild the spawning stock biomass as quickly as possible from the level below 200,000 tons in 1976 to about 800,000 tons, to optimize future recruitment.

RECENT MANAGEMENT

Since 1977, the coastal countries of the North Sea have introduced extended fisheries zones. This action resulted in a division of the North Sea into a Norwegian part and a part for which the European Communities have the management responsibilities.

In practice, this means that fisheries in the North Sea have to be managed jointly by Norway and the EC since almost all stocks are living in, or migrating through, both areas.

Under this new two-party management scheme, scientific advice for all North Sea stocks given by ICES was followed more closely than under the old NEAFC system. This is particularly the case with North Sea herring. From the beginning of the consultations of Norway and the EC in 1977, there has been no doubt about the urgent necessity to give the herring stock maximum protection. Consequently, the total ban on directed herring fishing in the North Sea was introduced in spring 1977 as recommended by ICES. There was only some small allowance for by-catches of herring in the fishery for other species accumulating to about 10,000 tons annually. This regulation was maintained for 1978 and 1979, and hopefully will remain in force for 1980.

Although a total ban on herring fishing in the North Sea is highly desirable on conservation grounds, it creates some scientific problems in monitoring and evaluating the effects of such a measure. At present, the two sources of information on the development in the stock are larval surveys to estimate the size of the spawning stock, and young fish surveys for estimating recruitment. In addition, some other ICES programs, such as hydroacoustic surveys and tagging experiments, are in preparation or under discussion with the aim of broadening the basis of information for stock assessments.

As a result of the stringent conservation measures imposed on North Sea herring, spawning stock biomass has increased to a level of about 400,000 tons at the beginning of 1980 even without the help of good or medium year-classes. Therefore, it is hoped that the herring fishery in the North Sea will be reopened in the near future. Reopening, however, should only be done very carefully in a well controlled manner. This requires the definition of the biological criteria which should be met before a restart of the fishery may be advised. It also requires development of a long-term strategy for the future management of the North Sea herring stocks, preferably with the close cooperation of biologists, economists and administrators.

CONCLUSIONS

The conclusions which can be drawn from the sad history of the North Sea herring are:

1) Lack of scientific information and incomplete understanding of obvious events indicating a declining trend beyond the range of normal fluctuations of the size of the stock should not serve to prevent or delay efficient management action.

2) Herring, like other pelagic species, cannot be managed on the basis of models developed for demersal species. High vulnerability due to specific schooling behavior may result in sudden recruitment overfishing.

3) Multinational management systems which offer the possibility of escaping regulations by means of subsequent objection are not suitable for the management of stocks for which quick and drastic action is sometimes required.

WORKSHOP SUMMARIES

RESEARCH WORKSHOP

The purpose of the research workshop was to discuss research methodologies used among the different herring investigators and to examine the feasibility of utilizing various methods for improving research on Alaskan herring stocks, particularly eastern Bering Sea stocks where extensive research activities have only recently begun. Originally, the workshop organizers hoped that it would be possible to identify a single best method for a research area, and avoid expensive and time-consuming false starts and blind ends; however, one overriding theme was that each geographic area and stock are unique, and it may be imprudent to discard methodology because it was unsuccessfully employed in other stocks or areas.

Different geographical approaches to research became clear in the workshop discussions. These differences were partly due to basic biology, especially spawning behavior: Atlantic herring spawn mainly in deep water (greater than 100 ft), while Pacific herring spawn mainly in the intertidal and shallow subtidal areas. The sharpest differences were between Pacific Coast biologists who advocated direct measurement or estimates of stock abundance, and western Atlantic biologists who preferred methods based on cohort analysis. Europeans fell somewhere in between and mixed direct and indirect methods.

