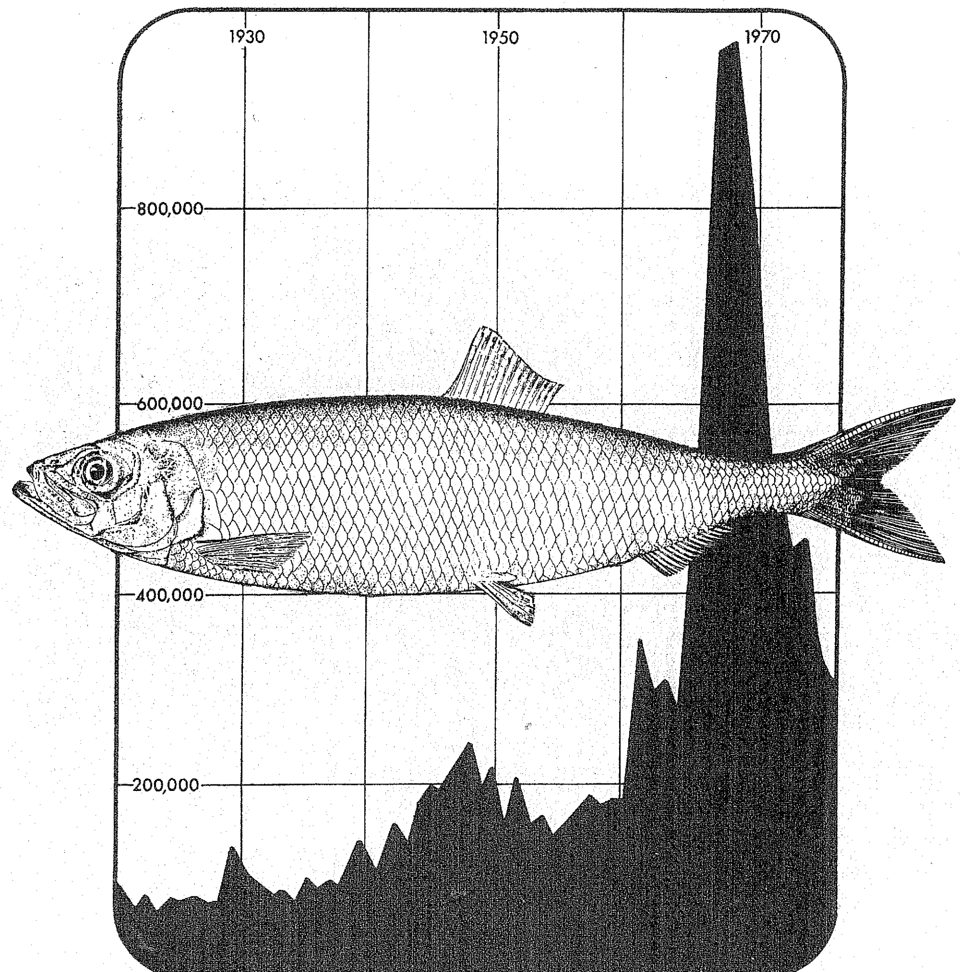
STATUS OF NORTHWEST ATLANTIC HERRING STOCKS OF CONCERN TO THE UNITED STATES



Carl J. Sindermann

STATUS OF NORTHWEST ATLANTIC HERRING STOCKS OF CONCERN TO THE UNITED STATES

Carl J. Sindermann
U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Sandy Hook Laboratory
Highlands, New Jersey 07732

Technical Series Report No. 23

December 1979

PREFACE

During the past two decades there has been a remarkable evolution in the herring fisheries of the western North Atlantic, including the introduction of new fishing methods, a dramatic increase in catches, and most recently a drastic reduction in landings. There has also been an evolution in management of stocks during the same period, from essentially unregulated fisheries, to international management under ICNAF, then to the beginning of national management under extended fisheries jurisdiction.

It seems timely to attempt a review of these recent events in the fishery and an assessment of the status of our understanding of herring stocks of concern to the United States - particularly since the last such review was published by Scattergood and Tibbo in 1959. It also seems relevant to examine information and stock management needs for the future.

This document attempts to do just that -- to review the status of our understanding of herring stocks of the western North Atlantic of concern to the United States, and to propose activities needed to increase our knowledge in areas relevant to long-term productivity of stocks under exploitation.

It has been designed to meet the following objectives: (1) to review the status of knowledge about Atlantic herring, particularly those stocks of concern to the United States; (2) to review the status of herring stock assessments; (3) to identify critical problem areas and hypotheses to be tested; and (4) to identify critical research needs, for the near-term and the long-term.

Specific questions addressed are:

"Where are we and where should we be in herring research?"

"What do we know -- and what do we think we know -- about herring?"

"What are the critical and persistent problems?"

"What hypotheses should be tested?"

"What surveys and long-term data series are needed?"

"What additional research is needed?"

Published information on herring of the Northwest Atlantic is voluminous; fortunately much of it is contained in the various ICNAF and ICES research reports, meeting documents, and working group summaries. A substantial part of the literature (available as of June, 1978) has been examined in preparing this document. Additionally, several recent summaries are part of the public record, particularly Vaughn Anthony's 1972 doctoral thesis on Gulf of Maine herring, NOAA's 1977 preliminary fishery management plan for herring, documents from testimony at public hearings on herring stocks held n 1977, and the New England Regional Fisheries Management Council's management plan for herring made available in April 1978, with an extensive appendix on herring biology from Stanley Chenoweth. These documents have been particularly useful, and excerpts have been taken from several. Other published reports that have proved very useful include Scattergood and Tibbo (1959), Tibbo (1970), Ridgway (1975), and Anthony and Waring (1978).

Additionally, two herring workshops have been held recently. A United States herring workshop was convened at Boothbay Harbor, Maine, April 20-21, 1978. Participants included federal, state, university, and Regional Council representatives with expertise in various areas of herring research. Results and recommendations from that workshop have been incorporated in the present report, and early drafts of sections of this report have been examined by a number of the workshop participants. (It should be clearly understood, however, that the opinions and conclusions in this document do not necessarily reflect those of all of the workshop participants).

A second workshop, a joint Canada-United States Herring Workshop, was held at Quebec City, P.Q., December 12-14, 1978. Participants from both countries reviewed the status of knowledge about herring of the Northwest Atlantic and discussed future cooperative research. A report of the workshop will be published in the Canadian CECAF series in 1979.

These sources, plus individual discussions with those most knowledgeable about herring, have formed the principal background and information base for this review. The conceptual framework for the document was developed during discussions with Dr. R. L. Edwards, Director, Northeast Fisheries Center, and Mr. R. C. Hennemuth, Assistant Director, Northeast Fisheries Center. Members of the scientific staff of the Northeast Fisheries Center contributed substantive information, ideas and comments, as did others outside the organization. Particular thanks are due to V. Anthony, H. C. Boyar, B. Brown, S. Chenoweth, R. Cooper, R. Cohen, J. Graham, M. Grosslein, R. Hennemuth, G. Lough, G. Ridgway, M. Sissenwine, A. Vrooman, and G. Waring. Final responsibility for statements and conclusions rests, of course, with the author.

I would like to thank Mrs. Kathe Melkers, who prepared the several typed drafts of this extensive document, and Mrs. Michele Cox, who prepared the numerous illustrations.

Sandy Hook, New Jersey

November 15, 1979

TABLE OF CONTENTS

Page

CHAPTER 5

CHAPTER 6

Page

CHAPTER 7

CHAPTER 8

CHAPTER 9

CHAPTER 1

1. INTRODUCTION

Examination of the history of exploitation of fish stocks is a fascinating but somewhat disillusioning exercise, since the pattern of overexploitation and subsequent decline is repeated over and over. In recent years, however, there have been increasing pressures for more rational exploitation, that will prevent or at least substantially delay the kinds of decline in abundance and catches that have characterized major fisheries of the past. It is important, in this more enlightened era, to determine what rational exploitation levels might be -- and this is of course where quantitative stock assessments must be made, to determine recruitment, mortality, and stock size, and to indicate allowable catches that will insure a viable stock size in the future.

The problems of assessment and management are particularly severe when considering species such as herring, which are characterized by extreme fluctuations in year class strength -- fluctuations which, even today, after almost a century of research, are only vaguely understood. It is difficult to manage variable fish stocks with sustained yield concepts, which do not apply in dynamic situations, since constant levels of production in the presence of sudden abundance or scarcity lead to either waste or overexploitation.

Herring of the western North Atlantic have been fished for several centuries, but except for very few instances (such as the juvenile fishery for sardine-size herring on the Maine and New Brunswick coasts) populations were underexploited or in some instances were not exploited at all. That state of affairs disappeared in the early 1960's with the arrival of foreign distant water fishing fleets off the U. S. coast, and with the great expansion of purse seining in Canadian waters.

Catches of herring from all stocks of the Northwest Atlantic increased annually to a peak of almost one million tons in 1969, and then began to decline. Peak catches for individual stocks varied by a few years, but the overall trend during the 1970's has been downward (Figure 1). The 1970's have also been a period of intensive stock assessment efforts and increasingly restrictive (in the past several years) regulation of catches of distant water fleets. Some of the logical critical questions that emerge are "Since fisheries are consequences of events as well as causes of events, what are the natural factors that determine abundance or scarcity?" "Why have we permitted what seems to have been overexploitation of existing adult stocks?" "What have we learned about management of herring stocks from previous failures?" "What are allowable catches for the future?"

This document attempts to address these questions, after first reviewing the status of our knowledge about herring of the western North Atlantic -- their biology and ecology, their migrations and

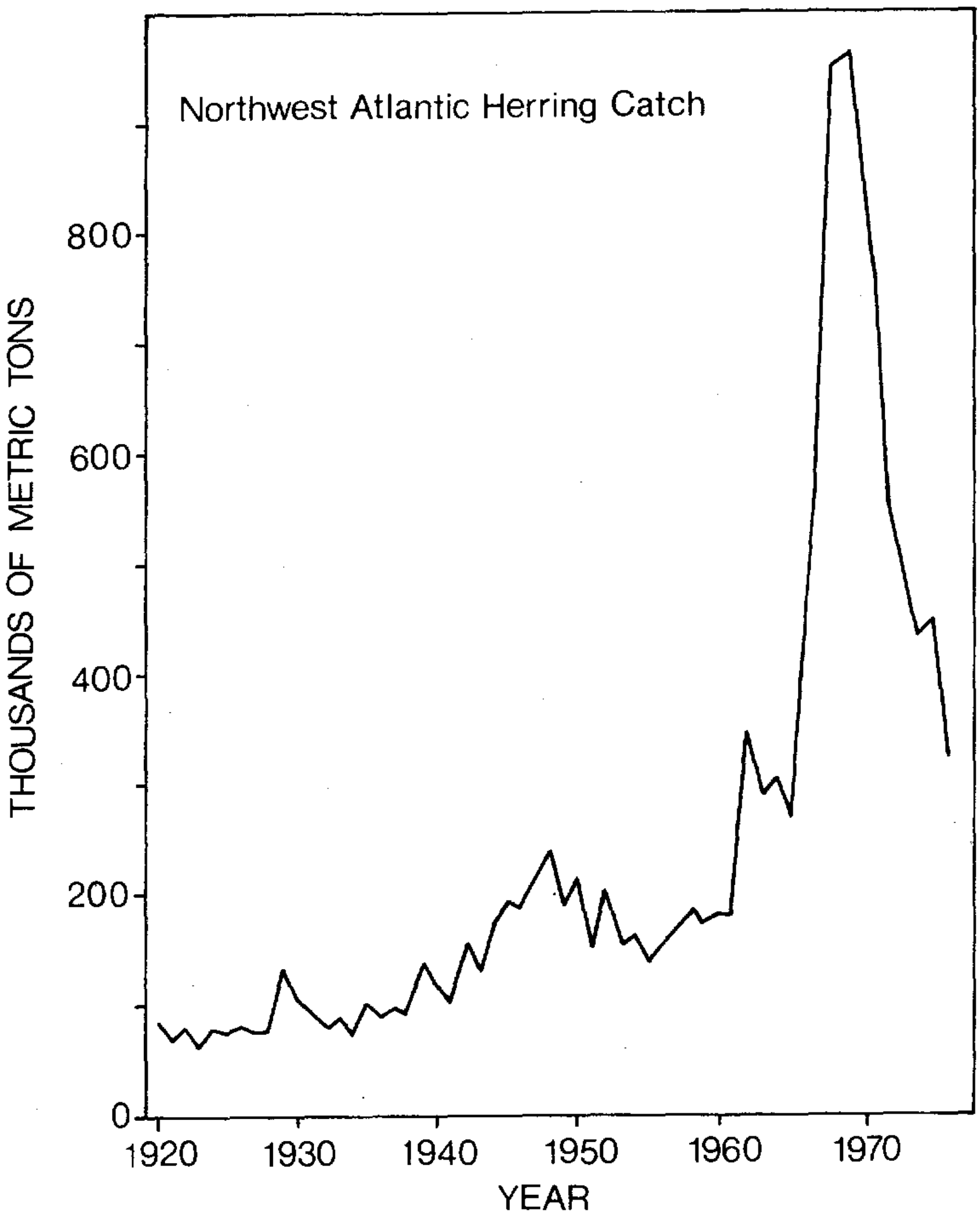


Figure 1. Herring landings in the western North Atlantic, 1952 to 1976. (From Anthony and Waring, 1978).

stock structure, and their abundance. Emphasis has been placed on events since 1961, which is when intensive exploitation began on Georges Bank, to be followed soon after by expansion of fisheries in the Gulf of Maine and in Canadian waters.

Persistent problems will be identified, and hypotheses relevant to solutions to these problems will be explored -- all leading to proposals for future management-oriented research and statistical activities which should assist in rational exploitation of stocks.

CHAPTER 2

2. HISTORY OF THE HERRING FISHERY IN THE WESTERN NORTH ATLANTIC

CONTENTS

2.1 INTRODUCTION

The earliest organized fishery for herring in the western North Atlantic was probably conducted by Indians using brush weirs (Earll, 1887). With the appearance of Europeans on American shores and in American waters, herring fisheries developed, with a number of critical motivating factors and in a series of phases:

(1) European vessels fishing for cod visited waters of the western North Atlantic beginning about 1500 AD. The Europeans discovered very early that herring for bait could be taken near the cod grounds by gill nets fished at night.

(2) Beginning with the earliest permanent settlement, herring were used as food by the colonists, as well as for cod bait. Following the Indian example, the Plymouth Colony built and operated a herring weir as early as 1641.

(3) During the early 19th century, salt herring -- either as food or as bait -- was much in demand, and substantial fisheries developed off Newfoundland, in the Gulf of St. Lawrence, and off New England.

(4) With the introduction of trawling for cod and other groundfish, demand for herring as bait declined in the later part of the 19th century, but at about that time (the 1870's) canning juveniles as sardines began and prospered on the Maine and New Brunswick coasts. Additionally, the lobster fishery expanded after 1860, and herring were a major source of bait. The "sardine" fishery for juvenile herring was the principal herring fishery during the first half of the 20th century.

(5) Beginning in 1961, exploitation of offshore adult herring stocks by foreign distant water fleets began, and increased annually until 1969, when almost a million tons were caught by all nations in waters of the western North Atlantic.

(6) During the 1970's, concern about overexploitation led to imposition of international catch limitations of increasing severity as herring stocks continued to decline. Almost total failure of the autumn 1977 adult herring fishery on Georges Bank was the most recent and most disturbing event during this period of intensive fishing and resultant decline in stock size.

In terms of relative impact on herring stocks, the entire history of the fishery can be divided into pre- and post-1961. Before 1961, exploitation by man was minimal, with some stocks (such as Georges Bank) untouched, and other stocks (such as southwest Nova Scotia and Gulf of St. Lawrence) harvested minimally and inefficiently by gill nets and other fixed gear (see Figure 2 for locations of immediate concern to this review). The only herring fishery that could be described as intensive prior to 1961 was the sardine fishery for juveniles on the Maine and New Brunswick coasts, and even this fishery was conducted principally with fixed gear. After 1961, fishing pressure on all stocks increased enormously, with mobile gear (otter trawls, paired trawls, mid-water trawls, and especially purse seines) accounting for dramatic increases in annual landings from all known herring stocks of the Northwest Atlantic (Figure 2).

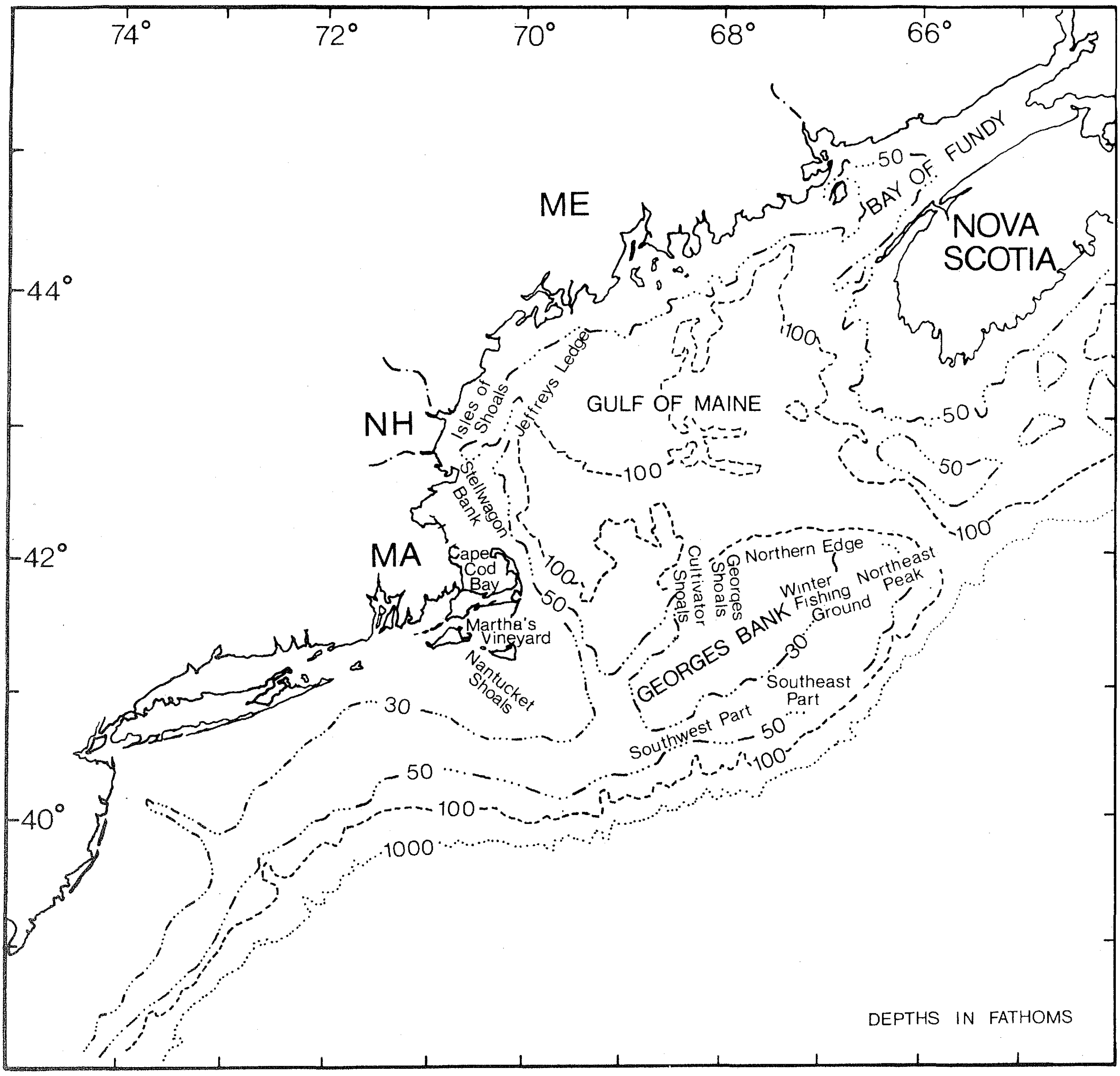


Figure 2. Chart of Georges Bank, Gulf of Maine and Nova Scotia (from Boyar et al., 1973b).

Landings from 1920 to 1940 were relatively stable at about 80-100,000 MT, then increased gradually through the 1940's to a peak of 242,000 MT in 1948. During the 1950's catches stabilized at about 160-200,000 MT. The decade of the 1960's saw an unprecedented increase in catches to 967,000 MT in 1969 because of almost simultaneous developments in several areas: the intensive Georges Bank fishery by several distant water fishing nations (notably USSR, Poland, the Federal Republic of Germany, and the German Democratic Republic) beginning in 1961; the Nova Scotia purse seine fishery for adults, beginning in 1964; the Gulf of St. Lawrence purse seine fishery, which intensified after 1965; and the western Gulf of Maine adult fishery, which began in 1967.

The great expansion of western North Atlantic herring fisheries was predicted quite specifically by Scattergood and Tibbo (1959) two decades ago and just before the beginning of the intensive fishery. Their comment (p. 38) was: "...with a continuing increase in population... the demand for herring products, both as fish meal and human food, may become great enough so that the fishery [for herring in the Northwest Atlantic] will eventually be prosecuted to the utmost". That extreme level of exploitation did develop quickly during the late 1960's, and was followed in the 1970's with rapidly declining stocks and restrictions on total catches from those much reduced stocks.

By hindsight, the vigorous exploitation of herring stocks of the western North Atlantic by distant water fleets from Europe was predictable since: (1) herring constitute a valuable food resource in a number of north European countries, and supplies of the species from European waters had been dwindling; (2) expansion of distant water fleets became a matter of government policy in a number of European socialist countries after World War II; and (3) the existence of large virgin stocks of herring (particularly the Georges Bank stock) had been reported in the scientific literature.

The presence of strong year classes resulted in an unusually high population level at the beginning of intensive exploitation. Thus it might be expected that a decline in population size would follow increased exploitation, particularly if stocks were not augmented by subsequent strong year classes.

Demand for herring, combined with constantly expanding fishing capacity, led to greater and greater pressure on existing stocks in international waters. The international regulatory regime (ICNAF) in effect at the time did not act quickly to reduce fishing pressure, even after signs of apparent stock reductions were recognized. With the recent extension of national fishery jurisdiction to 200 miles by the United States and Canada, a possible vehicle for effective regulation is in place, although its effectiveness has not been tested. At least some of the stocks may be at dangerously low levels -- low enough so that rebuilding may be difficult and slow, even if management is effective.*

*This report contains information available up to mid-1979. It is apparent that major events are occurring that may totally reverse the rather pessimistic tone of much of the conclusions. Of possible great significance is the increasing evidence that the 1975 year class was above average, the 1976 year class was very good, and the 1977 year class may also be good. If this proves to be the case, it will mean that three successive good year classes exist -- an unprecedented event in the recent history of the fishery, and one that could lead to rapid rebuilding of stocks.

There are four principal stocks or stock complexes of herring in Northwest Atlantic waters (Figure 3):

(1) Georges Bank-Southern New England

(2) Gulf of Maine

(3) Southwest Nova Scotia

(4) Southern Gulf of St. Lawrence-Southwest Newfoundland.

Since this paper is concerned with herring in United States waters, most of the emphasis will be on the Georges Bank-Southern New England and Gulf of Maine stocks, but since there is good evidence of contributions from the southwest Nova Scotia stock to United States stocks, as well as to the Chedabucto Bay fisheries, and intermixing of Georges Bank, Gulf of Maine and Nova Scotia stocks, all three must be considered. There is little evidence for intermixing of these stocks with those of the Gulf of St. Lawrence, so the more northern stocks will not be included.