The workshop covered stock assessment, stock separation, environmental factors, and general fishery statistics. Stock assessment discussions focused on the methods used with various stocks and their relative advantages and disadvantages. Stock separation dealt with the necessity of identifying separate stocks, various efforts to define stocks, and the methods employed. The discussion of environmental factors examined possibilities of predicting or monitoring changes in herring abundance through various oceanographic or climatological parameters. Discussion of fishery statistics centered on collection, use, and interpretation of various fisheries statistics.

STOCK ASSESSMENT

The section on stock assessment covered: aerial surveys, spawn surveys, hydroacoustic-trawl surveys, larval-juvenile surveys, and statistical assessment procedures.

Stock assessment methodology differences were found to exist between biologists working with Atlantic stocks and those working with Pacific stocks. In the Pacific, efforts are concentrated on direct assessment of biomass, generally prespawning or spawning adults, while in the Atlantic fishery data is used to assess adults. Direct assessment in the Atlantic is generally limited to assessing fishery prerecruits.

Aerial Surveys

Aerial surveys are used by Alaska Department of Fish and Game to assess spawning biomass along eastern Bering Sea spawning grounds. This method is also reportedly used in the USSR on spawning grounds in the western Pacific Ocean. Basically, the procedure in the eastern Bering Sea involves counting herring schools and determining the total surface area of schools on the spawning grounds per day. The highest daily surface area count obtained for the season is used to estimate spawning biomass where spawning grounds are in close proximity, while in areas where spawning grounds are widely separated, peak counts separated by two week intervals are summed. Peak counts are used to prevent multiple counts of the same school which could occur from prolonged stays on the spawning grounds or movement between spawning areas. Movement patterns are presently unknown, but within the major spawning area, two post-spawning "staging" areas and exit routes are postulated.

Herring school surface area is converted to biomass estimates on the basis of herring density estimates obtained from commercial purse seine catches. A range of densities, derived from the observed densities, are applied in converting school surface area to biomass to account for depth differences between areas. The estimated biomass of schooling fish is adjusted to account for other schooling fish in the area as determined from variable mesh gillnet samples.

Most of the participants in the workshop were unfamiliar with aerial assessment of spawning biomass, but all believed that it was a very advantageous method. The prevailing view was that aerial surveys should be used as a primary stock monitoring technique for eastern Bering Sea herring stocks and that emphasis should be placed on refining the technique.

It was pointed out that in the absence of data on movement patterns into, within, and out of spawning areas it was advantageous to use peak counts to avoid erroneous estimates due to multiple counts of the same schools. Also, it was thought that efforts should be placed toward obtaining a greater number of school density estimates, since the present sample size is extremely small.

Some concern was expressed that biomass estimates may be overly conservative since herring are known to spawn in waves over the spawning season. Concern was also expressed that since surveys were flown during the day at low tide, a significant portion of the biomass might not be observed. This was recognized as a problem which might be solved with increased effort to measure variability, but one of secondary importance. Herring are known to spawn at night in other areas, and movement into and out of spawning areas is highly variable. Stocks act differently and annual variation is also common. A high degree of variability was felt to be a standard problem with instantaneous surveys of this kind.

Spawn Surveys

Spawning deposition surveys are used in California, Washington, and British Columbia as a means of estimating the size of the spawning stock. Spawning substrates are observed during the spawning period to monitor egg deposition. The number of eggs deposited is estimated, and the stock size is estimated by calculating age composition, eggs per female, and sex ratios. In British Columbia, harvest strategy is designed to allow an escapement of an "optimum" amount of spawning herring. The premise of optimum egg coverage is that if enough eggs are properly distributed, the maximum number of eggs survive into the critical larval stage. Applying growth and mortality rates to the estimated spawning escapement provides an estimate of survivors from the previous fishery. Addition of recruitment estimates total population for the next fishery.

Hydroacoustic-Trawl Surveys

Hydroacoustic-trawl surveys are used for stock assessment with varying success depending on local conditions. In Southeast Alaska, British Columbia, and Washington, hydroacoustic surveys are performed prior to spawning in order to assess recruitment and total spawning biomass. In Norway, hydroacoustic surveys are done in the autumn on juvenile herring to estimate recruitment; however, in the past it was found difficult to use on adults. In the northwest Atlantic, groundfish trawl surveys are believed to provide good estimates of adult herring biomass.

The consensus of the group was that hydroacoustic-trawl surveys were a useful assessment tool but, as with other methods, have shortcomings. Especially critical are the requirements for a good knowledge of distribution, and for surveys to be accomplished in a short time frame to avoid multiple observations. Densities obtained in a narrow trackline need to be extrapolated over a larger area, and extensive trawl sampling is needed where herring are mixed with other species.

Hydroacoustic-trawl surveys also have potential in assessing juvenile herring; however, as with adults, it is very important to have a good knowledge of distribution patterns. As with adult surveys, effort must be intensive. Examples were cited from the Barents Sea (which is equivalent in area to the Bering Sea), where young capelin have been surveyed acoustically annually using three to four vessels in a 10 to 12 day period. This survey has been conducted for 15 years, and the biologists believe that they may not have enough distributional data to reduce the current level of survey effort.

Larval-Juvenile Surveys

It was felt that results of larval-juvenile surveys are proportional to the size of the fish (i.e., better results from larger fish). Larval surveys were believed to be of little value, if it was possible to carry out assessment at later life stages. In the North Sea, larval surveys are used because there is no direct access to the spawning grounds; larvae are well dispersed, and standard surveys give some indication of spawning stock size and an estimate of the size of the year-class. In the Pacific, it was felt that larval and juvenile surveys may be invalid in some areas due to variable, patchy distribution patterns, and that standard grid patterns may give very imprecise results. Washington state biologists, however, reported that surveys of 6 to 9 month old juveniles are providing a good index of recruitment.

In all stocks discussed, juveniles are known to have a distribution pattern distinct from adult herring, and age 0 herring are generally separate from age 1. The typical pattern for age 0 and 1 herring is to remain inshore; offshore movement and increased migration occur as the juveniles approach maturity. In the Gulf of Maine, juvenile surveys were found to be difficult because of the behavior of juvenile herring to concentrate nearshore in scattered schools except when strong year-classes occur. In these years, young herring are more widely distributed and are found in offshore areas in large numbers.

In general, it was felt that prerecruit surveys are only usable after a long-time series has been established, thereby allowing comparisons with direct estimates and identification of inconsistencies. Pilot studies are needed to define distribution patterns, and behavioral anomalies induced by density and environmental changes. Also, the closer the survey is to recruitment to the fishable stock, the more reliable the estimates are. However, there was some concern expressed that if young herring from several discrete stocks were intermingled, it may be difficult to apportion estimates to the various stocks.

Fishery Statistics

Virtual population analysis (VPA) or its variant, cohort analysis, was discussed as a stock assessment tool. This method is utilized extensively in the North Atlantic for herring and other species. In the North Pacific, its use has been limited to a few demersal species for which a long-time series of catch data exists.

The method involves computations of stock size based on rates of fishing and natural mortality. It estimates past values of fishing mortality and stock size, which then may be used to indicate present stock conditions and to forecast future conditions. Good catch-at-age data and estimates of natural and fishing mortality are needed. The procedure only estimates the portion of the population subject to fishing, and the abundance of newly recruiting fish must be estimated independently.

The application of this method to Pacific herring was questioned from the standpoint of much higher natural mortality rates for Pacific herring (m = .4 to .5) versus Atlantic herring (m = .2 to .3), and the high variability in age and rate of maturity (recruitment to the roe fishery). This, and the fact that Pacific herring survive for only a few years following recruitment, caused concern that the method would yield results vastly different from those obtained from direct measurements such as spawn, trawl, or aerial survey. However, biologists working with Atlantic herring did not feel that these factors precluded the use of the method, and that the method would be a very useful means of examining variability. Also, they felt that the data used for cohort analysis are standard management data, and very little extra effort or expense is needed to collect the data needed. The opinion was offered that while exploitation was low (as in the Bering Sea), attempts should be made to get a data base on rate processes to use later on to prevent overfishing in years of low abundance.