2.2 HISTORY OF THE FISHERY IN RECENT DECADES

1950-1960

Herring fisheries of New England and southeastern Canada were primarily for sardines -- juveniles in their first, second, and third year of life -- using weirs and stop seines. Many fish less than a year old were taken for pearl essence and reduction in the Bay of Fundy. Some adults were taken for lobster bait, reduction, and pickling, by trawlers in Block Island Sound, by floating traps in New Jersey in spring, by purse seining near outer islands (Isles of Shoals, Matinicus, Grand Manan), and by gill nets off southern Nova Scotia.

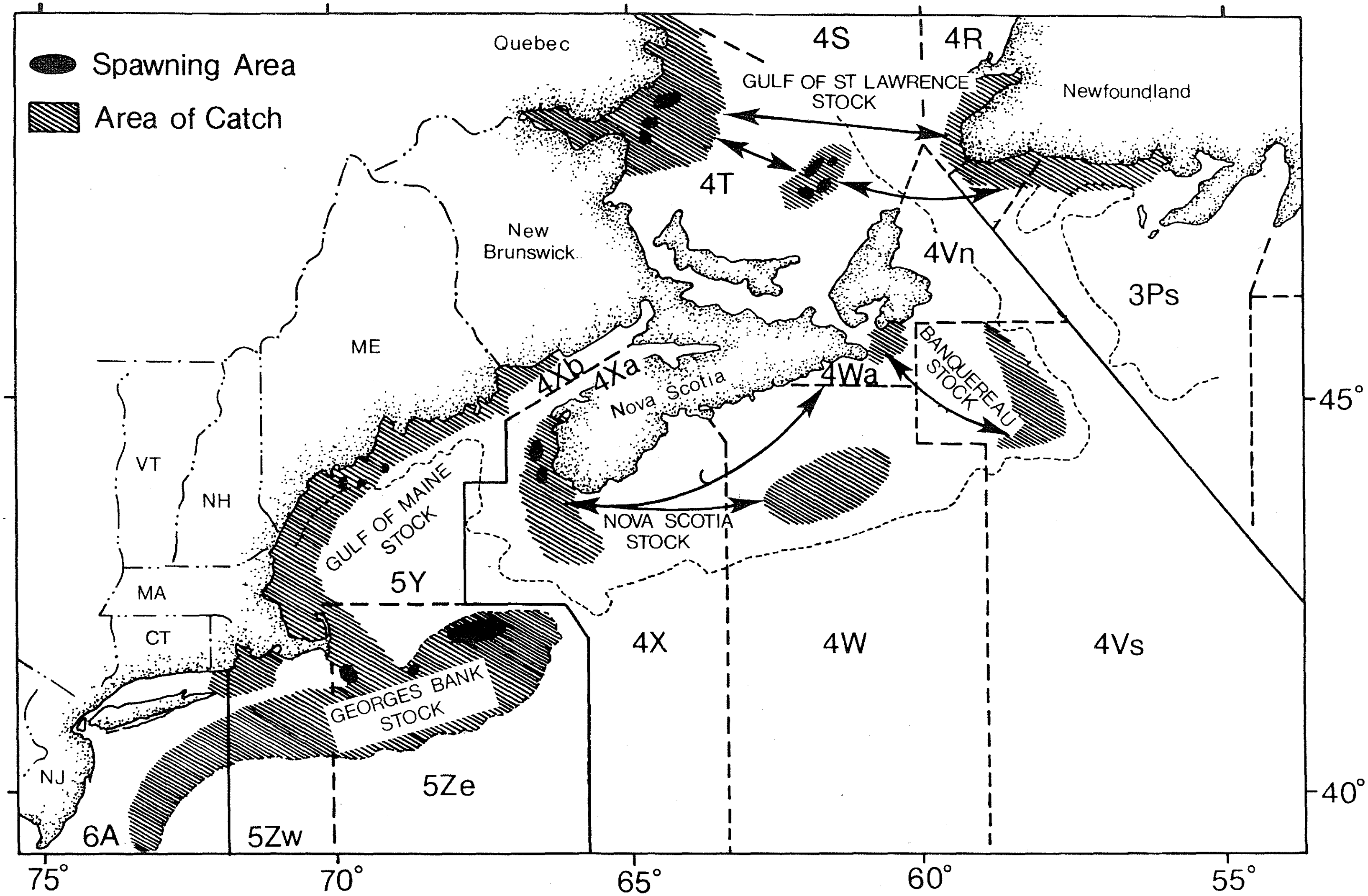


Figure 3. Herring stock structure in Subareas 4 and 5 and Statistical Area 6. (Solid lines indicate stock management areas; solid black areas indicate the general spawning grounds). (from Report of the Herring Working Group, ICNAF Redbook, App. II, 1972).

From the late 1940's to the early 1960's the annual Maine sardine catch averaged about 65,000 tons (1,800 million fish) of which age 2 herring constituted about 28,000 tons. Fisheries of the Gulf of Maine are usually categorized as juvenile ("sardine") fisheries and adult fisheries. The division is not crisp, however, since some adults may be mixed in with juvenile catches, and some juveniles may be taken in the adult fisheries. The division is particularly indistinct when age 3 fish are considered. They may make up a significant proportion of adult stocks in certain years, but they may also be purse seined as juvenile schools several miles off the coast.

Throughout the 1950's, and until 1967, most of the Gulf of Maine catches were of juveniles in the "sardine" fishery. Large annual variations in catches have occurred during the period since World War II, with peak catches in 1950 of 90,000 MT and in 1958 of 81,000 MT. Decline in "sardine" catches began in the early 1950's on the eastern Maine coast (Figure 4), while the greatest decline in the central and western sectors of the coast occurred in the 1960's, reaching a low ebb in 1971, and with some slight resurgence in the past few years (Figure 5).

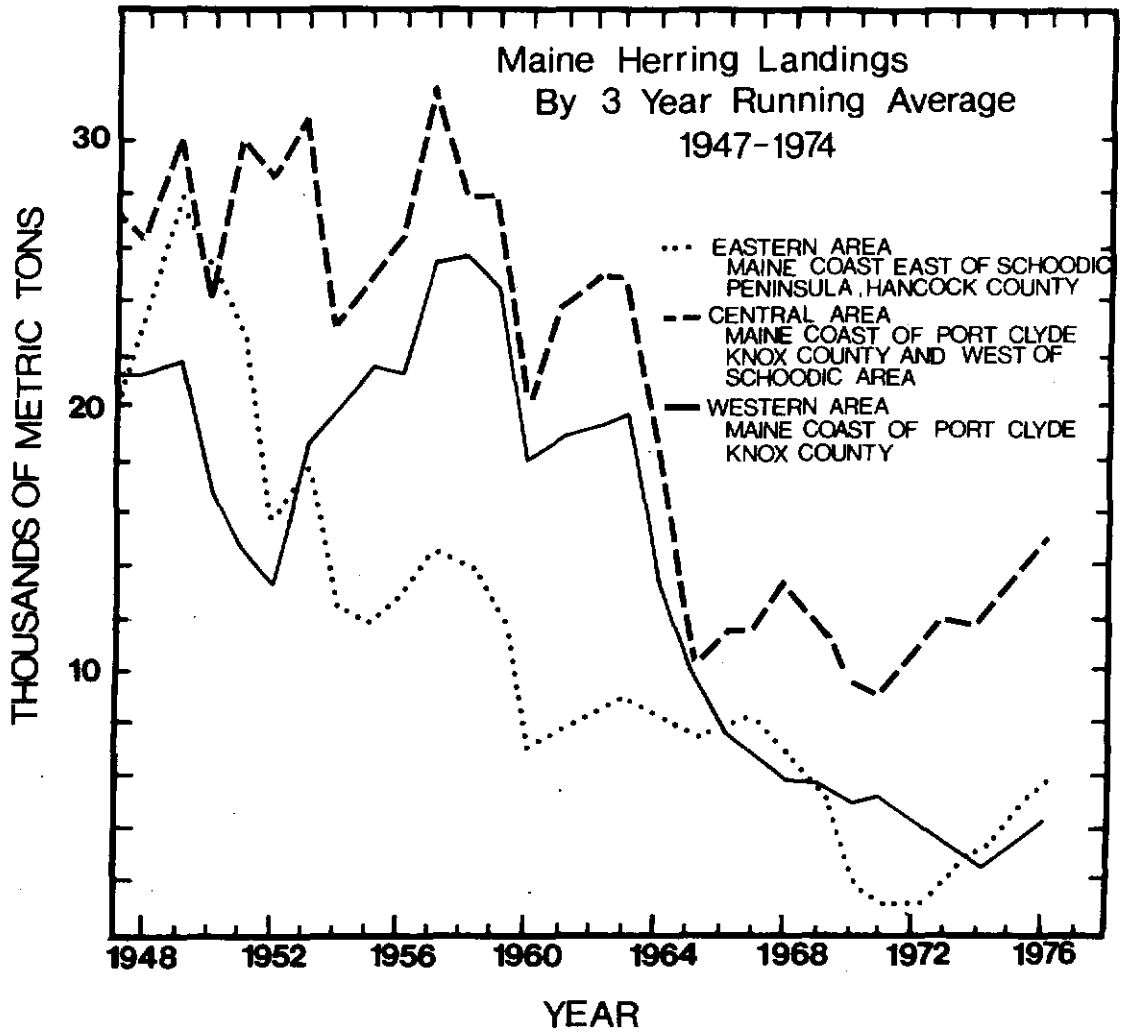


Figure 4. Maine juvenile herring landings, 1937-1974 (from Anthony, 1977b).

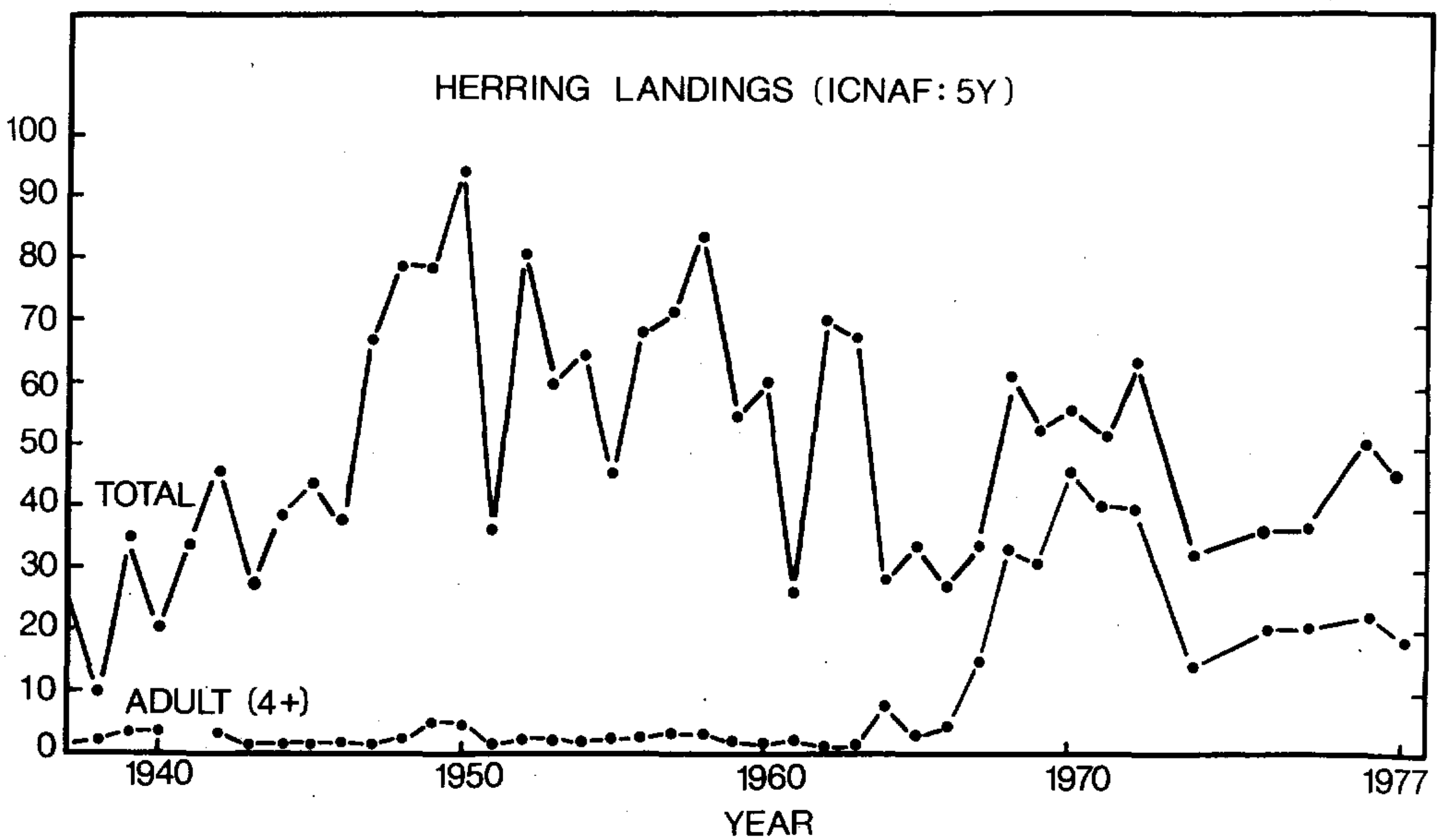


Figure 5. Herring landings in the Gulf of Maine, 1938-1977 (from Anthony, 1977b).

1960-1970

The Soviet distant water fleet appeared on Georges Bank in force in the autumn of 1961, after several years of exploratory fishing by research vessels. Gill nets and bottom trawls were used first, then later mid-water trawls and finally purse seines of large dimensions. After initial success by the Soviets, vessels from other countries (notably East Germany, Poland, and West Germany) began to appear in increasing numbers. The Georges Bank herring fishery, non-existent in 1960, had reached a production of 373,000 MT by 1968. Initial concentration on spawning aggregations was broadened and expanded to include fisheries on overwintering groups from southern New England to Cape Hatteras and on spawning and overwintering groups in the Gulf of Maine.

The bulk of the catch from the Georges Bank stock during these years was taken by the USSR, FRG, GDR, and Poland; some catches were also taken by Canada, the USA, Japan, Bulgaria, Iceland (on contract to United States), Norway, France, and Romania. Spain, Greece, and Italy were not involved. In the Gulf of Maine, the USA, Canada, FRG, and GDR were the only participants of consequence during these years, with lesser amounts reported by Poland, USSR, Bulgaria, France, and Japan.

Failure of the Pacific herring fishery off British Columbia in the 1960's -- combined with increased demand for fish meal -- diverted Canadian purse seine effort to the Atlantic. Catches in the Gulf of St. Lawrence, off Newfoundland, and off Nova Scotia increased enormously. This, combined with the increasing foreign catches on Georges Bank and in the Gulf of Maine, resulted in an enormous increase in total herring landings in the Northwest Atlantic during the decade -- from a catch of 180,000 MT in 1960 to 300,000 MT in 1964, then to 600,000 MT in 1967, then to a phenomenal 967,000 MT in 1969 (Table 1).

During the 1960's, the Maine sardine fishery, which is largely dependent on annual recruitment of two-year-old herring, continued a decline which began in eastern Maine in the 1950's -- hastened by a succession of weak year classes (1963 through 1965, and 1967 through 1969). These years of repeated poor recruitment were interspersed with years in which recruitment was good, but the overall decline continued, and included central and western Maine juvenile stocks. The 1960 and 1961 year classes were excellent, the 1966 was good, the 1970 was excellent, and the 1974 was good (in terms of relative catches in the juvenile fishery); all other year classes up to 1974 were poor to very poor.

Declines in juvenile catches on the Maine coast preceded the intensive fisheries on adult stocks on Georges Bank and Jeffrey's Ledge by a number of years. Looking at adult stock size, obvious decline began after 1969 on Georges Bank and after 1971 for Jeffrey's Ledge, and may have begun a few years prior to these dates. Thus there seems to be little obvious relationship between reduction in adult stock size on Georges Bank and Jeffrey's Ledge, and the decline in juvenile catches on the Maine coast; the decline in the juvenile fishery clearly preceded the increase in exploitation of adult herring in the Gulf of Maine and on Georges Bank.

Table 1. Total US and total Northwest Atlantic herring catches, 1960-1977.

	TOTAL US CATCH (1000 METRIC TONS)	TOTAL NW ATLANTIC CATCH BY ALL NATIONS (1000 METRIC TONS)
1960	70	182
1961	27	180
1962	72	344
1963	70	285
1964	28	303
1965	35	265
1966	33.6	431
1967	32	594
1968	42	952
1969	32	969
1970	31	852
1971	35	826
1972	41	548
1973	26.3	485
1974	33	433
1975	36	448
1976	50	323
1977	51	283

Significant events occurred in Canadian waters during the 1960's. A new fishery started in the Banquereau area late in 1968, and by the end of the first full year of exploitation, more than 250,000 MT had been taken. Landings from southwest Newfoundland increased from 6,000 MT in 1961 to 145,000 MT in 1968, and there were fivefold increases in Canadian catches from the Gulf of St. Lawrence and the Bay of Fundy during this same period.

The fishery for juveniles on the western side of the Bay of Fundy took an average of 43,000 tons annually during 1963-1965; 62,000 tons during 1966-1969; and 23,000 tons in 1970 and 1971 (Herring WG Report, 1972). Of these catches, the winter purse seine fishery took about 54% -- principally very small fish less than 1-1/2-years old.

During the 1960's, three distinct kinds of Canadian fisheries existed in southern Nova Scotia waters (ICNAF Division 4Xa and 4Wb): the inshore gill-net fishery for adults extending from Yarmouth to Halifax; the weir fishery for juveniles along the southeastern shore; and the purse seine fishery for pre-spawning fish off the southwestern coast.

Catches from the traditional weir and gill net fisheries fluctuated very little from 1960 to 1970 -- each accounting for about 10,000 tons annually. However, catches by purse seiners increased dramatically in the mid-1960's, reaching a peak of about 120,000 tons in 1967 and 1968, and then declining to about 30,000-40,000 tons by 1971. Additionally, a Soviet offshore fishery for overwintering adults developed on Emerald Bank and adjacent areas. Catch from this fishery was reported at 60,000 tons in 1970.

1970 to present

During the 1970's, several major events took place:

(1) Intensive fishing pressure on all stocks continued until (and even after) national quotas and total allowable catches were imposed by ICNAF in 1972.

(2) The Georges Bank stock continued a decline which began before 1969, and the fishery failed almost completely in 1977, despite imposition of severe catch restrictions (TAC - 60,000 MT) in 1976.

(3) The United States withdrew from ICNAF and extended its fishery jurisdiction to 200 miles in March 1977. Fishing on U. S. herring stocks in 1977 was limited. Quotas (TAC) were 7,000 MT (Gulf of Maine), with allocations to Canada and others, and 33,000 MT (Georges Bank) with allocations to Canada, Cuba, France, FRG, GDR, Poland, Romania, USSR and others.

(4) During the early 1970's, juvenile catches were low, with an average of less than 20,000 MT, except for 1976, when the catch reached 26,000 MT. The 1971 catch of juveniles in the Maine sardine fishery was only 12,000 MT -- the lowest in the history of the fishery. Good year classes occurred in 1970 and probably in 1974 (based on relative catches in the juvenile fishery).

(5) By the end of 1971 the winter purse seine fishery for very small juveniles on the west side of the Bay of Fundy was virtually eliminated by a size restriction imposed as a conservation measure.

(6) The Gulf of Maine fishery for adult herring, mainly in the Cape Ann-Jeffrey's Ledge area, began in 1967 and reached a peak period in 1970-1972 with catches of 38-43,000 tons. Catches then leveled off at 16-22,000 tons during 1973-1976. Beginning in 1975 the catch has been taken principally by the United States.

(7) Canadian catches (Division 4X and 4Wb) which had begun at about 20,000 MT in the early 1960's (total catches including juveniles and gill net fish) rose to 114,000 MT in 1971, 116,000 MT in 1972, 136,000 MT in 1973, 140,000 MT in 1974, and 145,000 MT in 1975.

2.3 ANNUAL SUMMARY OF THE FISHERY, 1961 TO PRESENT

Included in this section are (1) brief narrative descriptions of events of significance for every year since 1961, and (2) tables of catches from U.S. juvenile and adult fisheries in the Gulf of Maine, as well as U.S. and total catches from the Georges Bank stock (Tables 2 and 3).

Table 2. 5Y Herring Catches from the Juvenile and Adult Fisheries - Juveniles (Age 1,2,3), Adults (Age 4+)

Year	Maine Sardine Fishery			Adult Fishery			Total	Total	US 5Y
	Juveniles	Adults	Total	Juveniles	Adults	Total	Juveniles	Adults	Total
1963	66,895		66,895		2,990	2,990	66,895	2,990	69,885
1964	21,877	4,418	26,295		1,421	1,421	21,877	5,839	27,716
1965	30,997	1,091	32,038		1,546	1,546	30,997	2,637	33,634
1966	25,000	1,178	26,178		3,178	3,178	25,000	4,356	29,356
1967	22,290	6,287	28,577	10	2,571	2,581	22,300	8,858	31,158
1968	30,234	839	31,073	638	9,765	10,403	30,872	10,604	41,476
1969	22,684	1,169	23,853	695	4,139	4,834	23,379	5,308	28,687
1970	11,119	4,498	15,617	366	13,198	13,564	11,485	17,696	29,181
1971	7,395	5,013	12,408	1,240	17,837	19,077	8,635	22,850	31,485
1972	18,206	1,307	19,513	431	18,267	18,698	18,637	19,574	38,211
1973	15,720	680	16,400	1,031	4,201	5,201	16,751	4,850	21,601
1974	15,049	4,094	19,143	1,424	8,809	10,233	16,473	12,903	29,376
1976	26,446	3,749	30,195	2,576	16,628	19,204	29,022	20,377	49,399
1977	27,879	4,478	32,357	701	17,190	17,891	28,580	21,668	50,248

Table 3. Catch of herring from Georges Bank

Year	USA	Canada	FGR	GDR	USSR	Poland	Japan	Bulg.	France	Iceland	Norway	Romania	Others	Cuba	Total
1960															
1961	105				67,550										67,655
1962	101				151,864	277									157,242
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	71,006	67,719	143,097	75,000	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				605			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)		174,190 (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	3,370 (6,955)	217 (2,980)	23,690 (23,900)	31,530 (31,440)	41,541 (41,725)	39,312 (39,000)	2,442	1,773	3,617			2,018	(4,000)		149,510 (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	10 (4,200)	1,162	146,096 (150,000)
1976	744 (12,400)	(1,000)	8,806 (9,200)	7,891 (9,300)	12,996 (12,190)	10,517 (11,000)	868 (1,100)	105 (900)	1,166 (1,000)			115 (800)	3 (10)	296 (1,000)	43,507 (60,000)
1977	361 (12,000)	2 (1,000)	-- (4,725)	-- (4,825)	1,492 (3,400)	119 (5,100)	--	1 (100)	-- (1,000)			-- (100)	(50)	152 700	2,127 33,000

Note: National allocations in parentheses

1961

First Soviet fishing vessels appeared on Georges Bank, fishing on spawning herring aggregations with drift nets and bottom trawls (Figure 6). Drift nets accounted for more than half the catch in 1961-1962. Total catch was 68,000 MT.