Various aspects of fishery statistics were discussed during the discussion of stock assessment. Topics included use of catch per unit effort (CPUE) data, gear selectivity, age composition data, aging techniques and fecundity analysis.

CPUE data was generally felt to be of little value as an indicator of herring abundance. Opinions were expressed that schooling behavior makes CPUE data misleading. Also in roe fisheries or other intensive fisheries, gear saturation can occur if there is a rapid congregation of a large amount of gear. CPUE data is also negated if quota or effort limitations exist. However, it was pointed out that if fishermen do not alter their fishing behavior during declines or increases in stock abundance, the CPUE data can be useful, but not sufficient.

Gear selectivity was discussed as an important aspect of determining and evaluating abundance data, and measuring age composition. Variable mesh gillnets, as used to sample age composition in the Bering Sea, were believed to be an adequate means of sampling age composition, but care must be taken in the interpretation of data as there may be a tendency toward sampling larger, faster growing fish in a year-class.

Trawl sampling of pre- or post-spawning concentrations was suggested as a possible means of estimating age composition and obtaining reliable abundance data. Canadian scientists found that in Barkely Sound, B.C., age distribution and relative abundance were essentially the same between pre-spawning and post-spawning herring. Traps, weirs, and other similar gear types were suggested as possible sampling tools to overcome problems of gear saturation in determining CPUE and age composition.

Age composition data were generally regarded as a major consideration in designing a field program. It was emphasized that care must be taken in sampling gear and in differentiating between catch samples and population samples. Age composition data are needed from both the catch and the population to determine relative removals and for input into analytical models for determining stock status and trends.

Some discussion occurred relative to what structure should be used for aging. North American biologists studying Atlantic herring use otoliths, while those involved with Pacific herring use scales. Otoliths were generally regarded as having the advantage that they can be recovered from every fish in a sample, whereas herring can be completely scaled or have a high percentage of regenerated scales. Lack of clarity of the first annulus of an otolith was cited as a reason for not using otoliths from Pacific herring, but samples from the Bering Sea indicate that herring in that region may be aged using otoliths. Ease of collecting, processing, and storing scales is a factor favoring these structures.

Herring fecundity analysis was discussed along with spawn surveys. The consensus was that for purposes other than to compute the size of the parent population, there was little purpose in collecting this data. Further, it was noted that if spawn surveys are used, it should be recognized that fecundity is variable and fecundity measurements must be reevaluated annually or semiannually.

ENVIRONMENTAL PARAMETERS

Oceanographic and environmental relationships were discussed with the purpose of determining parameters which could indicate changes in year-class survival. This subject has been explored to varying degrees among the major herring stocks, but definite predictive relationships have not been identified. The parameters discussed as having potential impact on year-class success were temperature, salinity, currents, food availability, and predation. Generally, it was regarded that these factors were most effective during the larval stage of development.

Temperature relationships have been found to exist at a gross level. An example cited was the occurrence of large year-classes in the northwest Atlantic which were associated with years of high water temperatures in the mid 1950s. Temperature was also believed to indirectly influence year-class abundance through food availability. In the North Sea, Calanus sp. distribution and abundance have been found to be temperature related. Indications are that the distribution and abundance of Calanus sp. at the time larvae begin to feed is an important factor of larval survival and subsequent year-class strength.

Currents or net water transport were also considered to be factors affecting herring survival. In the North Atlantic, herring spawn in deep water where temperature and other oceanographic parameters are nearly constant. In these areas, drift patterns are believed to be important determinants of survival with regard to the movement of larvae into or away from predators or food sources. Some discussion occurred on whether or not larvae were mobile and unaffected by drift. Canadian scientists reported that in the Bay of Fundy, herring drift to some extent, especially prior to formation of the caudal fin, and that some correlation was found between year-class strength and the length of time drift bottles remained in the bay.

Salinity did not appear to correlate with year-class strength, but it was observed that in western Canada the best survival of eggs under laboratory conditions occurs between 17 and 20 $^{o}/oo$ salinity. It was speculated that survival may be greatest in years of above average precipitation and run-off, where fresh water inflows maintain coastal salinity at this level.

Mathematical models as management tools were touched upon during the discussion of ecosystem relationships and environmental parameters. Multispecies ecosystem-type models received support as a learning tool, however, poor data and lack of understanding of biotic and abiotic interrelationships make these models unreliable (and possibly dangerous) for management use. Single species models were viewed as a more useful technique, recognizing that models developed for demersal species are not applicable to herring. Hindcasting and forecasting through use of cohort analysis seem to be valuable tools that require an independent index of abundance.

STOCK IDENTIFICATION

The problem of stock identification was discussed, focusing on studies in progress in the eastern Bering Sea, to examine the methodology employed and the potential of these and other methods of stock identification. Two papers presented to the workshop on current eastern Bering Sea stock separation research formed much of the discussion on stock separation, and summaries of the papers follow.

The consensus of the participants was that there is no method that is totally definitive of stock structure, but of all the methods available, tagging provides the most conclusive results. However, results are dependent on recovering a sufficient number of tags, which may not be possible when some stocks are not fished or only lightly fished.

Morphometric measurements, growth differences, parasite analysis, and scale analysis have all been tried among the world's major stocks with mixed results. However, although a method was unsuccessful in separating stocks in one area, it may be useful in another, and these methods have been found to corroborate results achieved through tagging.

Biochemical Genetic Variation in North Pacific Herring[1]

Summary

The rationale for using biochemical genetic markers to identify herring stocks, or any fish stocks, is that whenever populations become isolated from one another they tend to diverge genetically because of chance changes in their genetic structures. Isolation can be achieved through the imposition of physical barriers to migration or through behavioral changes in spawning. At any point in evolutionary time, the degree of divergence between geographic stocks can be measured by surveying a large number of genetic loci, those coding for enzymatic proteins, can be assayed for inherited variants using starch gel electrophoresis.

In this study, samples of herring were collected from several locations in the western and eastern North Pacific Ocean and in the eastern Bering Sea. Gene frequencies at 28 polymorphic loci were determined from the samples and used to describe the prominent features of population subdivision of North Pacific herring. Cluster analysis of genetic similarities between the samples revealed two major geographic races. One group included populations in the western North Pacific Ocean and Bering Sea and the other group included populations in the Gulf of Alaska and the eastern North Pacific Ocean. Presumably, the Alaska Peninsula and the Aleutian Island chain are the boundary between these two groups. Future sampling will provide a better understanding of the populations in the transition area. Analyses of the Bering Sea samples and the eastern Pacific samples indicated that within each area gene frequencies were homogeneous.

The results of this study indicate that there are large genetic differences between two groups of North Pacific herring, but that within each group genetic differences among populations are minimal. This genetic population is sufficient to prevent major local genetic differentiation. Furthermore, the homogeneity of gene frequencies within each major group does not permit the use of biochemical genetic markers for local stock identification.

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Separation of Spawning Stocks of Bering Sea Herring Based on Scale Growth Patterns[1]

Summary

The reasoning behind the use of scale patterns to identify fish stocks is that scale growth patterns reflect, to varying degrees, environmental and genetic differences between stocks. In an effort to determine whether scale analysis would be useful for identifying stocks of herring within the eastern Bering Sea, a study was initiated with the following objectives: 1) to examine scale growth patterns of fish from four spawning locations, 2) to examine scale growth patterns in one brood year for successive years, 3) to examine temporal variation during the spawning season, and 4) to quantify scale pattern differences among locations using discriminant function analysis.