1962

Reported Soviet catch on Georges Bank increased to 152,000 MT. Poland entered the fishery in a minor way (only 22 MT).

1963

Reported Soviet Catch on Georges Bank was 98,000 MT. Some Soviet effort was diverted to silver hake.

1964

Reported Soviet catch on Georges Bank was 131,000 MT. Nova Scotia adult purse seine fishery began.

1965

Reported Soviet catch on Georges Bank was only 38,000 MT because of fleet diversion to haddock and red hake. Poland and Romania took minor amounts of herring in the Georges Bank fishery (1,447 and 1,982 MT respectively).

Purse seine fishery (late autumn and winter) began on the southwest Newfoundland coast.

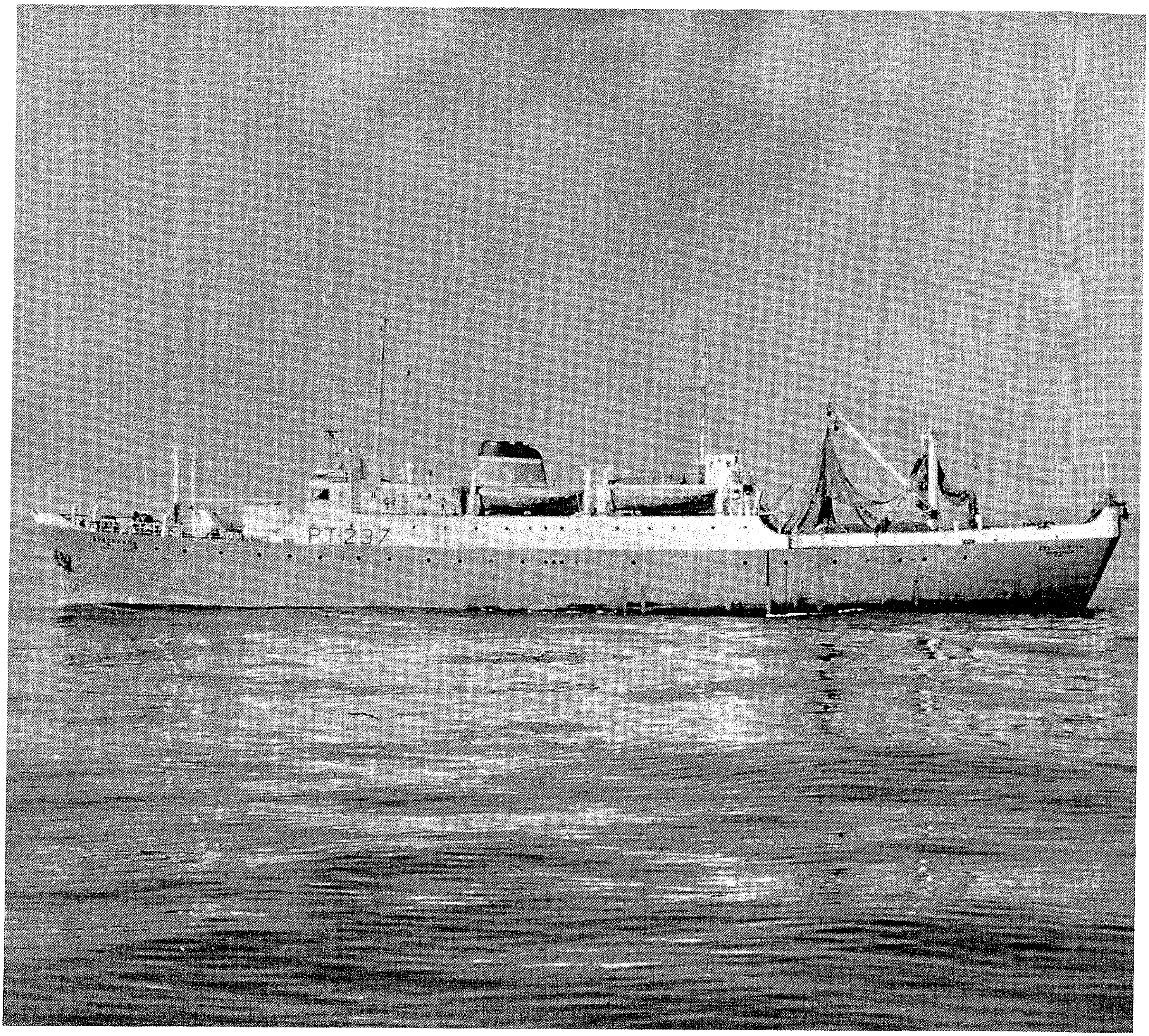


Figure 6. Soviet stern trawler, Georges Bank, 1962.

1966

Reported Soviet catch on Georges Bank was 120,000 MT, while Polish catch increased to 14,000 MT. Romania and GDR caught minor amounts.

During the period 1962-1966 Nova Scotia catches (including juveniles) were around 20,000 MT. Herring catches in the Gulf of St. Lawrence were 65,000 MT.

1967

Poland, FRG, GDR, and Canada entered the Georges Bank herring fishery in force. These countries took 88,000 MT, and Soviets took 126,000 MT. The total herring catch in 1967 was 219,000 MT.

Nova Scotia catches began a slow rise which continued through the rest of the 1960's.

A substantial adult fishery began in the western portion of the Gulf of Maine, concentrating on Jeffrey's Ledge, Stellwagen Bank, and adjacent areas. Catch was 7,800 MT.

Gulf of St. Lawrence herring catches increased to 146,000 MT.

1968

The total Georges Bank herring catch was 373,000 MT. This, as the later record shows, was the high point of the herring fishery on Georges Bank in terms of catch.

Fishery by foreign fleets on adult stocks in Gulf of Maine (particularly Jeffrey's Ledge) increased rapidly. Participants were GDR, FRG, Canada, Poland, USSR, as well as U. S. Catch was 31,900 MT.

Catches of adult herring from Bay of Fundy and southwestern Nova Scotia reached 230,000 MT. Gulf of St. Lawrence herring catches increased to 279,000 MT.

1969

The total Georges Bank herring catch was 310,000 MT. This was the year when herring production from the western North Atlantic reached an all-time peak of 967,000 MT.

1970

Decline in Georges Bank herring catch began. Total catch was 247,000 MT, of which FRG took 82,000 MT, Poland took 71,000 MT, and USSR took 62,000 MT.

1971

Georges Bank herring catch was 267,000 MT. GDR introduced mid-water trawling to Georges Bank fishery.

Catch of herring in Nova Scotia (4WX) (including juveniles) reached 114,000 MT -- a five-fold increase since 1966.

1972

ICNAF management of herring stocks began. Total allowable herring catch for Georges Bank established by ICNAF at 150,000 MT. (The TAC was ineffective because of catches by GDR -- not a member of ICNAF). Total catch for 1972 from Georges Bank was 174,000 MT. Detailed assessments of Georges Bank herring stock began.

Decline in herring catch from Jeffrey's Ledge (5Y) began. Nova Scotia (4WX) catch quota (TAC) imposed for first time at 60,000 MT, but the catch (including juveniles) was 116,000 MT.

1973

Total allowable catch for Georges Bank herring continued at level of 150,000 MT, but was again ineffective because of catches of GDR -- a non-member of ICNAF. Total herring catch for 1973 from Georges Bank was almost 200,000 MT. Nova Scotia (4WX) TAC was increased to 90,000 MT; the catch (including juveniles) was 135,000 MT.

1974

TAC for Georges Bank herring continued at 150,000 MT. GDR joined ICNAF -- so it was not until 1974 that the herring catch on Georges Bank was restricted to the TAC. Georges Bank catch in 1974 was 148,000 MT.

Nova Scotia (4WX) TAC continued at 90,000 MT; the catch (including juveniles) was 140,000 MT.

1975

TAC for Georges Bank herring continued at 150,000 MT; catch in 1975 was 146,000 MT. Nova Scotia (4WX) TAC continued at 90,000 MT; catch (including juveniles) was 145,000 MT.

1976

TAC for Georges Bank herring reduced to 60,000 MT, but actual catch was only 43,000 MT.

Total Gulf of Maine herring catch (juveniles and adults) was the largest since 1963 (almost 50,000 MT). TAC for Nova Scotia (4WX) continued at 90,000 MT. TAC for Gulf of Maine adults was 7,000 MT, but 20,000 MT were taken.

1977

TAC for Georges Bank herring was 33,000 MT which was later reduced to 17,000 MT.

Actual catch did not exceed 1,000 MT. TAC for Nova Scotia (4WX) reduced to 84,000 MT.

TAC for Gulf of Maine adults set at 7,000 MT -- catch was much higher since the TAC for domestic fishermen was unlimited.

2.4 SUMMARY OF THE MAINE-NEW BRUNSWICK JUVENILE FISHERY

Because of the long history and unique character of the juvenile (sardine) fishery of Maine and New Brunswick, and because statistics from that fishery tend to get lost in considerations of adult fisheries and adult stocks, it seems worthwhile in the early part of this document to attempt a summary -- an overview -- of its past and present status.

The Maine juvenile fishery for sardines began in the mid-1870's, and has been characterized by great annual variations in supply, but by longer-term trends in production (Figure 7). These trends have been reviewed recently (Anthony, 1972; Anthony and Waring, 1978). Periods of abundance and scarcity seem apparent: from 1896 to 1916 catches averaged 60,000 MT, then dropped drastically during the period 1917-1940 to an average of 25,000 MT. From the late 1940's through the early 1960's production increased to early levels (around 60,000 MT average, with large annual fluctuations). During the late 1960's production decreased again to an average of 28,000 MT, and

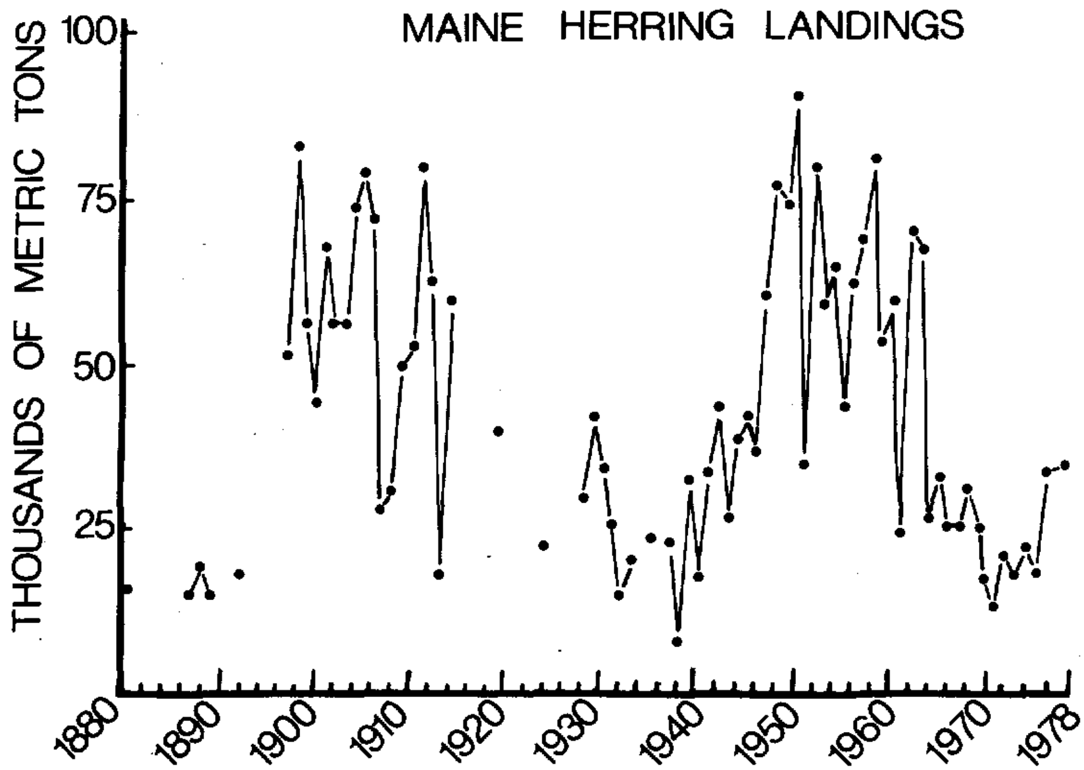


Figure 7. Catches of Atlantic herring along the coast of Maine used primarily by the sardine industry. (From Anthony and Waring, 1978).

decreased still further during the early 1970's to an average of only 17,400 MT. Some resurgence was seen in 1976 and 1977, however, when catches were 26,400 MT and 27,800 MT respectively. Whether early periods of low catches (such as the period 1917-1940) were reflections of biological events or merely economic events is not completely understood.

Catches in the New Brunswick juvenile fishery averaged 55,800 MT from 1964 to 1969, and 28,000 MT from 1970 to 1976.

The sardine fishery concentrates on age 2 fish (Figure 8), but still will use age 3 fish early in the season and age 1 fish late in the season, to an extent determined by relative availability of age 2 fish. The history of the Maine sardine industry has been one of reduction in production since the early 1950's. Operating canneries have decreased from 50 in the early 1950's to 15 in 1977, and production during that period has declined from 2 to 3 million cases per year in the early 1950's to about 1 million cases in recent years.

Intensive fishing of adult herring has been cited by the sardine industry as the cause of reduced abundance of juveniles in coastal waters of Maine. The industry is well-organized, and has spoken vigorously for effective management of adult herring stocks, both within State territorial waters and in the fishery conservation zone.

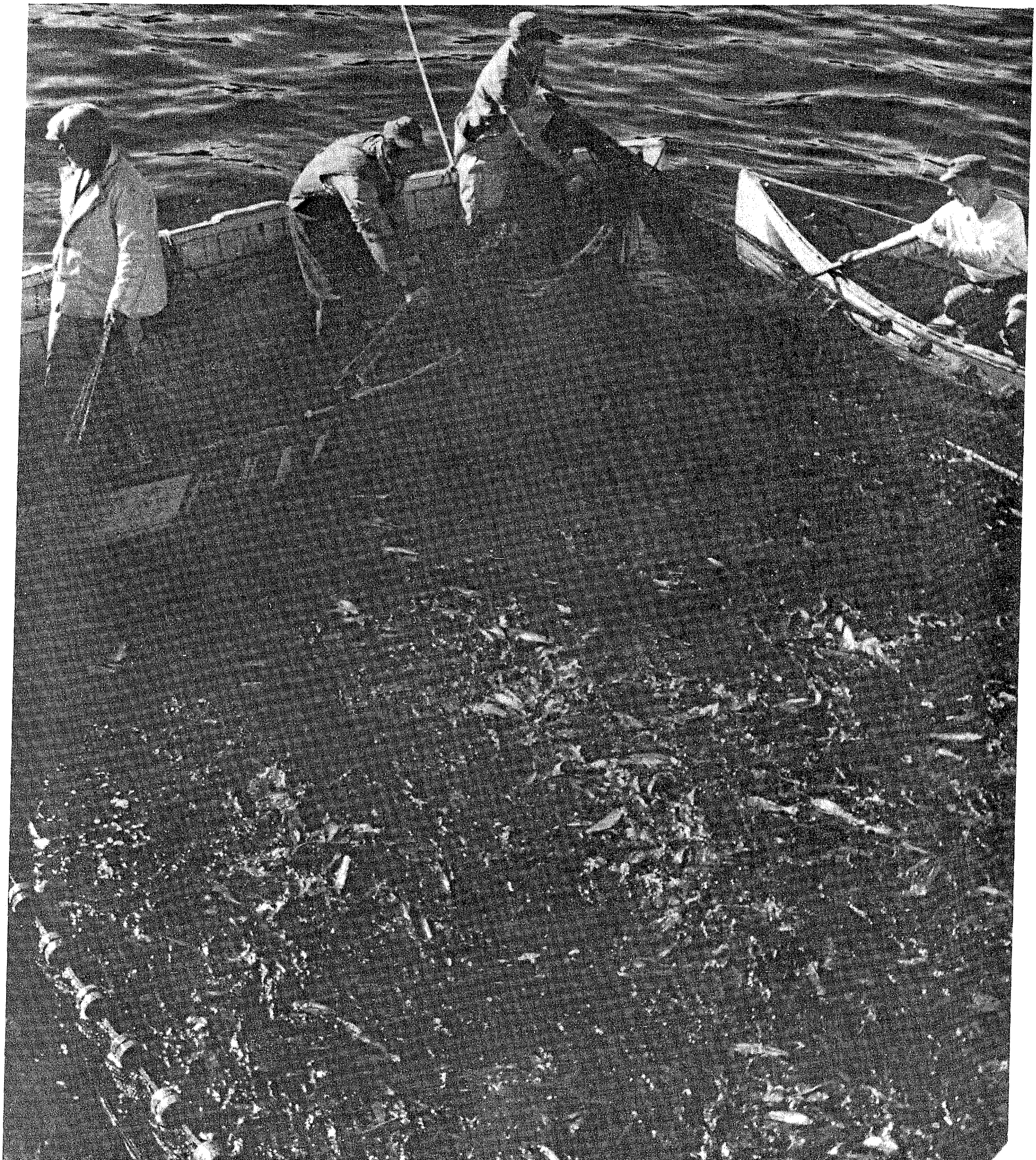


Figure 8. Stop seine catch of juvenile herring on the Maine coast.

CHAPTER 3

3. BIOLOGICAL INFORMATION: STATUS OF KNOWLEDGE

CONTENTS

3.1 INTRODUCTION

Herring, Clupea harengus, have an almost continuous distribution in the North Atlantic from Cape Hatteras northward and eastward to the Baltic Sea, with evidence for localized populations and in some instances extensive migrations. Major herring stocks of the western North Atlantic occur in continental shelf waters from Cape Hatteras to Labrador, usually within the 200 meter contour. The principal subdivision of western North Atlantic stocks seems to occur off northern Nova Scotia, with other but probably lesser subdivisions north and south. The southern component of the population, which is the subject of this review, has been considered to consist of three subgroups: Nova Scotia, Gulf of Maine, and Georges Bank, although seasonal movements undoubtedly result in significant geographic overlap and intermixing.

Herring are densely schooling plankton feeders, important throughout their life history as forage for many predators -- fish, bird, and mammal. Adherent eggs are spawned demersally principally in autumn; soon after hatching, larvae rise off the bottom and become widely dispersed throughout the water column; and juveniles are found in shallow waters, often in bays and estuaries. Maturation begins at age 3 but usually occurs at age 4 (and even at age 5 for a significant number of Gulf of Maine herring), and adults often perform extensive feeding and overwintering migrations, in addition to forming spawning aggregations near offshore ledges and banks.

The life history of herring is often considered for convenience in three principal phases: larva, juvenile, and adult. Larval existence for autumn spawned fish usually lasts about seven months; during this period the organisms are planktonic, subject to near-surface oceanic conditions. Metamorphosis occurs in spring, and post-larvae begin to school. Juvenile feeding aggregations occur in shallow coastal waters throughout the warmer months, but then move further offshore during winter. Maturation begins at age 3, but occur principally at age 4, and even at age 5 (with annual geographic variations), and distance of movements seems to increase with increasing age until maturity. Adults often perform extensive spawning, feeding, and overwintering migrations, some of which are only now beginning to be understood.*

---

*Note: There has been and continues to be some confusion about "adult" versus "juvenile", and "mature" versus "immature" herring. Since some herring spawn for the first time at age 3 and most at age 4 or 5, it seems reasonable to use maturation (gonadal development) or evidence of having spawned, as a criterion of adulthood. Immature three-year-olds may be taken in the juvenile fishery, while mature three-year-olds may be taken in fisheries on spawning aggregations. Their classification as adults or juveniles would therefore seem to depend on their habits and associates.

Biological studies of Atlantic herring extend back over a century, and consequently much is known about many aspects of the life history. Environmental factors which influence survival have logically received attention, but much remains to be learned.

The plan of this chapter is to review available information about the life history from egg to maturation, and to then look more specifically at factors affecting survival.

3.2 BIOLOGICAL ASPECTS OF THE HERRING LIFE HISTORY

The life history of herring, beginning with egg deposition, is a complex interplay of organisms and environment. Development, as well as behavioral and physiological characteristics, can be modified by external factors.

It is difficult, especially when dealing with mass schooling fish such as herring, to keep the biology of the individual somehow discrete in our thinking from the responses of the population as a whole to external factors -- yet it is the individual fish that hatches, grows, reproduces, and dies. These individual life history events are of course translated in total into responses of the next level of biological organization, the population or stock.

3.2.1 Egg Deposition

Atlantic herring produce adherent demersal eggs, thus conditions on and near the bottom at the time of spawning are most critical. Environmental requirements and ranges for spawning include (1) bottom temperatures of 5-15°C;

(2) depths of from 10 to 100 meters; (3) reasonably level gravel-rock substrate (vegetation and shells may also be utilized; (4) adequate water exchange by currents of at least 1-2 km/hr.

Cooper et al. (1975) conducted extensive underwater observations of spawning on Jeffrey's Ledge in 1974 and found that 80-90% of the eggs were adhering to clumps of red algae, Ptilota serrata, and the remainder was deposited on the upper surfaces of rocks and boulders.

Cooper et al. (1975) also found that three of the six spawning grounds examined on Jeffrey's Ledge were characterized by very rough boulder-rock substrate, with slope gradients ranging from 0 to 40°. They found too that bottom water currents throughout a tidal cycle at Jeffrey's Ledge sites ranged from 0 to 2 km/hr, with the average about 0.3 to 0.5 km/hr.

On herring spawning grounds, precise areas of egg deposition are usually small, often discontinuous, and variable from year to year. Eggs are laid in sheets, and successive layers may number 3 to 7 and occasionally more in areas of intense spawning. Maximum thicknesses of egg layers were reported as 1 to 2 cm on Georges Bank (Caddy and Iles, 1973) and 3.25 cm on Trinity Ledges (McKenzie, 1964). Rates of development of eggs in the different layers were not uniform in studies by Blaxter (1971). Deposition of additional layers seemed to retard development of deeper layers, and egg mortality was greater in the deeper layers. Egg mortality averaged about 12% at hatching (17-18 days incubation). Predation on herring eggs by haddock was also considered to be a significant mortality factor (Hempel and Hempel, 1971). Estimates of predation rates were made; one haddock consumed the total egg production of one herring each day (Hempel, 1971) (Figure 9).

Additional very precise information on Jeffrey's Ledge spawning beds has been provided from diver observations by Cooper et al. (1975) and Cooper (personal communication). Egg beds covered from 2/3 to 1-1/3 sq.km of bottom. They encompassed distinct and well-defined areas. Marked variability was found in characteristics of egg beds. For example, one bed had the following characteristics: egg layers, 3 to 15 eggs deep; lower 50-70% of eggs non viable; incubation period 8-10 days; substrate coarse sand/gravel/shell fragments; depth 40-50 meters; no vegetation; bottom temperature 9.5-11.5°C. An adjacent bed had the following dissimilar characteristics: egg layers, 1 to 4 eggs deep; no evident mortality due to layering; incubation period 8-9 days; substrate boulder/rock with vegetation; depth 30-45 meters; bottom temperature 9.3-10.8°C.