Scales were collected from fish at four spawning locations in the eastern Bering Sea in 1978 and 1979: Port Clarence, Cape Denbigh, Cape Romanzof, and Togiak. Age classes with sample sizes large enough for analysis were the 1979 age 3, 1978 age 4, 1979 age 5, and 1978 age 6 groups. Only the 1979 age 5 group was represented from all locations. The remaining age classes were represented by samples only from Cape Denbigh, Cape Romanzof, and Togiak. The standard length of each fish was measured, gonad development noted, and several scales removed for analysis. Scales were observed at 40X magnification, and the distance from each annulus to the focus of the scale was measured in millimeters. Fish body lengths were backcalculated from these measurements, and growth increments were computed for each year.

All of the scale measurements and body lengths for each age class were normally distributed except for the measurements of the Port Clarence 1979, age 5 samples, which were bimodally distributed. Bimodality was apparent in both fish length and total scale radius measurements. These results suggest that this sample was composed of two populations and was, therefore, divided into two groups having body lengths of 200 mm or less (A), or greater than 200 mm (B).

An examination of growth curves indicated that the Cape Denbigh and Cape Romanzof samples were similar for all age classes. These data also indicated that Togiak fish grew

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faster and, hence, were larger than fish at other locations for comparable age classes. Age 5, 1979 fish were available from all locations sampled and backcalculated growth curves for these samples indicated the presence of three distinct geographic groups. The first group, Port Clarence A, had the lowest growth rates. Growth curves for Port Clarence B, Cape Denbigh, and Cape Romanzof were similar and were considered to encompass the second group. Togiak fish had the greatest growth rates and formed the third group.

Samples were taken at Togiak throughout the 1978 and 1979 spawning seasons to detect possible temporal variation in scale characters. However, scale variables and body lengths for each age class did not change during the spawning season. In addition, the backcalculated body lengths, estimated from the same brood year, did not change for the two successive years. These results suggest that one sample per spawning season is adequate to characterize a population and that data taken one year can be used in subsequent years.

Discriminant function analysis was used to distinguish among the samples where the backcalculated body lengths of each annulus were used as the discriminating variables. This method could not distinguish between Cape Denbigh and Cape Romanzof fish for any of the age classes. Togiak fish were distinct from the other locations.

Classification of test samples using a discriminant function generated by learning samples at the same locations was most successful with 1978, age 5 fish. Overall, the classification success was 84 percent. The classification success rate for the Port Clarence A sample was 100 percent, for the Port Clarence B-Cape Denbigh-Cape Romanzof group was 81 percent, and that of the Togiak sample was 71 percent. Another classification test was made where 1979, age 5 Togiak samples were classified using data from 1978, age 4 fish for the discriminant functions. In these results, 71 percent of the Togiak fish were correctly classifed as Togiak fish.

The results of this study show that at least three distinct stocks can be distinguished in the eastern Bering Sea using discriminant analysis of scale growth patterns. The high success rate in correctly classifying samples of one year class using discriminant function based on the same brood class collected in the previous year indicates that this method can be useful for identifying stocks in areas of mixing.

MANAGEMENT WORKSHOP

The management workshop focused on four issues: 1) yield strategies, 2) mixed stock fishing, 3) juvenile fisheries, and 4) allocation between gear types. Management differences were found to exist between the Pacific herring currently falling under single country management and Atlantic herring subjected to multi-national management. The common thread through discussions of Atlantic herring management is the inability of the participating nations to respond rapidly to seriously declining stocks with an effective, coordinated program which all nations could accept.

In the Atlantic, before the crash of the herring populations, fisheries occurred on nearly all stages of the herring life cycle. Fishing began on herring as early as age 0, often for reduction to oil and meal and for use as sardines. Heavy fishing occurred on spawning herring and also on the feeding grounds. Technology increased effectiveness of the fleets, and the stocks characteristically declined during the 1960s. Scientists pointed out warning signs and recommended drastic reduction in harvest, but the multi-national management regime prevented effective action. Concomitant with the declining abundance, the stocks often showed major deviations in behavior, commonly reducing the migratory range and increasing rates of growth and time of maturity.

YIELD STRATEGIES

Yield strategies used in herring management worldwide moved from a maximum yield basis to those which recognize the importance of maintaining a certain level of spawning biomass. It is generally recognized that herring cannot be managed on a sustained yield basis, and MSY should only be used as a general guide.

In the northwest Atlantic, herring stocks are managed to produce yields at or below the $F_{0.1}$ level. The $F_{0.1}$ level is derived from yield-per-recruit analysis and is the point on the yield/effort curve where yield/effort diminishes to 10 percent of what would have been achieved in a virgin fishery. The $F_{0.1}$ level is regarded as a guideline upper limit, and some stocks are fished at lower levels. Control of fishing effort is recommended by some biologists as a means of achieving the proper level of yield rather than catch quotas. Harvesting above the $F_{0.1}$ level occurs when strong year-classes occur, but it was recommended that pulse fishing of strong year-classes should only take place if it can be done without adding additional fishing effort.

European scientists also recommend management be based on yield strategies that maintain spawning biomass above a minimum threshold level. Regulation is by quota and is largely influenced by assessment of recruiting year-classes. They believe that by maintaining an adequate spawning biomass and adjusting catch quotas to recruitment trends, exploited herring populations should achieve a balanced age structure which in turn should stabilize fisheries and planning.

In the northeastern Pacific, herring are generally managed on escapement (egg deposition) or catch quotas based on total population size. In British Columbia, escapement is set at a level that historically produced the greatest recruitment; herring that are surplus to escapement requirements are harvested. In Southeast Alaska, optimum escapement is unknown but stock abundance is known to be low and only 10 percent of the estimated biomass is harvested in order to increase abundance. When a stock is below a determined minimum biomass, no fishing occurs, and if strong year-classes are present, 20 percent of the biomass may be harvested. In Washington, harvest is limited to a catch ceiling of 20 percent of the total abundance, with a minimum spawning escapement threshold below which fishing will not be allowed. In this way, it is assumed the stock will be protected from sharp reductions due to recruitment failures, and herring are maintained at a level that provides adequate forage for predators (i.e., salmon).

Management for escapement requires that the spawning population be evaluated prior to spawning in order to assess the recruiting age classes. Also, it necessitates a close monitoring of spawning to insure that the proper level of escapement occurs.

MIXED STOCK FISHERIES

The subject of fishing on mixed stocks was discussed in great detail in the workshop. Discussion centered on whether it is best to limit fishing to the spawning period when stocks are separated into discrete units or to allow fishing when stocks are mixed. Also discussed were the impacts of mixed stock fishing.

The general consensus among the biologists present was that mixed stock fishing per se could not be viewed as detrimental to individual stocks or the well-being of a group of stocks. In the Atlantic Ocean, herring are generally fished when stocks are mixed. Atlanto-Scandia herring are composed of Icelandic and Norwegian spawning stocks which are fished together. When stocks declined, the decline was equal in all stocks and independent of stock size. Canadian and U.S. herring stocks in the northwest Atlantic mix as adults off Nova Scotia and Maine and as juveniles mix along the New Brunswick coast. Year-classes in the different stocks fluctuate similarly, indicating that a mixed stock fishery does not affect stocks differentially.

In the northeastern Pacific Ocean, stock relationships are not clearly understood. Tagging studies of the herring reduction fishery in Southeast Alaska showed that fishing occurred on mixed stocks and that fishing mortality was often disproportionate among the stocks, but no indications of stock decline were evident. In British Columbia, scientists are uncertain of stock discreteness, since evidence indicates that 25 percent of the herring population strays between stocks annually. The greatest amount of mixing is between stocks spawning within the same general area, but large stock composition changes have been documented. They feel that if small stocks are overexploited, an accretion may occur from other stocks.