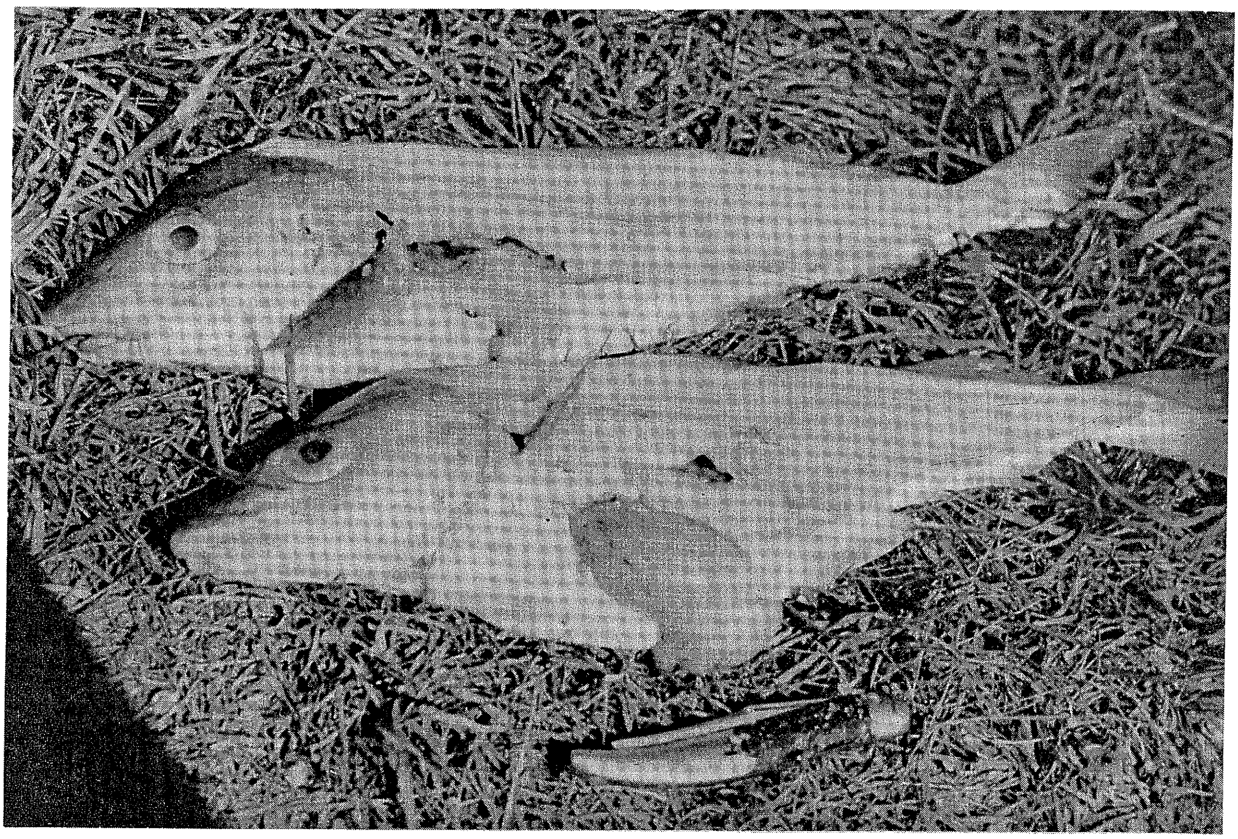


Figure 9. Haddock (below) with stomach engorged with herring eggs.

Boyar et al. (1971) have summarized the timing of herring spawning in the area of concern to this review as follows:

> "The onset of spawning on Georges Bank and in the coastal Gulf of Maine usually occurs during late August or early September. The peak of spawning is during late September or early October. Spawning decreases in intensity in November and by December and early January spawning is completed (Boyar, 1968). In Nova Scotia spawning takes place from May through December. The bulk of the spawning, however, is in September and October".

In recent years, however, spawning in the Georges Bank-Gulf of Maine area has been later, with a peak usually near the end of October (Lough et al., 1979).

3.2.2 <u>Hatching and Larval Development</u>

The incubation period of herring eggs ranges from 7 to 15 days, depending on temperature. Some observed periods are 7 days at 13°C and 12 days at 8°C (Boyar et al., 1973). Newly hatched yolk-sac larvae may be retained for one to several days in clusters of algae, if egg deposition is in an area of vegetation (Cooper et al., 1975). Also, there are scuba and submersible observations of dense aggregations of yolk-sac larvae being carried by currents near the bottom adjacent to areas of egg deposition (Graham and Chenoweth, 1973).

Larvae are initially concentrated in the upper water column immediately over spawning areas (Lough, 1975), but are then dispersed by surface and near-surface water currents. A number of studies have indicated that larval movements depend principally on existing currents, but that movements within estuaries may be influenced by vertical migrations.

The larval phase of autumn spawned herring persists for from 6 to 8 months. Newly hatched yolk-sac larvae are 5-7 mm long; growth is continuous (dependent on stored yolk for the first few days, and thereafter on availability of food particles of proper size) until metamorphosis at about 40-45 mm.

Larval growth rates in areas of concern to this report were computed recently by Lough (1976) from results of 1971-1976 surveys. A daily average growth increment of 0.195 mm was determined.

Feeding habits of larval herring were summarized by Lett (1976). Important aspects mentioned by Lett were:

(a) Larvae begin feeding before the yolk-sac is resorbed, feeding first on copepod eggs, and nauplii, larval mollusks, and algae. The yolk sac is completely resorbed within 7 days of hatching. Studies with Norwegian herring indicated that resorption rate varies with race and temperature (Rudabova, 1971).

(b) Size of food particles ingested is related to size of larvae and gape of the jaw, so the diet expands in size range to include larger particles such as the smaller copepods (Pseudocalanus for example) as larvae grow.

(c) The significance of larger size and greater feeding ability of herring larvae is especially important in winter when food is scarce, particularly in the size range of adult copepods.

(d) Abnormally-high environmental temperatures can result in improper lower jaw development in herring larvae, offsetting the advantages of larger size at hatching (Alderdice and Velsen, 1971).

Herring larvae feed by selective capture of individual food particles; small larvae dart at any particles within 5 mm, and the distance increases with age and size, whether the particles are motile or not; but the larvae are selective in the types of particles that they actually ingest (Arthur, 1956). The rate of gut clearance is directly related to temperature and to the "feeding history" of larvae (Blaxter, 1965). Herring larvae require a threshold light intensity before they will feed, and they are active daytime feeders (Hentschel, 1950; Blaxter, 1965).

A recent study of the food of larval herring on Georges Bank, examining zooplankton and larvae sampled from 1965 to 1975 (Noskov et al., 1978), resulted in the following observations:

(1) Zooplankton abundance fluctuated from year to year by a factor of five, with much of the fluctuation due to temporal abundance of particular copepod species. (In 1969 and 1970, for example, Oithona sp. dominated the October collections).

(2) Only 20% of the larvae sampled had food in their digestive tracts. This is lower than percentages obtained from the North Sea (30-50%) (Lebour, 1921b; Bhattacharyya, 1957; Schnack, 1972) and in coastal waters of the Gulf of Maine (43%), by Sherman and Honey (1968).

(3) Abundance of larval food organisms was 4 to 16 per liter, far below the optimum suggested by Schnack of 200 organisms per liter, but close to the abundance determined experimentally by Rosenthal and Hempel (1971), which was 4 to 8 nauplii per liter for 10 to 11 mm larvae.

(4) Condition factor of larvae varied from year to year, with the highest in 1970 and 1971. In those years mean weights of 10 mm larvae were 28% higher than the mean for the 10-year observation period. (It is interesting that the 1970 and 1971 year classes varied in abundance by more than an order of magnitude, with the 1970 year class among the strongest observed to date, and 1971 the weakest).

(5) The feeding of larvae on Georges Bank was less intensive on the average than in the other regions.

3.2.3 Metamorphosis

Beginning in April, after 6-8 months of planktonic larval existence, metamorphosis from larval to juvenile form occurs. The size when this phenomenon begins is 40-45 mm. Pronounced behavioral changes accompany metamorphosis -- the most obvious being the development of schooling responses.

3.2.4 Juvenile Behavior and Habits

The schooling phenomenon has been examined in a number of fish species, including herring, and its major survival value in reducing predation has been described. Other functions of the school, as mentioned by Ridgway (1975) are to reinforce directive behavioral tendencies -- behavior such as contranatal migrations of juveniles. Otherwise random movements of individuals are thus transformed into more purposeful migrations.

Schooling of herring begins early in life, during the late post-larval period, and persists throughout life. The composition of schools is to a large extent homogeneous by size and thus by year class, although there may be in any school some representation of other sizes. Schools may subdivide or coalesce.

Next to schooling, probably the most important behavioral response of herring is vertical movement in response to changing light intensity. Experimental work with juveniles by Brawn (1960b), Tibbo (1964) and Stickney (1972) demonstrated clearly that herring moved toward the surface when light intensity did not exceed 15 mc; that maximum activity occurred at about 100 mc; that activity of juveniles had a diurnal pattern, with maxima just after sunrise and just before sunset; and that vertical diurnal movements occur at all seasons, except that median depths increase in winter.

Field observations and catch information also attest to the importance of light intensity to the behavior of juveniles. Moonlight, and the phase of the moon, are important determinants of the success of the juvenile fishery -- to the extent that Anthony (1971) was able to demonstrate successive monthly peaks in the sardine herring fishery that coincided with the dark of the moon. Juveniles move up in the water at twilight and remain near the surface if light intensity is low enough.

Movements of schools are to some extent determined by ocean currents (this is particularly true of juveniles in coastal areas). Purposeful movements of schools seem to be responsive to visual cues, although other environmental and physiological stimuli are undoubtedly involved.

Movements of schools are also clearly influenced by seasonal environmental cycles -- principally those of temperature, salinity, and food abundance. Several workers have examined the temperature responses of juvenile herring of the western North Atlantic. Preferred environmental temperatures in one study were 8-12°C (Stickney, 1969); physiological stress occurred below 4°C and above 16°C; and temperatures below 0°C and above 20°C were lethal (Brawn, 1960a).

The reality of experimentally determined temperature preferences can be demonstrated by the major activity in weir and stop seine fisheries for juveniles on the Maine coast, which coincides with the period when nearshore water temperatures are in the 10-13°C range. Activity declines during mid-summer on the western coast, when nearshore water temperatures may exceed 13°C; and during the colder months (November to March) schools of juveniles disappear from nearshore waters of the Gulf of Maine. The observations of juvenile herring movements in one estuary on the Maine coast by Recksieck and McCleave (1973) also support the experimental findings of temperature optima.

There are some field observations that suggest a lower temperature optimum for adult herring. A study of their seasonal distribution on Georges Bank during the period 1962-1965 by Zinkevich (1967) suggested a preferred temperature range of 5-9°C.

There is also some experimental evidence that juvenile herring respond to changes in salinity, but that salinity is probably a less critical factor than temperature in influencing movements and distribution. Brawn (1960b) examined the tolerance of juvenile herring to several environmental variables -- notably salinity and temperature. She found that 28-32 o/oo salinity was preferred, but salinities as low as 5 o/oo could be tolerated for brief periods. Stickney (1967) reported that salinity preference of juveniles was in excess of 29 o/oo at temperatures under 10°C, but that no preference could be demonstrated when environmental temperatures exceeded 10°C.

Field observations support the concept of increasing preference for higher salinities with increasing age. Zero age group herring can be found frequently in inshore coves and estuaries where salinities are markedly reduced. However, older juveniles were reported to avoid brackish estuarine conditions (Recksieck and McCleave, 1973), and adults are rarely found in waters with reduced salinities.

The distribution of juvenile herring can be also related to food concentrations, although it is difficult to isolate individual environmental factors and demonstrate clear relationships. Seasonal abundance of zooplankton in coastal waters of the Gulf of Maine during warmer months of the year (May to November) is undoubtedly an important determinant of distribution.

Seasonal blooms of phytoplankton can also act to exclude schools from localized areas. This has been demonstrated for herring in European waters, particularly during blooms of Phaeocystis (Savage and Wimpenny, 1936) and to some extent on Georges Bank, where Bryantsev (1965) noted that adults avoided shoal areas during summer phytoplankton maxima.

3.2.5 Feeding and Growth

The food of herring in the northwest Atlantic has been reviewed recently (NERFMC, 1978). Principal diet components at various life cycle stages are as follows:

Larvae — Larvae begin feeding on copepod eggs, nauplii, and copepodids, mollusc larvae, and algae; during winter, small copepods such as Pseudocalanus minutus and copepodid stages are primary food organisms for larvae; and somewhat larger copepods and copepodid stages, and cirriped larvae, crustacean eggs, and tintinnids are principal food organisms in spring (Sherman and Honey, 1971).

Juveniles — Juveniles feed on copepods, decapod larvae, cladocerans, barnacle larvae, and bivalve larvae (Battle et al., 1936; Legare and McClellan, 1960; Sherman and Perkins, 1971). Calanus finmarchicus is a common dietary item in offshore schools.

Adults — Adult herring feed principally on euphausids (*Meganyctiphanes norvegica*), chaetognaths (Maurer and Bowman, 1975; Maurer, 1976), and to a lesser degree copepods -- particularly *Calanus finmarchicus*.

The food of herring varies markedly with size, with season, and with geography (in terms of what food organisms may be present in abundance in a specific location). Larvae, juveniles, and adults are selective opportunistic feeders, taking advantage of concentrations of whatever prey of appropriate size is available in their immediate environment (Sherman and Honey, 1971; Sherman and Perkins, 1971). Thus in early spring dense swarms of barnacle larvae or cladocerans will constitute the principal prey, while later in the season copepods and euphausids may dominate.

Spring and summer are times of most intensive feeding for juveniles and adults. Adults cease feeding when spawning begins (Pankratov and Sigajev, 1973).

Using saturation diving techniques, Cooper (personal communication) has provided additional very significant observations on elective feeding behavior of adult herring under different environmental conditions. During one late afternoon observation period, with no current, at a depth of 33-40 meters, adult herring and pollock were mixed and layered horizontally to obliquely 3-6 meters off the bottom. Individuals were spaced from each other and would, every 5-20 seconds, dart .3 to .6 meters after a visually sensed "food item". This behavior lasted for ≃1 hr during slack waters.

During another observation period, beginning about 1:00 am with a current of 1.8 km/hr at a depth of 40-45 meters, tightly-schooled adult herring (less than one body length separating individuals in the school) were observed for half an hour. The fish appeared to be feeding selectively, but maintained a tight school formation. School speed over bottom was approximately 1-1.5 km/hr.

Growth rates were found in several studies to increase progressively in a gradient from Nova Scotia to Georges Bank, with western Maine herring intermediate between Nova Scotia and Georges Bank, but with only slight differences. Georges Bank herring grew more rapidly (Figure 10), but the maximum size attained was only 35 cm at 14 years; Nova Scotia and eastern Maine herring grew slower, but reached a greater maximum size (39 cm in 16-18 years).

Growth throughout the life span of individual herring from the Gulf of Maine, Georges Bank, and Nova Scotia has been summarized in NERFMC (1978):

"The growth of juveniles is very rapid at ages 1 and 2 (Anthony, 1972). In western Maine, age 1 herring grow as much as 10 cm from early spring to November, and age 2 herring as much as 8 cm. There is great variation in growth between year

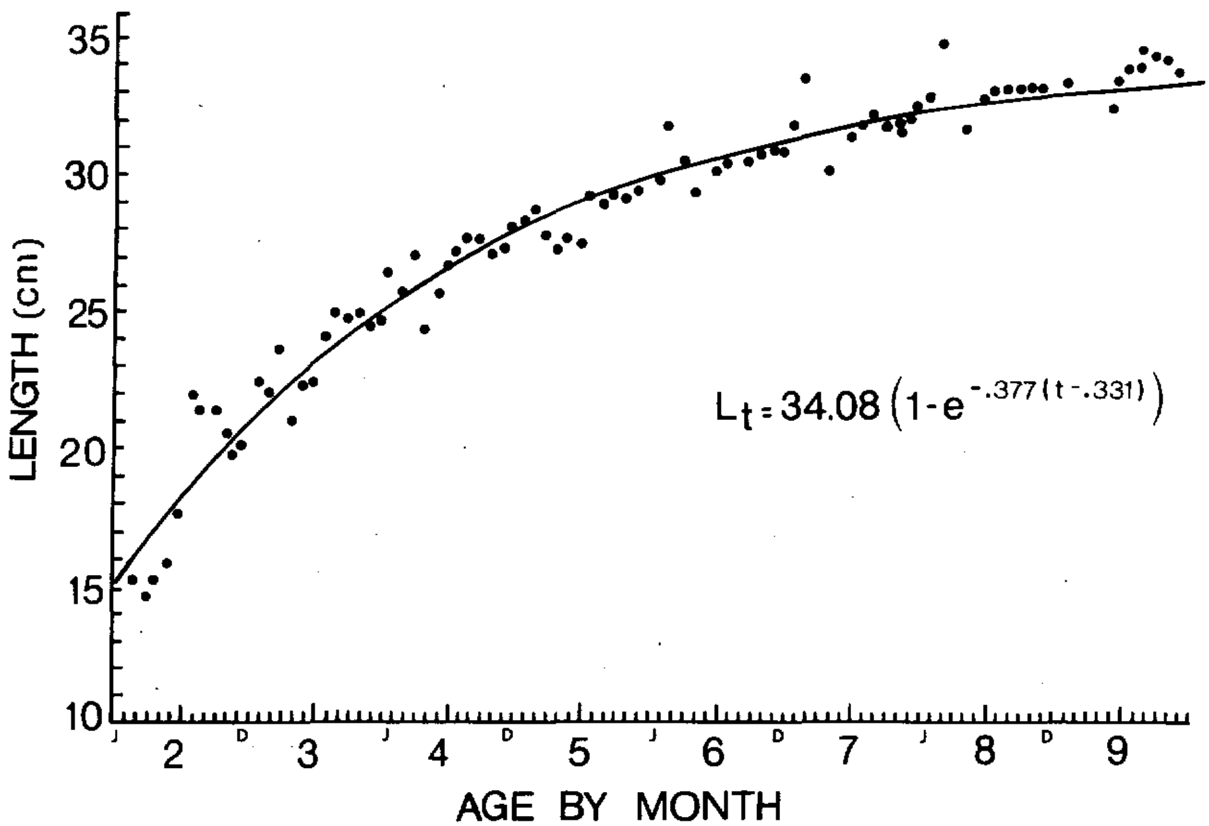


Figure 10. Growth curve for Georges Bank herring (1960-1971 year classes). (From Anthony and Waring, 1978).

classes; the size of age 2 herring can vary as much as 6 cm between year classes in one area (Anthony, 1971). Therefore, the composition of age groups entering the juvenile fishery is not the same each year. The fishery is selective to 17 cm fish. Fast growing age 1 fish will enter the fishery in late summer and slow growing age 3 fish in the early summer .... Herring in western Maine grow faster than those in eastern Maine and average nearly 3 cm longer at the end of the second year ..... Although herring in eastern Maine grow very slowly at age 1, they increase their rate of growth at age 3 and are the same lengths as western Maine herring at age 5".

An apparent increase in growth rate in juvenile and adult fish from Georges Bank and the Gulf of Maine was observed by Anthony and Waring (1978), beginning with the 1968 year class. Calculated growth rates (K) increased from 0.350 for 1960-1963 year classes to 0.510 for 1968-1971 year classes on Georges Bank, and from 0.250 to 0.400 for comparable year classes on Jeffrey's Ledge. Anthony and Waring pointed out that even the strong 1970 year class grew rapidly, and suggested that the increase in growth rate for all year classes may be due to decline in overall stock biomass. There was no change in maximum size attained.

3.2.6 Maturation, Fecundity, and Spawning Behavior

Lett et al. (1976) recently reviewed the subject of maturation and fecundity, referring to Bowers and Halliday's (1961) finding that herring produce a constant number of oocytes for a particular length, but that some of them are reabsorbed during maturation. Extending these observations, Hempel (1971) stated (concerning herring of the eastern North Atlantic) that low fat content of pre-spawning females reduced the number of eggs in a given size group -- so that in years when food production is poor, growth rate and fecundity are both low. He further stated that there was a generally positive relationship between adult stock biomass and egg production. Annual variations in fecundity at a given length have been noted for Dogger and Downs stocks (Sijlstra and Polder, 1959; Bridger, 1961). An increase in relative fecundity was found in Gulf of St. Lawrence herring between 1967 and 1970 (Lett, 1976).

Extensive examinations of adult herring from Georges Bank, the Gulf of Maine, and southern Nova Scotia during the 1960's led Boyar (1968) to the conclusion that herring in those areas spawn at age 4 at an average total length of 27.5 cm. Some herring spawn at age 3 and a length of 26.0 cm. The percent contribution of age 3 fish to spawning stocks is variable from year to year (probably related to abundance of the particular year class being recruited). In 1960, for example, age 3 herring made up 62% of the Georges Bank stock.

Livingstone and Hamer (1978) reviewed data on age at maturity, and found that from 1960 to 1965 about 29% of age 3 herring from Georges Bank and about 9% of Gulf of Maine age 3 herring were mature. For the period 1966 to 1970, 34% of age 3 herring were mature. Early maturation (at age 3) of the 1970 year class was reported by Dornheim (1975). Since 1971, samples available to Lingstone and Hamer were too small to calculate meaningful percentages, but they observed that there seemed to be fewer age 3 herring in samples from spawning populations.

From the limited maturity data available, Livingstone and Hamer were unable to detect a change in the age and length at which 50% of herring were mature (M_{50}) during the period 1973-1977. However, they did find a decrease in the relative numbers of age 3 herring in samples, and an increase in mean age and length.

There is some evidence that, as fish stocks are exploited fully, age at maturity tends to decrease, but this does not seem to have occurred in the Georges Bank or Gulf of Maine adult stocks. It may well be, however, that the available data are inadequate to support any conclusion on this point.

Fecundity of the adult stock is therefore influenced by the following:

(1) Size of stock which determines to a large extent the number of eggs deposited;

(2) Age representation in the spawning stock (recruit spawners produce fewer eggs than older fish); and

(3) Feeding conditions for adult stocks (the number of viable eggs produced per female can be influenced by nutrition). Studies with other species -- but not with herring -- have shown that fecundity depends on the number of ovarian follicles not undergoing atresia, and that the degree of atresia is related to food intake (Lett and Kohler, 1976).

Concerning fecundity of herring in the area of concern to this review, Perkins and Anthony (1969) found that eggs produced ranged from 17,000 to 141,000 (for 25 to 33 cm fish respectively and that there were no significant differences in fecundity or egg size among the three stock complexes studies (Georges Bank, southwestern Gulf of Maine, and Nova Scotia). Messieh (1976) later reported that fecundity of autumn spawning Nova Scotia fish was higher than that of spring spawners from the southern Gulf of St. Lawrence, and that eggs were smaller.

Sex ratios in samples from Georges Bank and southern Nova Scotia were approximately 1:1 (Pankratov and Sigajev, 1973; McKenzie, 1964).

The effects of fishing on egg production were summarized in NERFMC (1978):

(1) Total egg production by a spawning population is dependent on the size and age composition of the population;

(2) Fecundity increases dramatically with size and age of spawners, so egg production by a given population composed mostly of older larger fish will be higher than the same size population with a significant proportion of recruit spawners.

(3) An intense fishery tends to reduce the proportion of older larger fish in the population, hence it will reduce the egg production, and may also reduce overall reproductive potential, assuming that all other things are equal, e.g., that there is no change in egg viability with age, and no change in subsequent larval survival.

Spawning beds have been surveyed repeatedly by divers in the Gulf of St. Lawrence and the Gulf of Maine, but observations of the act of spawning in deeper water have not been made. Cooper (personal communication) has pointed out, however, that the very definitive boundaries of the egg beds and the specific characteristics of the substrate on which spawning occurs, indicate that herring spawn in very close proximity to the ocean floor.