Conditions under which mixed stock fishing could have deleterious impacts were discussed. The primary conditions appear to be when small local stocks are available in conjunction with a larger migratory stock. Overfishing of the smaller stock can occur if fishing commences prior to the arrival of the larger stock. Also, it was noted that for migrating stocks, fishing rates are more evenly distributed at greater distance from spawning grounds, and that the likelihood of exceeding the desired level of harvest in small stocks increases as herring migrate to the spawning grounds. However, studies of Atlantic stocks have indicated that migrational distance varies with stock size, that small stocks migrate less than larger stocks, and that migrational patterns can alter.

The general consensus of the workshop was that in a mixed stock fishery, the percentage removal is related to the percentage of mixing of the stocks, and that if management objectives are for a general level of exploitation, then underfishing of the smaller stocks is as likely as overfishing.

JUVENILE FISHERIES

The harvesting of juveniles was brought out during discussions of mixed stock fisheries as an aspect of mixed fisheries that could have serious detrimental impacts on the resource. Scientists working with North Atlantic stocks were unanimous in pointing out that fisheries conducted on juveniles, or large juvenile bycatches in adult fisheries, can rapidly deplete a herring stock. Herring fisheries in the Gulf of Maine were primarily juvenile fisheries for over 100 years; in the 1960s a large scale adult fishery began, and stocks rapidly declined under the combined fisheries. The recent depletion of North Sea and Atlanto-Scandia stocks were also largely due to juvenile and adult fisheries, but these juvenile fisheries were added to established adult fisheries.

Even if directed juvenile fisheries do not occur, incidental juvenile harvests can pose a potential problem. Care must be taken in analyzing juvenile incidence rates, for even though it may comprise a small percentage of tonnage caught, the loss in numbers of herring and potential growth may equal or exceed the yield possible had the juveniles survived to maturity. It was also stated that harvests of juveniles in a trawl fishery may only be a minimum estimate of total mortality as a high proportion of juveniles may pass through trawl nets and suffer high mortality rates.

A solution to controlling incidental catches of juveniles is to close areas of high juvenile-adult mixing. This problem exists in the Barents Sea capelin fishery and the Icelandic cod fishery, and area closures have been effective in both cases in reducing juvenile fishing mortality. It was also suggested that in cases where catches could not be controlled by area closure, the impact of juvenile harvests could be lessened by reducing the overall rate of fishing mortality.

IMPACTS OF FISHING ON SPAWNING GROUNDS

The subject of impacts on the resource from fishing on the spawning grounds was discussed. However, most of the discussion was general and speculative, owing to a lack of specific impact data. In some North Atlantic stocks, it was felt that fishing on the spawning grounds disrupted spawning behavior and caused reduced rates of reproduction. In the North Sea, the first declines in stock abundance were associated with fishing on spawning grounds in the southern North Sea. Closures made in the Barents Sea to protect capelin spawning were reported to be based on evidence that fishing activity has interfered with capelin spawning migration and inhibited movement to coastal spawning sites. British Columbia scientists have not found any definitive impacts of fishing on the spawning grounds, since they have found fished and unfished stocks to exhibit similar behavioral patterns. However, they cautioned that gear losses on the grounds could cause problems. A specific concern was possible continued fishing by lost gillnets. They felt that the problem may be severe if more than one gillnet is fished. With more than one gillnet, unattended nets may fill with fish and sink, and possibly continue to fish.

ALLOCATION BETWEEN USER GROUPS

Allocation of a stock between user groups was found to be primarily a concern in western North America, and chiefly directed toward allocation between purse seine and gillnet roe fisheries. Various allocation schemes are used from a court mandated 50:50 allocation in Washington between Indian and non-Indian fishermen, to a 55:45 allocation between purse seine and gillnet gear in British Columbia based on economic analysis. Most allocations are made by stock, but in British Columbia the allocation is a coastwide average with some stocks exclusively gillnet, and some exclusively purse seine.

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