3.3 FACTORS AFFECTING SURVIVAL AND YEAR CLASS STRENGTH

One of the outstanding characteristics of fish populations is the extent of fluctuations in year class abundance. Atlantic herring as a species has received scientific attention for almost a century, yet a basic understanding of the factors which control abundance eludes us (as it does for all marine fish species). Some environmental variables, such as temperature and predation, are clearly involved, but the relationships are not simple, even for these. Others, such as population responses to existing densities, disease, and competition for food are undoubtedly also involved. The problem of determinants of abundance of herring has long intrigued quantitative biologists. Hypotheses have been proposed and simulation models developed to explain observed changes in abundance and to predict future changes. In many instances the data base has been inadequate, particularly for long time series.

In exploring this matter, it would seem reasonable to begin with some general ecological considerations, and then to progress to more complex interrelations of biotic and abiotic factors affecting abundance.

Herring abundance at any particular moment is of course the status at that time of dynamic processes tending to expand population size (reproductive potential) and to reduce the population size (environmental resistance). A summary of the environmental forces involved in reduction is presented in Figure 11.

BIOTIC POTENTIAL
AND
ENVIRONMENTAL RESISTANCE

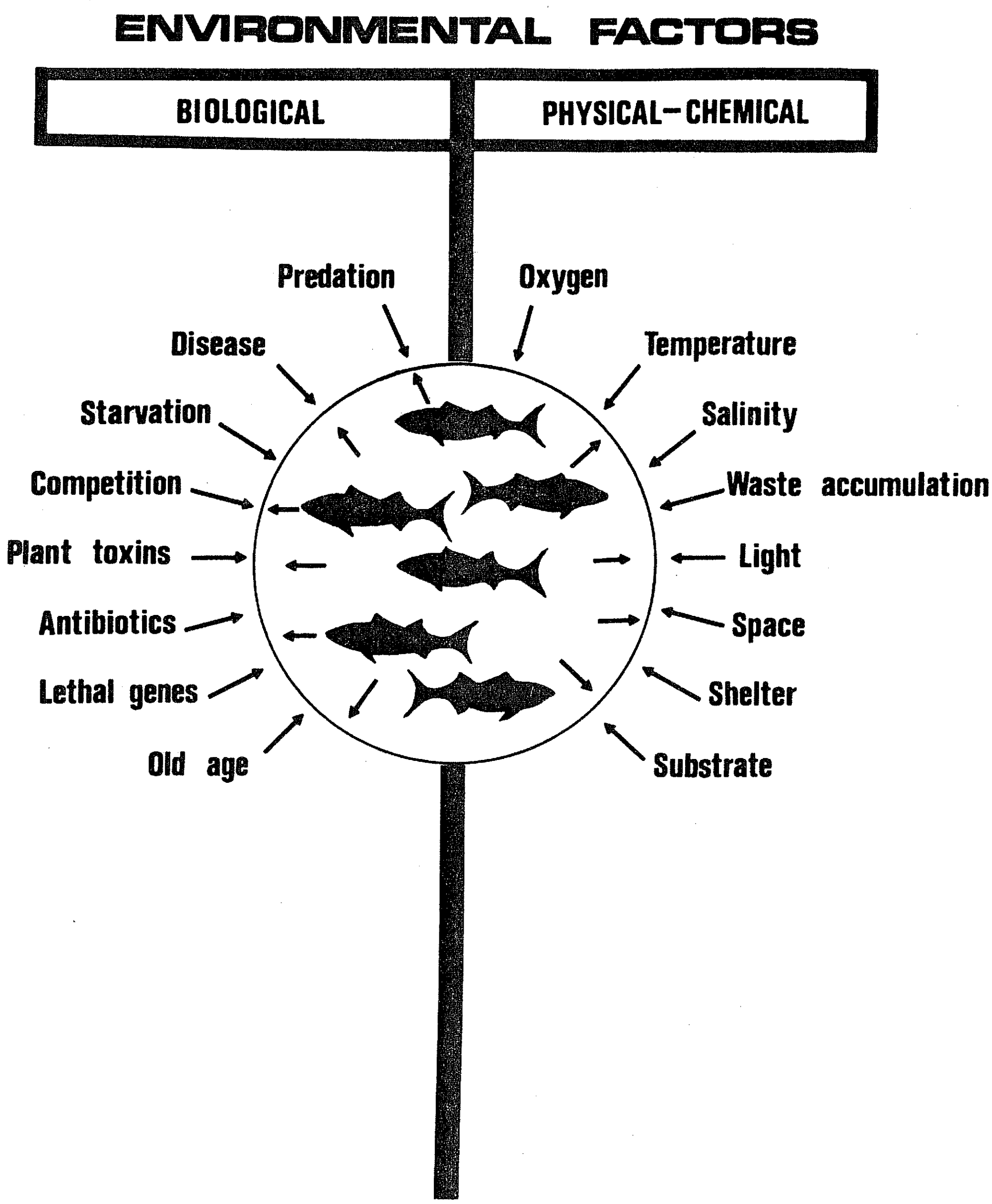


Figure 11. Environmental factors affecting survival in the marine environment.

Some of the environmental forces are density-dependent (variable with size of the population) while others are density-independent. Population size may be determined by representatives of either category. Each factor can vary temporally and spatially, and may act separately or synergistically with other factors. Density-dependent mortality includes any factor of mortality whose effectiveness increases or decreases with stock density (Ricker, 1954). When mortality increases with stock density it is called "compensatory", and when it decreases with stock density it is called "depensatory". Factors which have been considered important to survival of herring include egg size, availability of food, predation, temperature, salinity, transport of larvae by ocean currents, and disease. Each of these will be considered in the following subsections.

Before attempting to isolate and discuss each environmental factor, it should be noted that survival of spawned eggs and survival of larvae are matters of greatest concern. Bottom conditions (temperature, oxygen, currents, substrate for egg deposition, and predator abundance in particular) are critical to survival of eggs. Temperature can accelerate or retard rates of development; oxygen levels are important to normal embryonic development, and may be low at the bottom of thick layers of eggs; bottom currents can affect gas exchange of developing eggs, and the dispersion of newly hatched larvae; substrate can be important to egg survival since a three-dimensional algae-covered boulder/rock surface should result in higher survival than a level sand/gravel surface; and predator abundance can determine how many eggs survive to hatching.

Emphasis should also be placed on larval survival, since larval mortality is usually considered a dominant factor in determining year class strength. Primary causes of larval mortality are considered to be predation and starvation (Lough and Grosslein, 1975), but other environmental factors may be significant, and will be considered.

Mortality of newly-hatched larvae is high, with declining rates during winter and early spring (Graham et al., 1972a, 1972b; Graham, 1973). One clearly defined critical period in survival is when the yolk sac is finally absorbed; availability of food of the proper size is crucial at that point. Mortality rates for newly-hatched larvae on Georges Bank were estimated by Graham and Chenoweth (1973). The estimated rate was 75% for the four days of observation, which meant that 18% of the larval population died each day. The authors attributed the high mortality rate to the possibility that many larvae did not survive the transition from yolk sac absorption to feeding -- pointing out that a similar explanation had been offered by Dragesund and Nakken (1971) to explain high larval mortality of Norwegian herring. A recent estimate of seasonal average larval mortality rates of 3-5% per day was reported by Lough (1978) from analysis of 1971-1975 ICNAF larval surveys.

Survival of larvae through the winter, when environmental conditions are severe and food may be scarce (Blaxter, 1962; Chenoweth, 1970; Graham and Davis, 1971) may be another critical period in determining year class strength. A 30-day winter mortality of 31 to 50% was estimated by Graham and Davis (1971) for larvae overwintering in estuarine waters of the western Gulf of Maine, and a tentative correlation made between estimated winter mortality and subsequent percentages of two-year-old fish of that year class in the juvenile fishery (Graham et al., 1972). Lough's recent analysis also indicated annual variations in winter larval mortality rates; the 1975 winter rate was significantly lower than 1973 or 1974.

3.3.1 Egg Size

Egg size can influence survival. Hempel (1965) found that size of eggs varied among the European herring stocks, and seasonally within stocks. Egg size declines as the spawning season progresses (Hislop, 1975) and size is inversely proportional to temperature (Ware, 1975a). Several authors (Hempel, 1964; Blaxter and Hempel, 1963) have argued that larger eggs have greater survival potential since (1) if an egg is larger, fewer organisms can ingest it, (2) greater yolk content prolongs the period that larvae can survive without food after hatching, and (3) larger larvae are produced, and their feeding ability is enhanced by their being able to feed on larger prey (Lett, 1976). Hempel and Blaxter pointed out that smaller larvae, hatched from smaller eggs, are usually produced during warmer months, when small food organisms are more abundant; larger larvae, with greater yolk content, are hatched in winter when food is scarce -- especially the larval copepods.

3.3.2 Availability of Food

Availability of food of a proper size is logically an important factor in larval survival, but the degree of its importance is somewhat uncertain. Hjort (1926) considered starvation of larvae to be the most significant negative determining factor in year class strength; Lough (1976) considered starvation and predation to be important factors in survival. Other authors (considering other fish species) have concluded that variations in food supply explained only 25-57% of variations in larval abundance (Corlett, 1965; Grauman, 1973; Ehrlich et al., 1976). An important aspect of inadequate food supply (as pointed out by Lett (1976) and others) is that when larvae starve they lose their ability to eat and become more vulnerable to predation, and after a week or so of starvation they reach a point of no return.

Working with anchovy larvae, Lasker (1975) found that the actual biomass of food organisms was not as important as the distribution of particles. The anchovy larva, when feeding begins, needs to encounter particles at a critical density. Food organisms are concentrated in layers that provide such a density but the layers can be broken up by storms and may take some time to reform. Larvae may not survive such disruptions.

3.3.3 Predation

Looking at the real world of natural mortality, death, early and sudden, is the rule rather than the exception. Egg mortality before hatching can reach 80% (Runnestrom, 1942). This can be due in part to inadequate oxygen, as successive layers of eggs are deposited; or to predation by species such as haddock, pollock, cunner and cod, or even herring; or to genetic abnormalities that preclude normal embryonic development and hatching (Figure 12). It should be noted though that some estimates of egg mortality (other than predation) from underwater observations in the western North Atlantic have been remarkably low -- less than 1% (Pankratov and Sigajev, 1973; Caddy and Iles, 1973; Cooper et al., 1975).

Predation on spawned eggs was estimated earlier from numbers of eggs found in stomachs of haddock and estimates of the numbers and sizes of fish present on spawning grounds (Tibbo, 1970b). A more direct estimate was made by Caddy and Iles (1973) using submersible observations. They concluded that about 8% of spawned eggs had been removed by predators within 1-2 days of deposition.

Those eggs that actually hatch may produce some larvae that are abnormal and do not survive. Predation on early larvae by planktonic crustaceans, chaetognaths, salps, and other coelenterates, and fish (including herring) can be extensive and variable, depending on abundance of predator populations in the area (Figure 13).

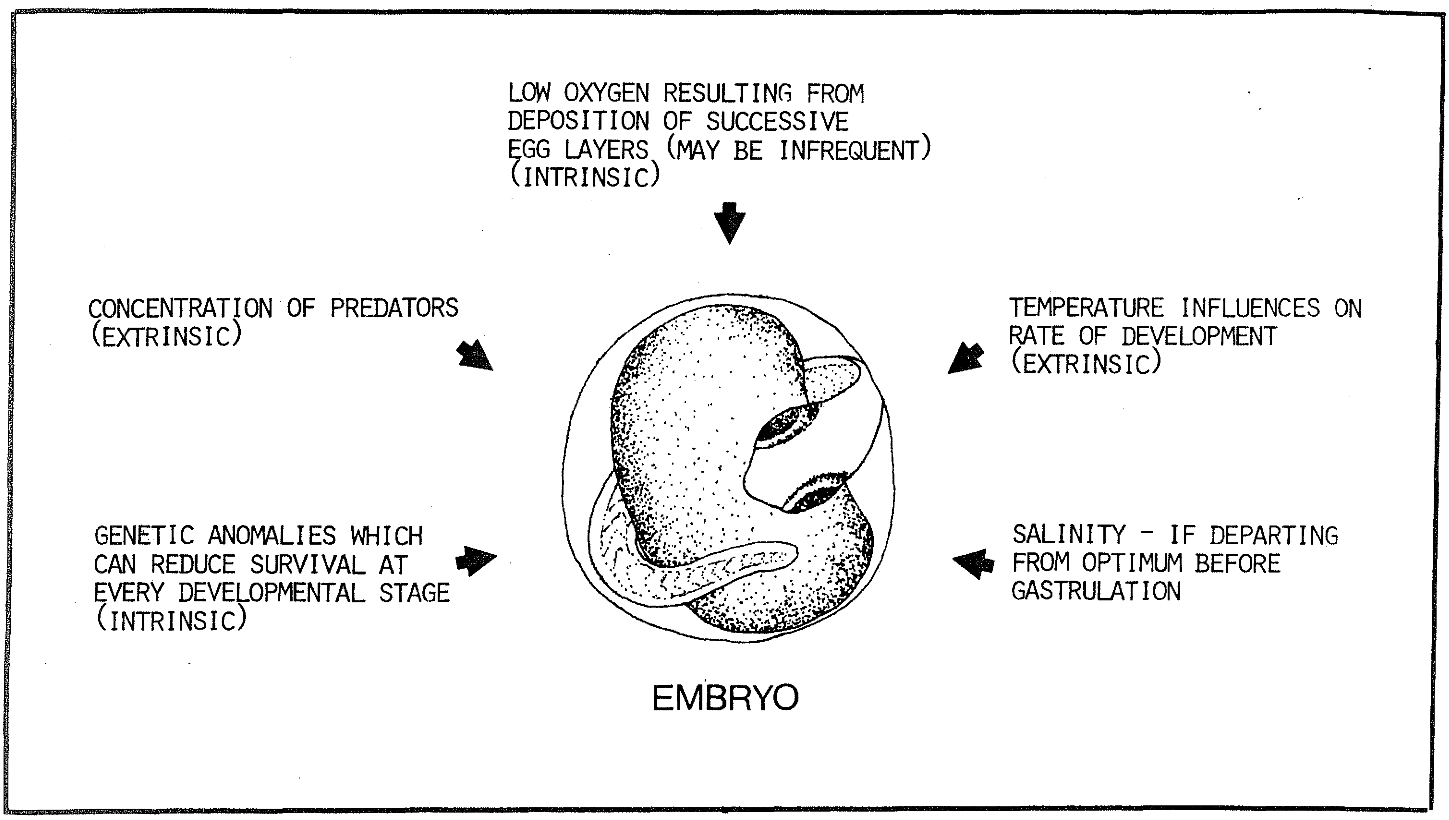


Figure 12. Some extrinsic and intrinsic population control measures operative during embryonic development.

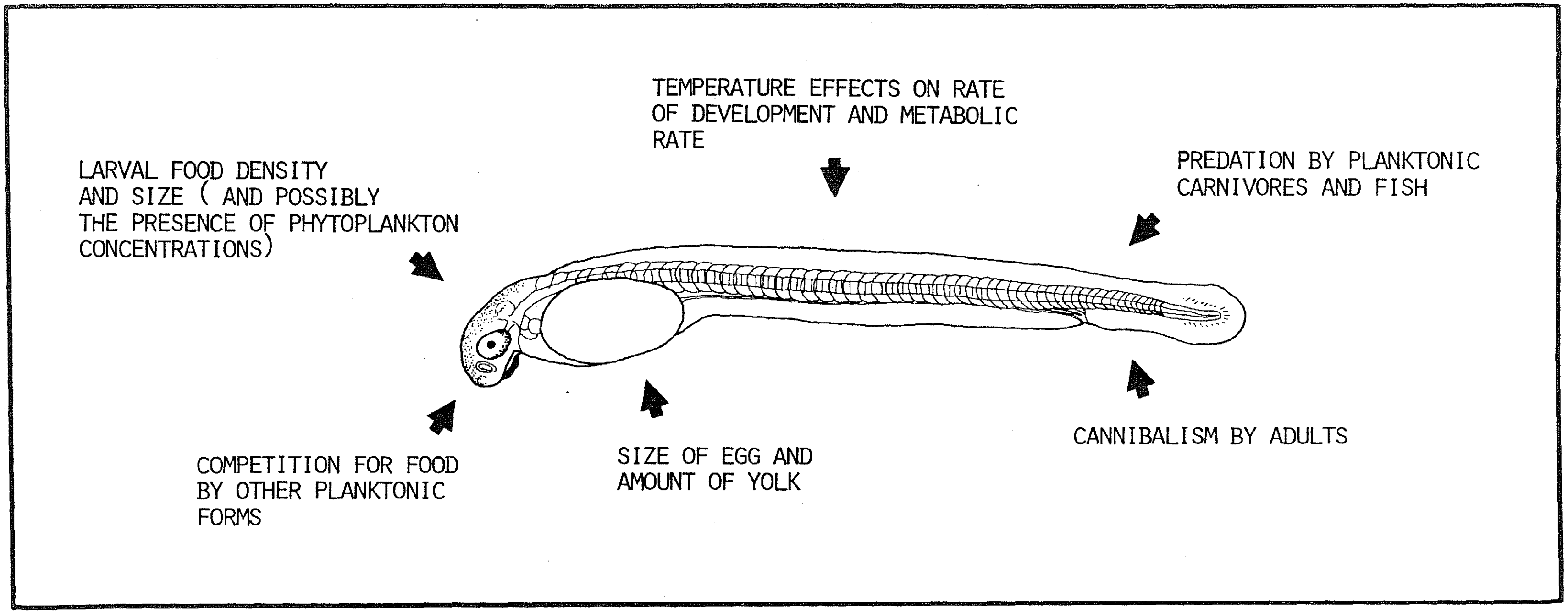


Figure 13. Some factors affecting larval survival.

Larvae are preyed upon by a number of other planktonic forms, notably chaetognaths, larger copepods, and euphausids (Theilacker and Lasker, 1974). Swimming ability is therefore a critical factor. Formation of the caudal fin, at about 15 mm, greatly increases swimming performance (Blaxter, 1962), hence ability to escape other weakly-swimming forms. Larvae are also preyed upon by juvenile and adult fishes of many species.

Eggs and larvae are also cannibalized by adult herring. Spent herring on spawning grounds have been observed by the author with eggs in their stomachs, as have adult herring with larvae in their stomachs. This may be a mechanism to adjust year class size to carrying capacity of the environment. However, as Sissenwine (personal communication) pointed out, cannibalism is a compensatory process which should stabilize population size; extreme fluctuations in year class strength observed in this species would seem to contradict the significance of this form of predation on eggs and larvae.

After metamorphosis, young juvenile schools in coastal waters are preyed upon by other fish, particularly pollock, cod, silver hake, and dogfish; by marine mammals (seals and whales); and by fish-eating birds. Juvenile schools in shallow coastal waters are often literally driven ashore and stranded by predator pressure (Figure 14). This is a particularly common

Figure 14. Mass mortality of juvenile herring at West Southport, Maine, as a result of stranding.

phenomenon when the year class is abundant. Where estimates of early mortality have been made, a mortality during the first year of life on the order of three to five log intervals has been found (Gulland, 1965; Bannister et al., 1975; Cushing, 1974; Ware, 1975b).

Predation continues to be a significant mortality factor for adult herring, with particular pressure at spawning time. Diver observations by Cooper et al. (1975) disclosed that bluefish, cod, and pollock were voracious predators on spawning concentrations in the southwestern Gulf of Maine, with maximum activity at night. Other significant predators of adult fish are larger oceanic predators such as tuna and billfish.

Herring are considered to be an extremely important "forage" species because of their numerical abundance and schooling behavior. The importance of this role is clearly seen in coastal waters, where silver hake, pollock, and dogfish encircle the school, with seals and whales supplying additional pressure, and with fish-eating birds circling overhead.

3.3.4 Temperature

Temperature is a major influence at all stages in the life history of herring. It can affect larval survival in a number of ways. Seasonal changes in temperature affect the abundance of larval food organisms, and thus the rate of growth of larvae. Higher environmental temperatures and high food abundance result in more rapid growth, reducing the time when larvae move weakly as part of the zooplankton, hence reducing predation. Synchronization of larval life history with food production can be of great significance in survival (Cushing, 1975). High environmental temperatures may result in abnormal jaw development -- hence impairment of feeding performance of larvae (Alderdice and Velsen, 1971).

Temperature is an obviously important environmental factor for survival of Georges Bank and Gulf of Maine herring. Significant aspects are locations of thermal fronts between colder less saline shelf waters and warmer more saline slope water. Onshore and offshore excursions of the fronts have been and are being recorded (Ingham, 1974). The location of the front may also be affected by Gulf Stream eddies (Bumpus, 1975).

Major offshore excursions and onshore intrusions of the shelf water/slope water boundary have occurred -- including intrusions which have covered a significant part of Georges Bank during the autumn spawning period for herring. Progressive intrusions of bottom water) presumably slope water) with temperatures above 8°C into the Gulf of Maine since 1971 have also been reported by Davis et al. (1975). Temperature variations resulting from such intrusions may well influence spawning.

Marked temperature variations on Georges Bank were found by Schlitz (1975), examining data from 1971, 1972, and 1973, and by Davis (1978) for data from 1963 to 1975. Two major areas of low temperatures -- the eastern edge of the Bank and the northern part of Great South Channel -- occurred from September to December in all three years examined by Schlitz. The shelf water-slope water front, defined by a sharp gradient of temperature, salinity, oxygen and nutrients, occurred along the southern edge of the Bank in all three years, with only minor intrusions. West of the Bank, the front was found in the Nantucket Shoals area often to the 60 m isobath -- showing greater penetration of oceanic waters in that area. Schlitz also found sharp rises in temperatures at 100 m through the autumn -- above the long-term mean rise. This may have been part of a longer-term trend of increase in temperatures on the continental shelf in the past several years. Other authors have made similar observations. Konstantinov and Noskov (1975) found a warming trend for waters off New England since 1966.

Looking more specifically at the possible relationship of water temperature at time of spawning with recruitment in subsequent years, Anthony (1972) "obtained a significant regression relating percent change from spawning stock to recruitment, and the temperature at the time of spawning (October)". In a later paper Anthony (1977b) summarized his interpretation of the relationship of temperature and Maine sardine catches. He noted that September-March temperatures rose in the 1940's to a peak in 1953-1954, then declined to 1967-1968. Maine herring catches followed the same general trend (Figure 15) -- with high catches in general correlation with high temperatures. However, the relationship disappeared beginning in 1968-1969, when temperatures increased, but catches continued to decline.

3.3.5 Salinity

Salinity can affect early development. Extremes of salinity -- high or low -- can damage herring eggs (Holliday and Blaxter, 1960). Immediately after spawning, the egg membrane is freely permeable; osmotic regulation begins after gastrulation. Thus the post-gastrulation stages are more tolerant to salinity changes. Temperature can affect hatching success and also influence effects of salinity changes on survival of eggs (Blaxter, 1956; Alderdice and Velsen, 1971). Hatching success was greatest at salinities of 1.5-4.5 o/oo, and at temperatures of 9-14°C in one series of experiments (Blaxter, 1956, 1965).

3.3.6 Ocean Currents

Characteristics of water masses on the continental shelves of the western North Atlantic are obviously important to the herring and other populations that inhabit these areas. Seasonal temperatures and currents at all depths can affect spawning and

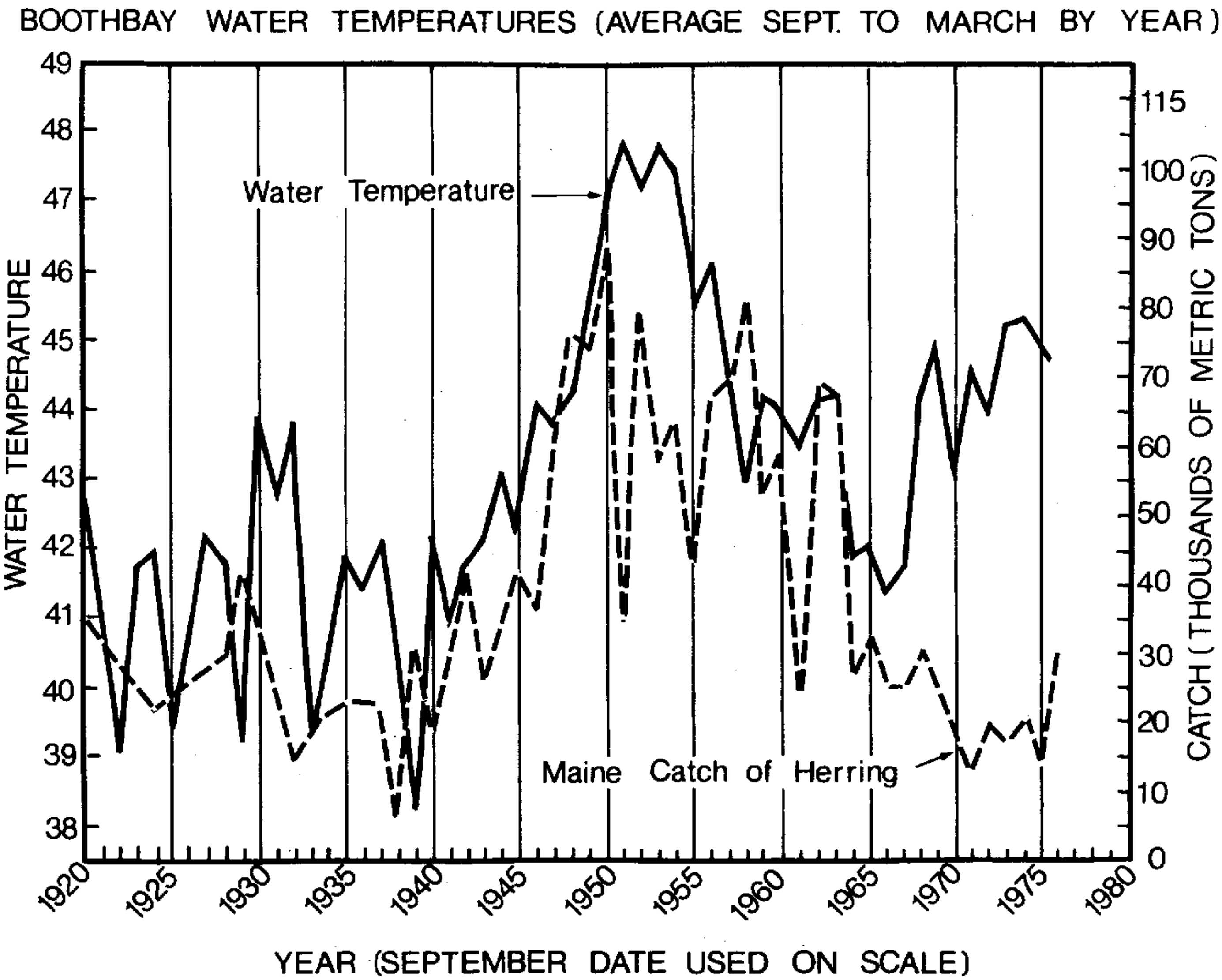


Figure 15. Water temperatures at Boothbay Harbor, Maine, and catches of juvenile herring on the Maine coast 1920-1975 (from Anthony, 1977b).

survival, and can play a role in movements of all life stages, particularly larvae. The physical oceanography of Georges Bank and the Gulf of Maine began with the work of Bigelow (1927) and continued with contributions of Bumpus and his associates (Bumpus and Lauzier, 1965; Bumpus, 1973, 1975).

Bumpus (1975) in summarizing the present state of knowledge about circulation patterns in the area of concern to this paper, said "...we still have only an approximate understanding of the circulation over Georges Bank, and many other continental shelf areas for that matter". Despite this, there is much that is known about the area.

Gulf of Maine circulation has been described in several papers (Bigelow, 1927; Bumpus and Lauzier, 1965; Bumpus, 1973), based principally on results of drift bottle, drifting buoy, and sea-bed drifter analyses. Principal features include:

(1) Winter circulation is characterized by (a) inflow across Browns Bank and the eastern Gulf of Maine into the Bay of Fundy, (b) a southerly flow along the western Gulf and past Cape Cod through Great South Channel, and (c) development of a divergence zone north of Georges Bank by February.

(2) The counterclockwise Gulf of Maine eddy develops rapidly in spring and is well established over the entire Gulf by late May, with a continuing indraft

on the eastern side from the Scotian Shelf and Browns Bank (Figure 16). The eddy begins to decay in June. By autumn the southern edge of the eddy has broken down to a drift across Georges Bank.

(3) Inferences from bottom drift across Georges Bank along the western edge of the Gulf flows are toward shore, while further offshore the bottom drift is westerly.

Features of coastal circulation in the Gulf of Maine that may be important to transport and survival of larval herring were examined by Graham (1970b). The principal findings were that net drift was from east to west along the coast, and predominantly shoreward, under the influence of winds, dynamic pressure gradients, Coriolis force, and bottom topography. These water mass movements are important since they transport and accumulate larvae and plankton inshore and into estuaries during the autumn-winter months.

Relevant aspects of Georges Bank circulation are:

(1) It is a submerged flat-topped plateau which profoundly influences ocean currents of the region. Waters over most of the Bank average 40-100 meters but shoal areas are only 5-15 meters.

(2) Turbulence produced by winds and tidal currents causes vertical mixing which results in almost uniform temperature-salinity profiles from surface to bottom at all seasons. This contrasts sharply with the surrounding stratified water masses.

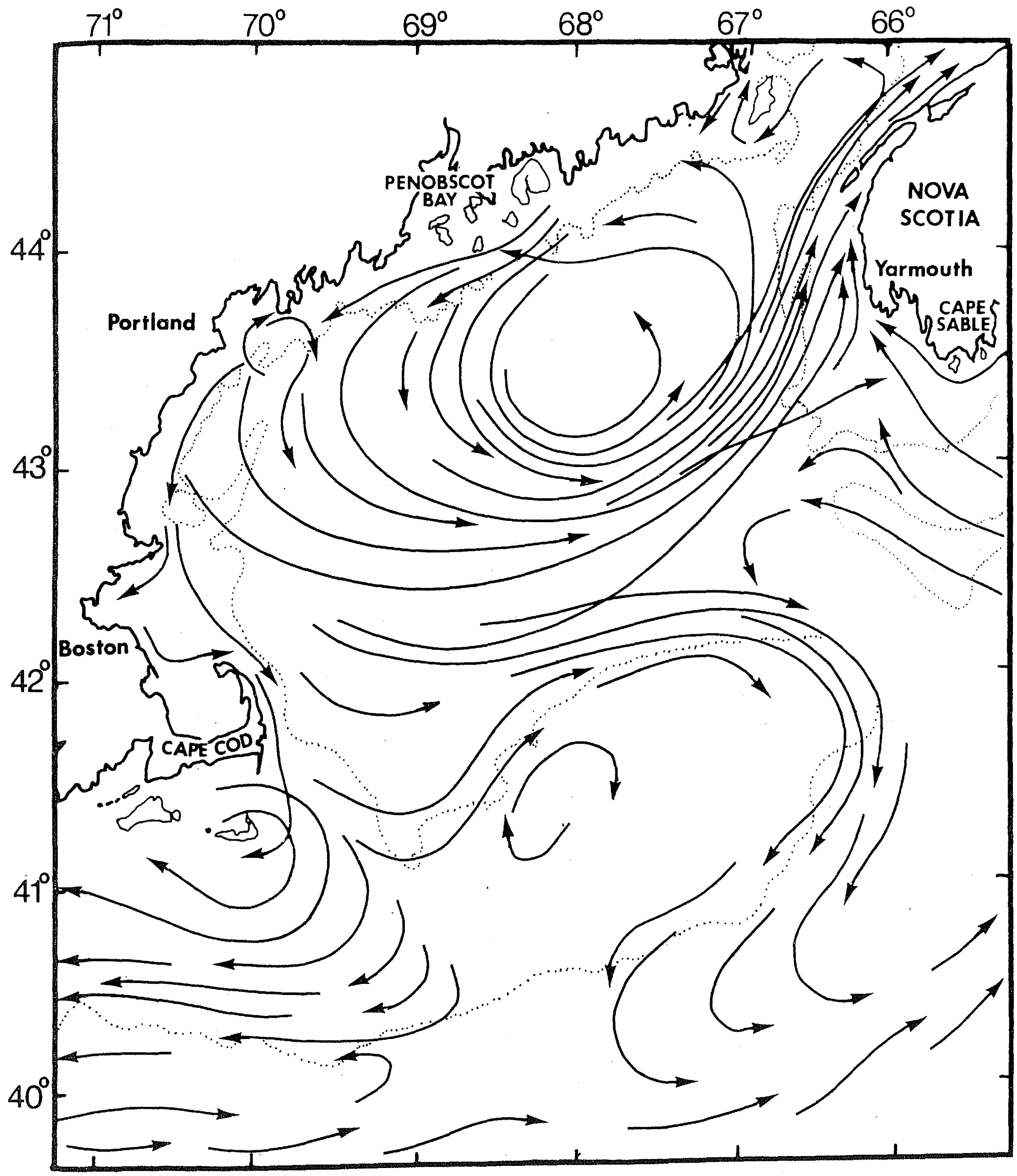


Figure 16. Schematic representation of the dominant non-tidal circulation of the Gulf of Maine, July to August (modified from Bigelow, 1927).

(3) Circulation is characterized by a southerly flow during winter with a westerly drift along the south side of the Bank; development of a clockwise eddy in spring, with its northern edge adjacent to the southern edge of the Gulf of Maine eddy; a southerly and offshore flow in summer on the eastern side of the eddy; and an autumn decay of the western side of the eddy into southerly and westerly flow (Figure 16).

(4) Few drift bottles or bottom drifters set out on Georges Bank in autumn or winter have been recovered, suggesting that they may be carried eastward into deep water -- a conclusion supported by drifting buoy studies (Bumpus, 1975).

(5) Surface water movements over the Bank respond to short-term wind effects (Chase, 1955; Beardsley and Butman, 1974), which dominate the circulation during winter.

The dispersion of larvae resulting from Georges Bank spawning in 1956 and 1957 was analyzed by Colton and Temple (1961). They found that for months when larvae occurred in the upper water layers, surface drift over Georges Bank was offshore in the direction of the slope water boundary -- indicating that larvae in the surface layers would be carried away from the Bank and presumably lost to the fishery. The authors pointed out a number of possible mitigating factors, particularly the possible differences in direction of deeper currents, as compared to wind-influenced surface currents. They also pointed out that the slope water band off the southern edge of the Bank would carry entrained larvae to the northeast, and that the temperature change between water masses could be lethal to larvae -- a situation that had been demonstrated for larvae of other species (whiting and yellowtail flounder) by Colton (1959).

The general conclusion reached by Colton and Temple was that hydrographic conditions over Georges Bank during the autumn are not favorable for retention of larvae over the Bank or for a drift into the Gulf of Maine; that under average conditions most larvae are carried away from the Bank in the direction of the slope water zone; and that egg production is always sufficient to produce a strong year class, but that mortalities of larvae due to drift into unfavorable zones (and other factors) are such that only a small percentage survive.

These conclusions about larval drift are somewhat different from those reached in a more recent analysis. The dispersion of larvae resulting from Georges Bank spawning in 1972, 1973, and 1974 was examined by Bumpus (1975). His general conclusions were that larvae <u>were</u> retained within the shelf water; that the area occupied expands as larvae grow, due to tidal stirring and advection principally toward the west, except for a northeasterly drift from Georges Shoal. Bumpus left open the possibility that some larvae may drift off the southeast edge of the Bank, and that Gulf Stream eddies may entrain shelf water (and contained larvae) along their periphery.

3.3.7 Disease

Herring stocks of the western North Atlantic have been ravaged periodically by epizootics of a systemic fungus pathogen, *Ichthyophonus hoferi*. Outbreaks of the disease have occurred in the Gulf of Maine in 1932 and 1947, and in the Gulf of St. Lawrence in 1898, 1916, 1940, and 1955 (Sindermann, 1963a, 1970).

The most recent fungus epizootic and associated mass mortalities occurred in the Gulf of St. Lawrence from 1953 to 1957 (Leim, 1955; Sindermann, 1958). From disease prevalences in 1955 and 1956, Sindermann estimated that at least half the herring of that Gulf were killed -- an estimate supported by the reduction in catches in the years immediately following the mortalities. A later examination of Gulf of St. Lawrence herring (Tibbo and Graham, 1963) indicated that spring spawning stocks were more severely affected than autumn spawning stocks. Parsons and Hodder (1975) suggested that the consequent reduction in predation and competition (since mackerel were affected also) undoubtedly provided conditions that were favorable for larval survival and the production of good year classes in 1958 and

and 1959, and that the consequent great abundance of these two year classes as juveniles during 1959-1962 and then as adults inhibited opportunities for good survival of young for several years thereafter. Poor recruitment to exploited stocks after 1959 led to a drastic decline in the southern Gulf of St. Lawrence herring fishery beginning in 1971-1972, once the strong 1958 and 1959 year classes had passed through the fishery (Parsons and Hodder, 1975).

Other diseases and parasites of herring are known (Sindermann, 1970) but thus far, except for the fungus disease, there is only one report that suggests that parasitism may affect abundance. Rosenthal (1967) described mortalities of larval herring in aquaria due to nematode, cestode and copepod parasitization. Larval helminths, acquired from feeding on wild plankton, caused the herring to stop feeding, resulting in death. Ectoparasitic copepods (Lernaeocera) caused decrease in swimming activity, cessation of feeding, and death of larvae. About 10% of the larvae were parasitized and killed in one experimental series. Of course it is unlikely that this intensity of parasitization would prevail under natural conditions, but it is important to note that even a single parasite, which would not be of great significance to juvenile or adult fish, is capable of killing its larval host.

3.4 INTRA- AND INTERSPECIES INTERACTIONS

The ecological interactions of herring are principally those related to its role as an important forage species for many predatory fishes, aquatic mammals, and fish-eating birds, and as a significant competitor to other plankton-eating fishes. The complexity of the food web interactions of herring has been effectively visualized by Hardy (1959) (Figure 7). Interspecies competition for food (and to some extent space) is probably underestimated in this figure; herring compete with other pelagic plankton-feeding schooling fish such as mackerel, alewives, blueback herring, pollock, and shad. The extent of interspecies competition will of course vary with species, with geographic abundance of competing species in any local area, with relative sizes of representatives of competing species in any local area, and with food preferences of the competing species. For example, 0-age-group mackerel compete seriously with immature herring for food in the Gulf of St. Lawrence, but mackerel in their second year of life compete less, since they filter feed on smaller particles at that age (Lett and Kohler, 1976). Conversely, species such as alewives and blueback herring compete as juveniles with juvenile herring in inshore waters, and as adults compete with adult herring in waters further offshore.

It is clear that survival and year class abundance are resultants of complex variables. Attempts have been made for decades to identify the most significant of these variables, to associate abundance changes with changes in the variables, and to create simulation models that attempt to explain interrelationships.

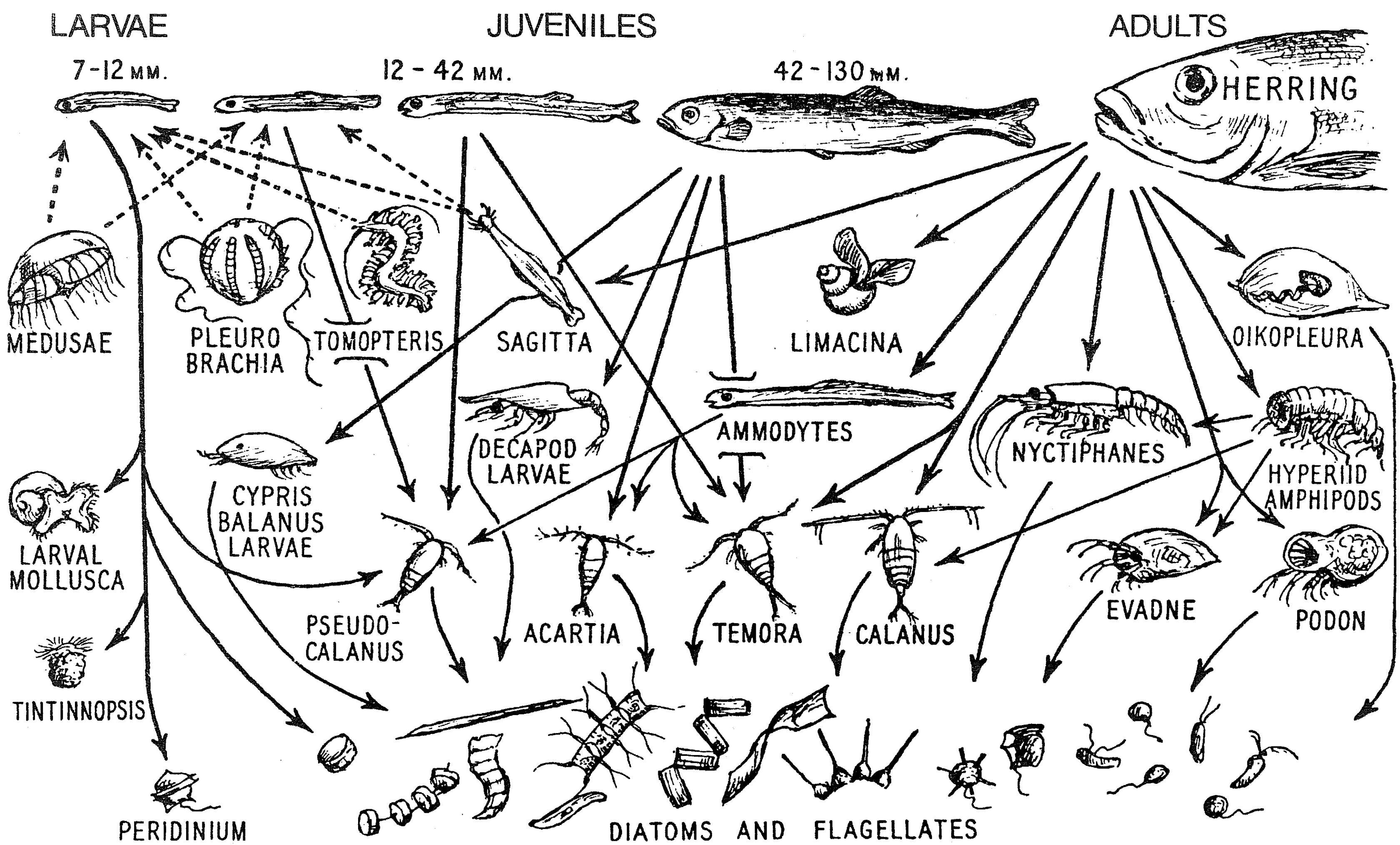


Figure 17. Feeding relationships between herring of different ages and the members of the plankton (modified from Hardy, 1959).

Significant among the summarizing contributions to understanding of recruitment was that of Ricker (1954). His thesis was that recruitment was a continuum, reflecting fecundity of the adult stock as modified by interspecific competition and cannibalism by the parent stock. Other authors have stressed the effects on larval survival of temperature, predation by other than the parent stock, epizootic disease, and starvation.

Some authors have found positive correlations between adult stock biomass and abundance of herring larvae (Cushing and Bridger, 1966; Burd and Purnell, 1973; Postuma and Zijlstra, 1974; Saville et al., 1974), but the correlations usually do not explain more than 60% of the observed variation in abundance. An additional part of the variation may be explained by changes in fecundity related to food availability and energy intake by the adult stock (Lett and Kohler, 1976). Another part of the variation in larval abundance may be explained by changes in temperature (Postuma, 1971; Postuma and Zijlstra, 1974). In their studies, abundance of spring-spawned larvae was positively correlated with temperature, while abundance of autumn-spawned larvae was negatively correlated. Effects could have been mediated through eggs or larvae or larval food supply, or combinations of these.

The relationship of herring spawning stock size and larval production in the western North Atlantic has been examined recently by Lough et al. (1979) from two viewpoints:

(1) estimating spawning stock size by back-calculating from larval abundance; and

(2) detecting major variations in egg mortality and/or hatching success based on reasonably adequate data on size and reproductive potential of the spawning stock.

Lough et al. examined data for the period 1968 to 1977 in three areas where offshore surveys have been conducted -- Georges Bank-Nantucket Shoals, Western Gulf of Maine, and Southwestern Nova Scotia (Lurcher Shoals). Their preliminary findings include:

(1) Estimates of larval production for 1972 to 1977 correlate fairly well with spawning stock size based on virtual population analysis (recognizing the limitations of virtual population analyses since 1973).

(2) Georges Bank larval production before 1972 seems to have been much lower relative to estimated spawning stock size than in recent years -- implying that egg survival may have been lower when density of spawners was higher.

(3) Initial abundance of larvae (September to December) was not correlated with subsequent year class success.

(4) Limited evidence from winter (December to February) larval surveys suggests some correlation of larval survival and year class abundance -- a finding similar to that of Graham (personal communication) that a relationship existed between over-winter survival rate of larval herring in the Sheepscot estuary and year class abundance in the Maine sardine fishery.

It should be clearly understood that these conclusions are preliminary, and are included here principally to indicate the direction of present thinking, based on extensive surveys of the area of concern to this report.

It is generally accepted (though not adequately demonstrated) that the abundance of a year class is largely determined during larval existence by a combination of density dependent growth and density dependent mortality (Cushing, 1974). Some studies of 1+ herring failed to show density dependent growth -- which is not unreasonable since, as Lett and Kohler (1976) and Lett et al. (1976) pointed out, "herring feed on small particles with high turnover rates, so a severe depletion of standing stocks of zooplankton through excessive grazing seems implausible unless there are dramatic increases in the grazing rate". Such increases in grazing rate can apparently result from good year classes of mackerel feeding in the same area. Lett and Kohler (1976) found that growth rate of 1+ herring in the Gulf of St. Lawrence declined rapidly in response to an increase in abundance of the 0 group mackerel year class, probably since they compete for zooplankton of the same particle size. However, when the mackerel return in their second year of life they filter-feed on particles smaller than those eaten by herring, and compete very little with them. It should be noted that herring growth changes are not explained by size of overall mackerel biomass -- only by size of the 0 group.

Density dependent growth of 0-group herring has been established for North Sea stocks, and Lett and Kohler (1976) also found a density dependent growth relationship with year class size in Gulf of St. Lawrence herring.

Anthony (1971) also concluded that growth of juvenile herring on the Maine coast during the first two years of life was density dependent -- mediated of course by regional differences in plankton abundance and water temperature. If these observations are coupled with Burd's (1962) hypothesis that the length of herring at the end of the first year of life results in marked length differences later in life, and with the premise that maturity is a fixed function of length, then the conclusion can be, as Lett and Kohler stated, that future year class sizes are regulated by the present ones, since variations in length can affect age at maturity and hence total egg production for individual fish for their entire life span.

Unfortunately, the population biomass stability suggested by this mechanism must be modified by extrinsic factors such as effects of temperature and effects of 0-group mackerel abundance on herring growth. Lett and Kohler (1976) concluded by suggesting that only under unusual conditions will length at the end of the first year of life vary enough to make density-dependent growth observable.

Another extrinsic factor is of course reduction in stock biomass by intensive fishing. Anthony and Waring (1978) reported that while density dependent growth was exhibited by Gulf of Maine juveniles of the 1957 to 1966 year classes (with the good year classes of 1958, 1960, 1961, and 1963 having the slowest growth and the poor year classes of 1959 and 1962 having the fastest growth), this density dependent relationship disappeared completely beginning with the 1968 year class. All year classes grew rapidly, even the very strong 1970 year class -- possibly because of the drastic decline in overall stock biomass.

A broader analysis of the species interactions of herring and other pelagic fishes of the western North Atlantic was recently completed by Grosslein et al. (1978). Major aspects considered were: herring-mackerel interactions; predation on herring by other species, and changes in demersal-pelagic biomass.

Since herring and mackerel are the principal pelagic species in the western North Atlantic, and since their food habits are similar, the entire spectrum of interrelationships is important. According to Grosslein et al. the biomass of herring and mackerel declined from a peak abundance of 3.7 million tons in 1968 to about 1.4 million tons in 1975. A principal part of the biomass decline was due to decrease in herring abundance, which began in the late 1960's. The mackerel, however, increased in abundance at about the time when herring stocks declined precipitously, due to the strong 1967 mackerel year class. The mackerel stock then declined rapidly after 1972.

Grosslein et al. examined the feeding relationships of herring and mackerel by examination of gut contents of samples from Georges Bank. They found no evidence that adults of either species preyed on larvae of the other -- but pointed out that their data do not prove that such predation does not occur at other life stages or in other locations.

The strongest recent year class of herring (1970) was produced at a time when mackerel biomass was high. At present (1978) both species are at a low level, suggesting (as Grosslein et al. pointed out) that "there are other factors than mackerel-herring predation that are influencing the biomass of these two species, most likely fishing pressure perhaps in combination with environmental factors".

Grosslein et al. also examined the relative biomass of pelagic and demersal fishes on Georges Bank, to see if major shifts in species composition and abundance from pelagic to demersal, comparable to those reported by Jones and Richards (1976) and Hempel (1977) for the North Sea, could be recognized in the western North Atlantic. The biomass of principal pelagic species on Georges Bank during the late 1960's was more than twice that of other finfish and squid, but by 1975 these two components were almost equal in biomass. Grosslein et al. concluded that it is unlikely that the decline in herring and mackerel stocks could be due to predation or competition by other finfish since most of the demersal finfish predators were also declining. The general observation was that except for increases in squid and sand lance, and decreases in herring, the overall composition of the finfish community had changed relatively little. The definitive statement (insofar as herring are concerned) was "...as yet there has been no consistent trend of increased recruitment of a number of species (e.g., gadoids whose larvae or juveniles depend on primary planktonic carnivores which make up a significant part of herring and mackerel diet) comparable to that which has been observed in the North Sea".

3.5 SIMULATION MODELS

A simulation model developed by Lett and Kohler (1976) stressed predation by mackerel and adult herring as important factors affecting larval production. They placed much emphasis on cannibalism of larvae. Results of their simulation studies were summarized as follows:

> "When there are surplus larvae resulting from a large adult stock, the result is a smaller-than-average year class in reply to overcropping by the stock that produced them. The smaller year classes lead to lower larval production, lower density-dependent predation, thus larger year classes. Therefore, density-dependent mortality through predation is a control mechanism that serves to produce a tendency toward optimal year class sizes".

Intuitively, cannibalism as an overriding mechanism for population regulation seems unlikely, and available published observations of extensive cannibalism by adults are few. In the author's experience, stomach contents of post-spawning herring occasionally consist of herring eggs and larvae -- but only occasionally. Since herring feed opportunistically, and since adult herring leave spawning grounds soon after the spawning period, contact with newly hatched larvae should be minimal. Of course the subsequent dispersal of older larvae could be to areas where adults are also found, so the spatial separation is by no means absolute.

It seems much more plausible to postulate mechanisms of survival that emphasize intraspecific and interspecific (with mackerel) competition for available food, and predator aggregation in areas of high larval density (this would be density-dependent predation but not cannibalism).

Some of the conclusions from Lett and Kohler's simulation model were:

(1) "Predictions of small year classes based on larval abundance will be much more reliable than predictions of larger year classes". Any estimations of year class size based on abundance of larvae less than 10 mm are particularly hazardous.

(2) "Recruitment is independent of stock size over a fairly wide range" (which agrees with the observations of others), and that "the only time any pattern in a stock recruitment diagram emerged was when the fishery was collapsing" (which also agrees with conclusions reached by others).

(3) "Once the year class formation loses its association with density-dependent predation, then the recruitment process is almost completely at the mercy of the effects of temperature on larval abundance".

(4) The total pelagic biomass of an area such as the Gulf of St. Lawrence is fixed within narrow limits such that the total remains fairly constant. Lett and Kohler (1976) stated: "Much of the decline in herring biomass in the Gulf of St. Lawrence between 1962 and 1972 may not have been due entirely to overfishing, but rather the results of increased proliferation of mackerel. Therefore, the management of mackerel may be as important as the direct manipulation of the herring stock in determining the available biomass for exploitation". Herring and mackerel cannot be exploited at an optimum level simultaneously.

Such simulation models as those of Lett and Kohler can be informative and stimulating, but must be tested over a long period against observed changes in environmental factors and changes in abundance. The models must also take into account the differences in ecosystems, when, for example, herring of the Gulf of St. Lawrence are contrasted with herring of the Gulf of Maine.

A thoughtful recent attempt to develop a conceptual model for herring stocks of the Gulf of Maine was published by Ridgway (1975). Environmental factors and stock-recruitment relationships logically constituted the focus of his attention. Most critical to a model, of course, are the premises on which it is based. Ridgway listed those for the herring stocks under consideration as:

(1) The three stocks are considered independent in terms of stock-recruitment and survival through the first year of life, with some density-dependent competitive interaction in terms of effects on growth and fecundity.

(2) The only variable significantly affecting survival beyond age 1 (except for density-dependent effects on growth and fecundity) is fishing mortality. (Ridgway also mentions possible catastrophic mortalities due to epizootic disease as another exception).

(3) Major causes of variation in natural mortality during the first year of life are variations of biotic and physical environmental factors, but density-dependent mortality also occurs.

(4) Principal biotic variables considered by Ridgway are available food of proper size when larvae begin feeding, synchronization of zooplankton production with increasing metabolic demands of post-larvae, and density of predators.

(5) Principal physical variables affecting survival during the the first year of life are temperature and the stability of oceanic systems dispersing or retaining larvae in suitable nursery areas.

Within the framework of these premises, Ridgway then applied the age-dependent fecundity-survival matrix approach developed and refined by Leslie (1948), Gales (1968), Paulik (1973) and Allen and Basasibwaki (1974). Advantages of this approach, as described by Ridgway, are that various age-specific effects on survival and fecundity can be isolated; and that a computer program is available for simulations, including methods for introducing density-dependent effects and for examining competition between species or stocks. Thus a range of simulation and analytical treatments can be applied, to examine the consequences of environmental changes or various management strategies.

Ridgway then proposed use of various multivariate methods which have been employed in other attempts to relate multiple environmental factors to survival and recruitment (Box and Hunter, 1962; Lindsey and Sandness, 1970; Lindsey et al., 1970; Ramey and Wickett, 1973). The insights developed and the approaches proposed by Ridgway have not been explored further, so it is difficult to predict the conclusions that might be reached. However, in some of the studies cited above -- particularly Ramey and Wickett (1973) physical hydrographic factors were related to recruitment of Pacific herring.

CHAPTER 4

4. HERRING STOCKS OF THE WESTERN NORTH ATLANTIC

CONTENTS

4.1 INTRODUCTION

The distribution of herring in the western North Atlantic extends from Cape Hatteras to Greenland, with a number of centers of abundance (so-called stocks or stock-complexes). Two of these -- Georges Bank and Gulf of Maine are in United States waters, while a third, southern Nova Scotia, contributes to catches here. The stocks can best be described at spawning time, since there is some evidence for intermixing and migrations at other times of the year. Spawning groups of concern to the United States fishery and their principal locations, as summarized by Ridgway (1975), are:

(1) Georges Bank -- with major spawning on the northern edge of the Bank and Nantucket Shoals, with minor spawning on the southeastern part of the Bank and on the east side of Great South Channel. Since 1970, the principal spawning area has shifted progressively westward to Nantucket Shoals.

(2) Gulf of Maine -- with major spawning on the southwestern part of Jeffrey's Ledge. Other spawning areas are Stellwagen Bank, Isles of Shoals; and several small areas off the Maine coast.

(3) Southern Nova Scotia -- with major spawning on Trinity Ledge and Lurcher Shoals, with minor spawning on Grand Manan Bank, the west side of Passamaquoddy Bay, and a number of locations on the Nova Scotia coast from Yarmouth to Halifax.

Since the term "stock" has been used repeatedly, it should be defined, at least pragmatically, as Anthony (1972) has done, as "a group of fish that remain sufficiently isolated so it can be managed as a unit separate from another one". In such a definition there is no requirement for genetic isolation, which would be a more exact description of a subpopulation within a species, nor does a stock have any taxonomic status. The significant question from a management viewpoint is "Are there sufficient distinctions among stocks to justify considering them as different management units?" (or conversely, "is their sufficient homogeneity to justify management as a single unit?") Those responsible for management decisions point out that they manage fisheries, and the location of fisheries suggests that despite some intermingling, management units, corresponding roughly to spawning stocks, do exist. Where the degree of intermixing between units is unknown, the more conservative approach is to manage individual units with a single overall management policy applying to all units. Thus if in fact single isolated stocks do exist, they are protected from overexploitation.

The ultimate utilitarian definition of "stock" might be "a practical management unit that allows fishing mortality to be allocated among discrete groups of fish" (NERFMC, 1978).

A stock may of course be described in biological (genetic) terms as well as in management terms. The existence of significant genetic differences between any two populations implies that there is not freedom of gene flow between them, and that they exist as recognizable entities.

A stock can probably be best defined at spawning times as "those individuals present in spawning aggregations". If members of such spawning aggregations perform known and characteristic migrations after spawning, for overwintering and feeding, then they continue to be identified with the spawning area. If, on the other hand, there is extensive intermingling at times other than spawning, it is difficult to use the term "stock" for such fish in the same sense as a spawning aggregation, since fish from other spawning aggregations may be present as well.

Stocks, then, are a reality at spawning time, when herring with particular characteristics aggregate year after year in quantities that relate to previous years. Intermingling of adults at other times of the year does not completely destroy this concept of a stock. What would be destructive to the concept, however, would be the demonstration that fish which spawned in one major area in one year could spawn in another major area in the next year, or that significant numbers of fish that were derived from one spawning population would themselves spawn as part of a different spawning population. No demonstration has been made one way or the other for stocks of the western North Atlantic.

Ridgway (1975) discussed the hypothesis that the three stocks considered in this paper -- Georges Bank, Gulf of Maine, and Nova Scotia -- are discrete self-perpetuating units in which recruitment from one stock to another is negligible, and in which progeny from one area would spawn only in that area. He argued that if there were sufficient random mixture among stocks, differences in age composition, fecundity, and parasite fauna, as reported by Perkins and Anthony (1969) and

Boyar and Perkins (1971) could hardly be maintained. Potentially the best information, from biochemical studies, was inconclusive, since the frequencies of several variable genetically determined characteristics were very close (Ridgway et al., 1971; Lewis and Ridgway, 1972; Odense et al., 1973), and not all samples were obtained from spawning aggregations at the time of spawning.

Ridgway pointed out that there is some evidence from other areas that herring return as adults to the area where they were spawned (Harden-Jones, 1968; Zjilstra, 1963; Iles, 1965), but that homing mechanisms comparable to those of salmon are difficult to postulate for herring, which spawn in open ocean areas. Maintenance of separate stocks, according to Ridgway, would be dependent on three mechanisms: (1) larval dispersal in a system which maintains early life history stages in shoal nursery areas close to the spawning area, (2) physiological and genetic adaptation to the oceanic regime (home territory) within that area, and (3) schooling behavior, which reinforces directive activity such as searching out appropriate spawning sites within the home territory.

Anthony (1972) also felt that Georges Bank and Gulf of Maine stocks were discrete, based principally on three lines of evidence:

(1) A persistent difference in overall abundance of spawners -- in that the Georges Bank spawning population has been estimated annually to be ten times that of the southwest Gulf of Maine spawning population (the Nova Scotia spawning population is also about as large as that of Georges Bank).

(2) Meristic counts (particularly pectoral fin ray counts) made for the 1958 to 1963 year classes showed significant differences between Georges Bank and Gulf of Maine. Adults from Nova Scotia and Maine had significantly higher pectoral fin ray counts than adults from Cape Cod and Georges Bank. (However, beginning with the 1964 year class, fin ray counts for all stocks increased, due apparently to lower environmental temperatures, and for several subsequent year classes there were no significant differences in the counts).

(3) Consistent differences in growth rates have been found, when Nova Scotia adults were compared with Georges Bank adults.

It seems equally tenable, from the data available, to conclude that there is a large degree of intermixing of the three stocks under consideration, and that progeny from one spawning area could contribute to spawning stocks in other areas. Significant genetic differences among spawning populations have not been demonstrated; and all the characteristics used to show distinctions among stocks are environmentally modifiable (meristics, parasites, growth rates). It seems that one possible mechanism determining distribution and possible intermixing is larval drift. Ocean currents can transport larvae and even post-larvae for great distances. Average seasonal current regimes are known to exist on Georges Bank and in the Gulf of Maine -- regimes which would tend to return progeny to spawning areas -- but significant anomalies occur and these could transport larvae out of the system which normally provides for their retention, and into other areas where they would eventually form part of another stock (Colton and Temple, 1961; Bumpus, 1975).

This kind of intermixing -- with a number of years of average conditions interspersed with occasional anomalous years -- could explain the inability to find genetic differences among stocks, and might explain, for example, the sudden breakdown in 1964 of meristic differences between stocks described by Anthony (1972).

According to this hypothesis intermixing of stocks (other than that which could occur during feeding migrations) would be episodic, with intervening periods of years in which it was minimal. The governing factor would be larval drift -- the major mechanism identified by Ridgway (1975) for maintenance of separate stocks. Gene flow among spawning populations would be reduced, but still sufficient to eliminate the likelihood of readily observable genetic differences among the populations. Differences in environmentally modifiable characters such as meristic counts, parasite frequencies, or growth rates, would be superimposed during juvenile and adult existence, regardless of the origin of the individual.

A significant unknown is the extent to which herring exhibit a homing instinct as they approach maturity. Ridgway (1975) considered this a negligible factor, but even though the likelihood is small, it must not be totally discounted.

From a fishery management point of view, the critical point in determining the extent of intermixing of stocks is of course whether the amount of exchange is sufficient to affect recruitment, and not whether intermixing occurs at all or to some minor degree. If recruitment in one stock can be affected by events in other stocks, then this argues for a more comprehensive and a different kind of management plan than would be needed if the stocks were clearly discrete and non-interactive.

This section of the paper will review the status of our information about stocks and their discreteness (or intermixing), since the problem is one of the most important in management of Northwest Atlantic herring fisheries.

4.2 SPAWNING LOCATIONS AND ABUNDANCE

Herring spawning has occurred during the past two decades at many places around the periphery of the Gulf of Maine (Figure 18), although there is variation in precise location and intensity. If one examines earlier literature (Bigelow and Schroeder, 1953; Scattergood et al., 1959) it is apparent that there have also been long-term trends -- especially a reduction in spawning sites along the immediate New England coast. At present, major spawning sites are Lurcher Shoal and Trinity Ledges, Jeffrey's Ledge and Stellwagen Bank, and Georges Bank and Nantucket Shoals. Minor sites such as Grand Manan, Matinicus, and Pumpkin Ledges, have been reported, but their relative contribution is probably small. There is also some slight indication of minor spring spawning in the Gulf of Maine (Boyar, 1968; Boyar et al., 1973b; Tibbo et al., 1958) but its contribution is probably negligible compared to late summer-autumn spawning.

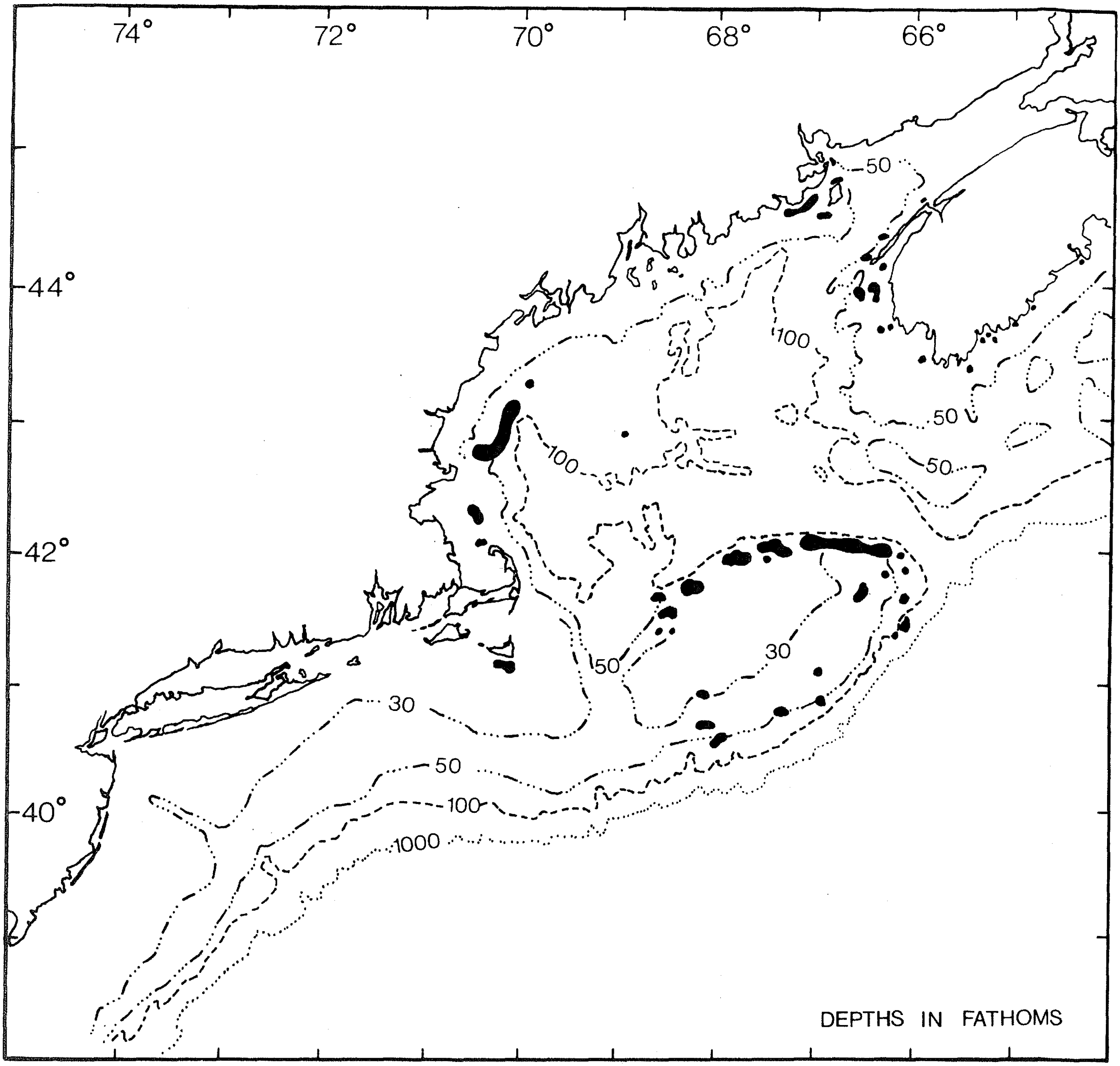


Figure 18. Spawning areas of sea herring (based on collections of adults in Stage VI of gonadal development) in the Georges Bank-Gulf of Maine area (from Boyar et al., 1973).

Location of spawning sites are determined from catches of ripe and running adults, presence of newly hatched (5-7 mm) larvae in plankton tows, dredging for eggs, and diver or submersible vehicle observations of egg beds. Of these, larval distribution studies (newly hatched larvae) are probably the most meaningful in achieving an overall assessment of location and intensity of spawning. Even this approach is not without difficulty since (1) there is a southward progression of the onset of spawning time -- from late August off Nova Scotia to September-October on Georges Bank, (2) egg development and hatching can be modified by bottom temperatures, (3) there may be successive waves of spawning in any locality, and (4) larvae may drift rapidly depending on surface or subsurface currents. All this means that accurate determination of spawning location and intensity in any given year is a difficult, costly, and uncertain undertaking. The degree of uncertainty is indicated by recent experiences on Jeffrey's Ledge reported by Cooper (personal communication). Major catches of ripe and running herring were made 16 km or more from sites where spawning actually occurred. Furthermore, Cooper estimated that all spawning at a given site on Jeffrey's Ledge occurred in 1-2 days, so surveys of newly hatched larvae could easily miss the peak, unless they were almost continuous.

Despite such difficulties, data about spawning locations and intensity exist for most years during the past decade. In some instances, blanks exist because information was not acquired -- and not because spawning did not occur. Probably the best data are those resulting from the International Larval Herring Surveys which began in 1971, but even here the areal coverage in some years is insufficient.

An analysis of initial larval herring abundance during the period 1968 to 1977 in three areas -- Georges Bank-Nantucket Shoals, western Gulf of Maine, and southwestern Nova Scotia (Lurcher Shoals) -- based on 56 survey cruises (Lough, 1978; Lough et al., 1979), disclosed marked annual variations. Initial larval abundance (larvae <10 mm) was high in 1973 and 1974; an order of magnitude lower in 1971, 1972, and 1975; extremely low in 1976; and very low in 1977.

4.3 LARVAL POPULATIONS AND MOVEMENTS

Larval surveys can have four important objectives:

(1) to gain information about the size of the spawning stock, assuming some knowledge about its average fecundity as determined by sizes and ages represented;

(2) to understand the possible interrelationship between spawning stock size and recruitment;

(3) to determine whether a relationship exists between larval abundance and subsequent recruitment strength of that year class; and

(4) to determine larval drift as an approach to understanding the degree to which progeny of separate spawning populations may intermix as larvae.

Surveys of the distribution and abundance of herring larvae in U.S. and Canadian waters of the western North Atlantic have been carried out sporadically since the late 1950's and routinely since 1971. A large international effort, which included coastal as well as offshore waters, was mounted by ICNAF nations in September-December 1971. This provided an excellent synoptic view of sites of larval production and some indication of early drift of larvae.

Larvae from spawning on the northern edge of Georges Bank were first detected during the latter part of September. By December they were widely dispersed over the Bank, with some indication of southwesterly drift.

Larvae from spawning on Nantucket Shoals west of Great South Channel were detected in early November. Dispersal was southwestward, but also northeastward to Georges Bank.

Larvae from spawning at Trinity Ledges and Lurcher Shoals appeared during the latter part of September, and principally early drift was northward along the eastern side of the Bay of Fundy.

Larvae from spawning in the southwestern Gulf of Maine (Cape Elizabeth, Jeffrey's Ledge, and Stellwagen Bank) were first seen in late September and early October. Dispersal was almost entirely shoreward.

Larvae from an undetermined spawning source were also detected off Mount Desert Island in early September. Dispersal was shoreward and southwestward along the coast.

The intensive 1971 larval surveys permitted quantitative estimates of the total number of larvae produced in that year. The general conclusion was that ten times as many larvae were produced in the Georges Bank-Nantucket Shoals area as were produced in coastal waters of the Gulf of Maine (Herring WG Report, 1972).

Overwintering concentrations of larvae exist on Georges Bank until April (and even May in some years), and metamorphose into juveniles at that time (some individuals begin metamorphosis earlier than April). Post larval movements are uncertain, except that schooling begins soon after metamorphosis.

Overwintering larval populations occur in the Gulf of Maine, with the principal concentrations close to shore and in the estuaries. With metamorphosis in early spring, schools of very small juveniles appear in shallow waters along the Maine coast. Larvae metamorphose and begin schooling in April, when they are about 50 mm long and already possess good swimming abilities.

One question which has been asked repeatedly is "Do larvae from Georges Bank spawning drift northward into the Gulf of Maine -- either toward Nova Scotia or toward the Maine coast?" Ichthyoplankton surveys in late autumn-early winter indicate dispersion, influenced by prevailing currents, but definitive answers to the question are not available. Another question might be "What is the nature and extent of movements of late stage larvae and early post-larvae". Some information has been assembled by Graham (personal communication) suggesting appearance of disparate groups of larger larvae in coastal and estuarine waters, but much remains to be learned about these phases of the herring life cycle.

Boyar et al. (1973) summarized opinions about the movement of larvae spawned on Georges Bank. Several authors felt that progeny from Georges Bank spawners could contribute to coastal Gulf of Maine stocks (Tibbo, 1958; Bumpus, 1960) while others felt that this would be unlikely (Colton and Temple, 1961). There is some agreement that progeny of Georges Bank spawners would not be carried northward into the Bay of Fundy (Tibbo and Legare, 1960; Bigelow, 1927; Day, 1958a, 1958b; Bumpus, 1960).

Boyar et al. (1973) added an important overview to the 1971 international survey findings about larval distribution and abundance, reporting on surveys conducted on Georges Bank and in the Gulf of Maine from 1962 through 1970:

(1) Yolk sac larvae were found in most years in close proximity to major spawning sites -- Georges Bank, coastal Gulf of Maine and Nova Scotia -- indicating the existence of three discrete autumn-spawning populations.

(2) Larval herring were obtained in September 1964, 1965, and 1968 but not in 1963, 1966, or 1967. This they related to annual variations in onset of spawning.

(3) Larval herring were taken in October of all years at most of the stations.

(4) In November, larvae were somewhat dispersed, but were most abundant at stations near specific spawning areas (Georges Bank, coastal Gulf of Maine, and Nova Scotia). Only a few larvae were taken at stations in the central part of the Gulf of Maine.

(5) Larvae were present at most stations in December, but only a few were taken north of Georges Bank.

(6) In February, March, and April, larvae were still most abundant on or near Georges Bank.

The statements and diagrams in Boyar et al. (1973) suggest strongly that larvae resulting from Georges Bank spawning most probably remain in the area. Their conclusion was that "the major distribution of larval herring on Georges Bank is restricted to the Bank and its contiguous waters". The authors also concluded that (1) larvae from spawning in the western and central parts of the coastal Gulf of Maine appear to be restricted to those waters; (2) the majority of larvae from Nova Scotia spawning either remain near the spawning sites or are carried into the Bay of Fundy; and (3) some larvae from the Bay of Fundy drift to eastern coastal Maine, and may even be carried as far south as Cape Cod. Monthly summaries of larval distribution from Boyar et al. (1973) are reproduced as Figures 19 through 27.

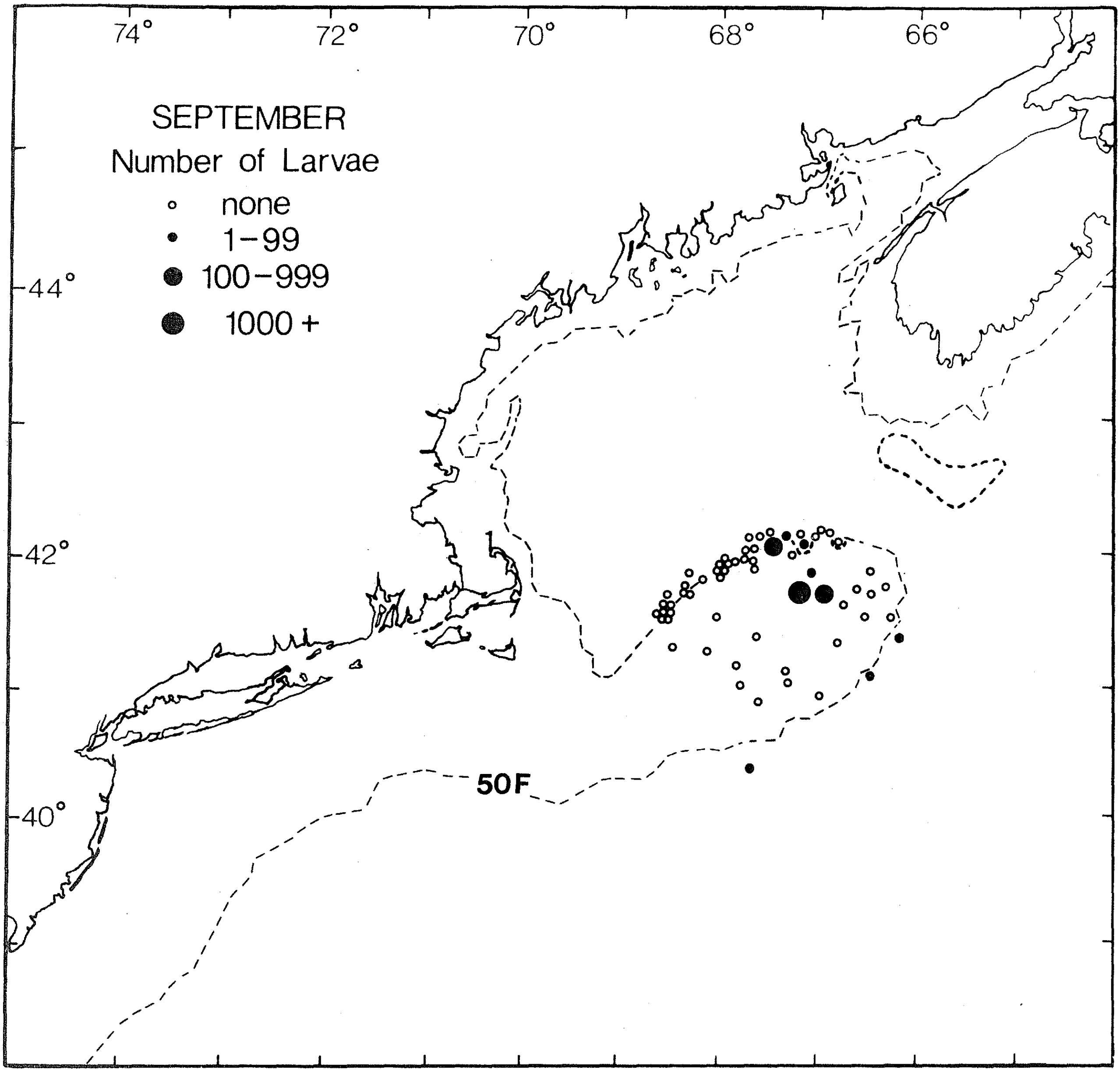


Figure 19. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in September 1963-1968 (from Boyar et al., 1973).

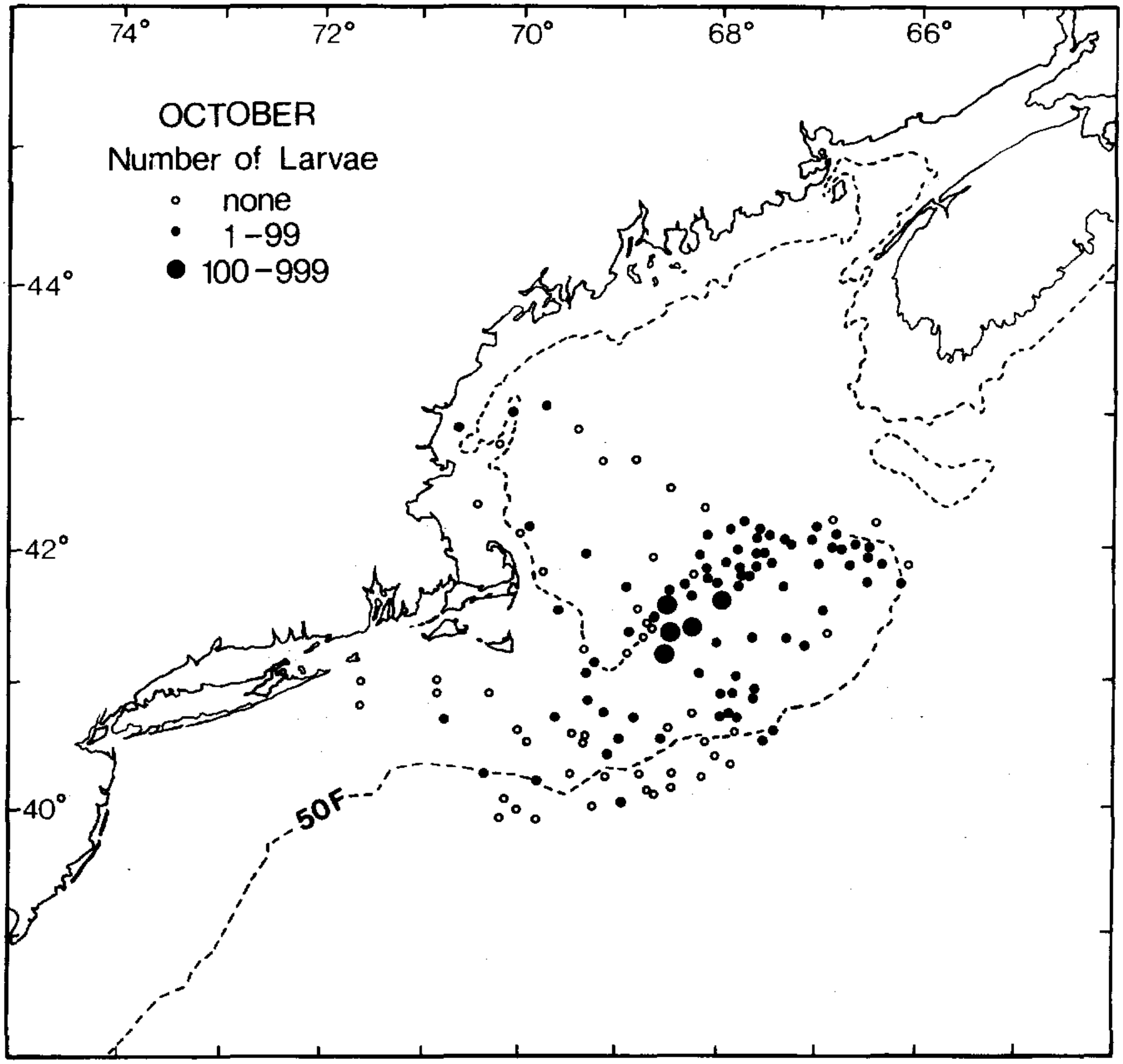


Figure 20. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in October 1964 and 1966-1969 (from Boyar et al., 1973)

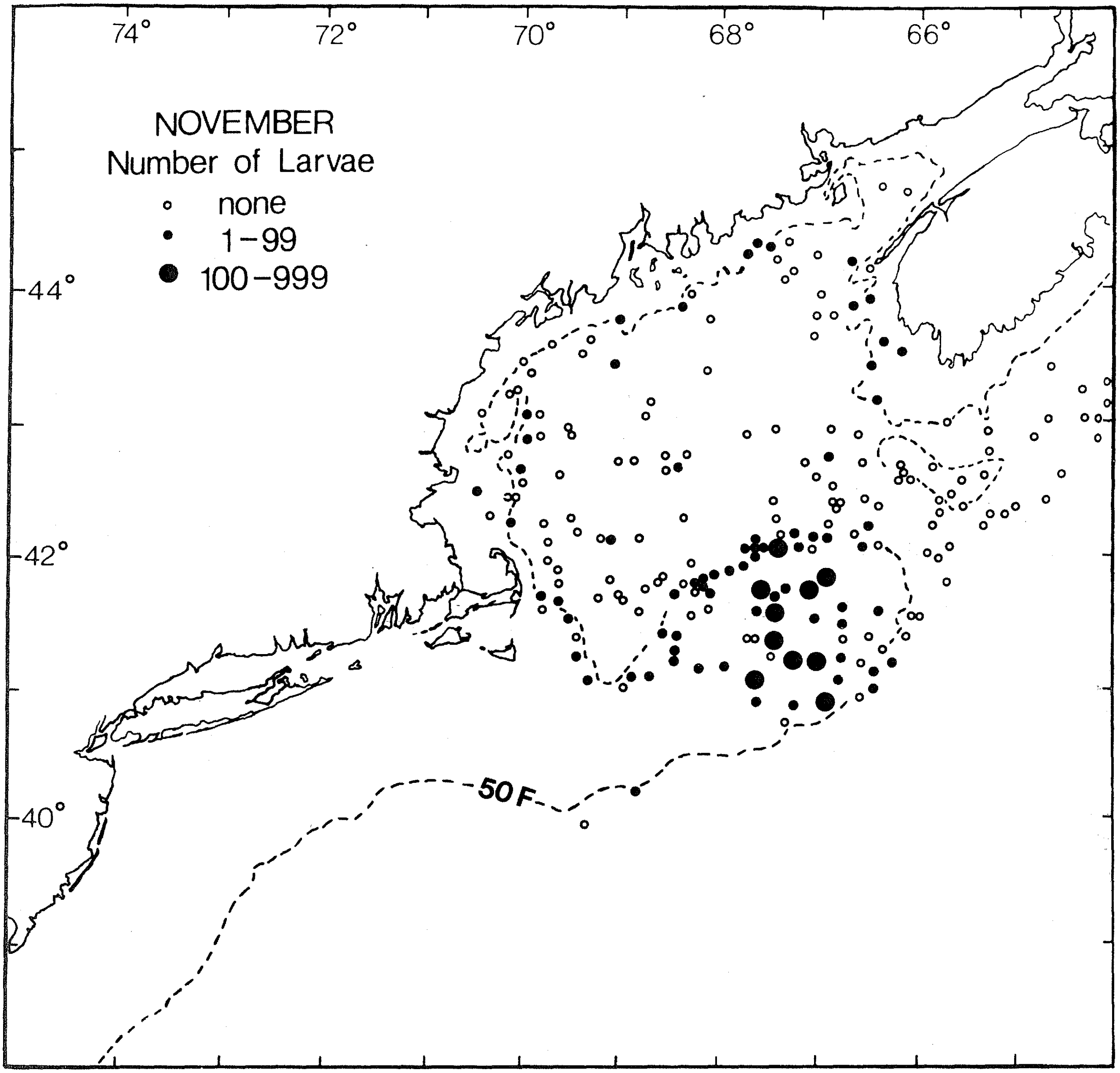


Figure 21. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in November 1962-1965 and 1968-1969 (from Boyar et al., 1973).

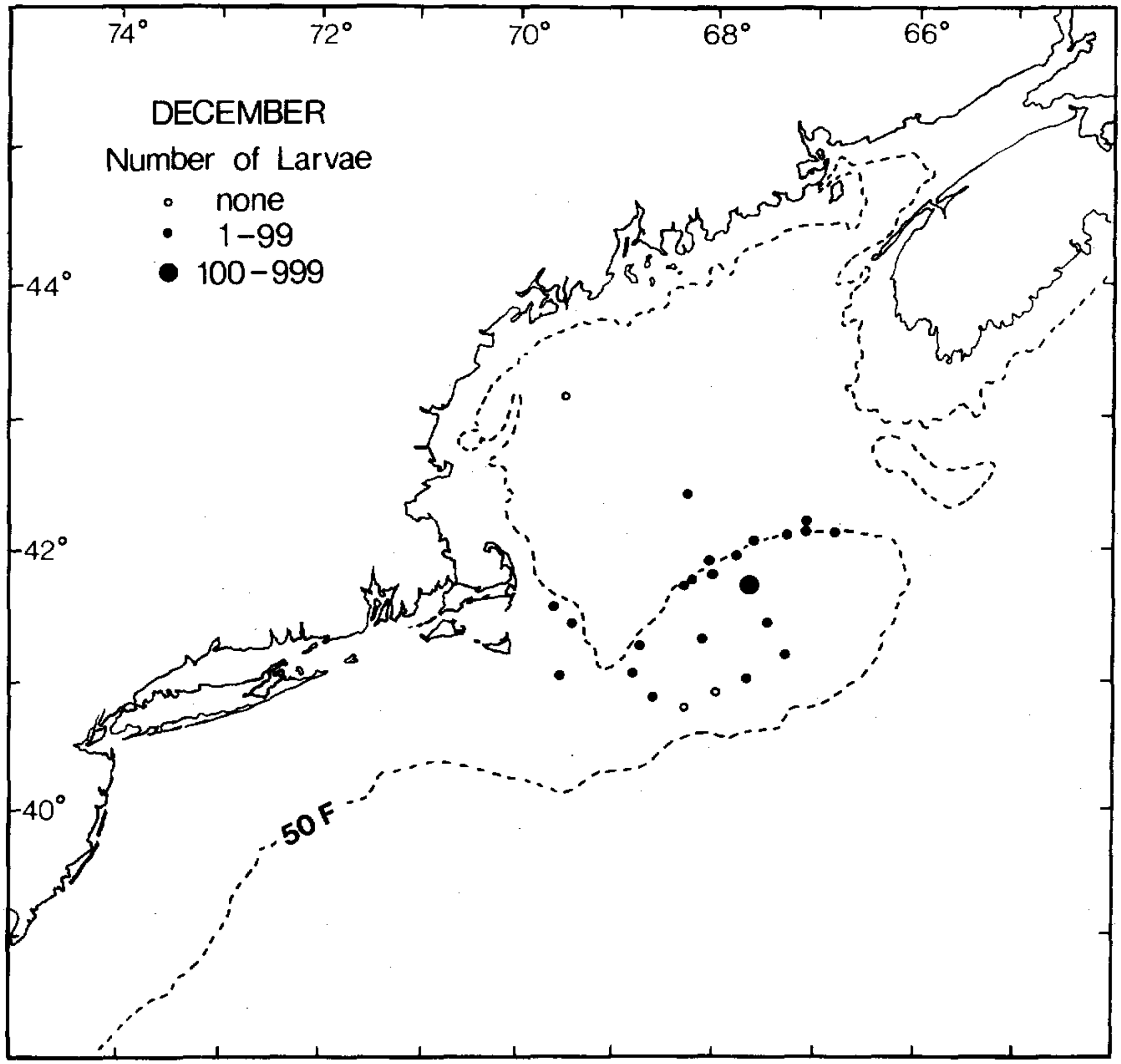


Figure 22. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in December 1962-1963 (from Boyar et al., 1973).

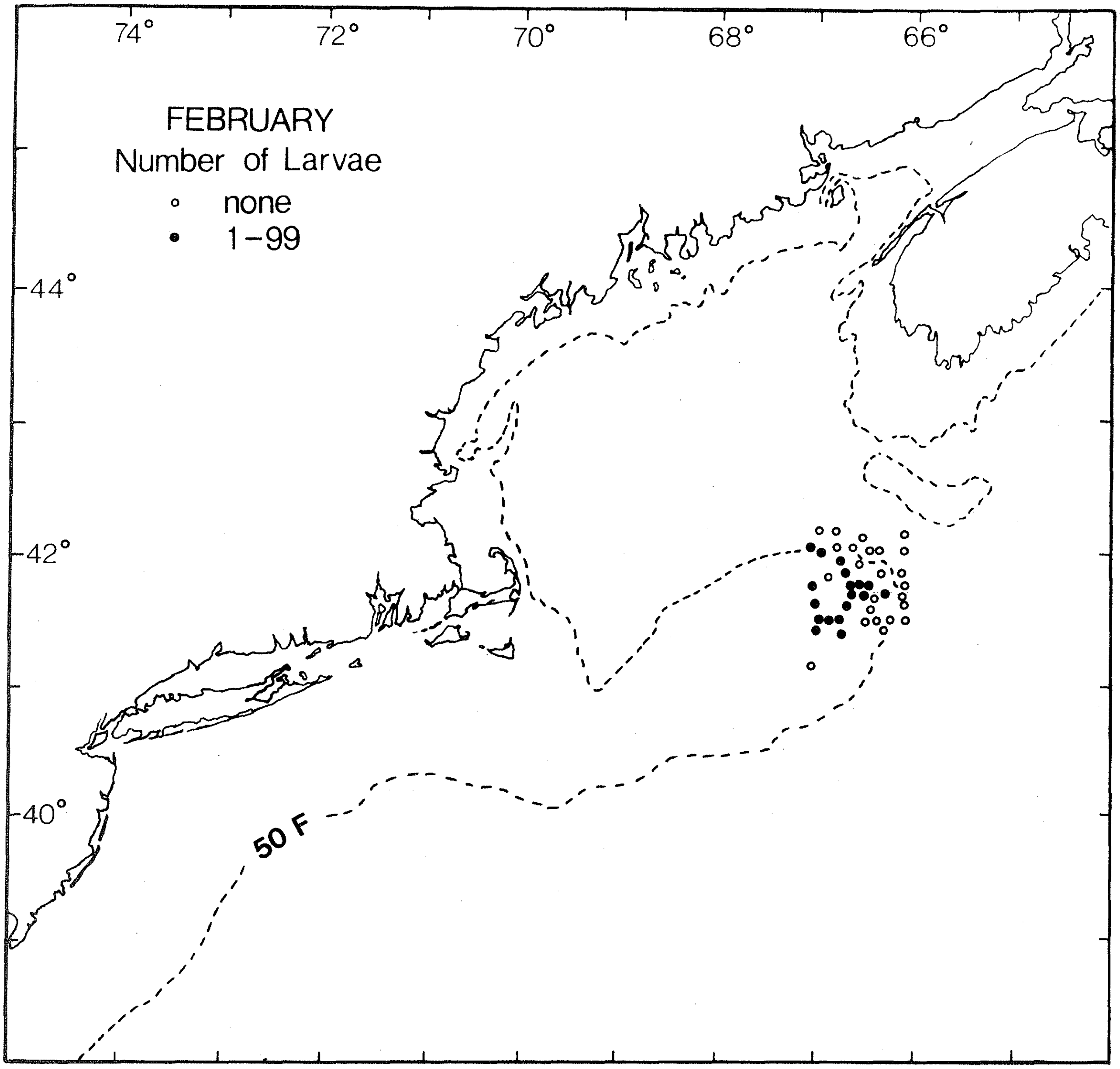


Figure 23. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in February 1968 (from Boyar et al., 1973).

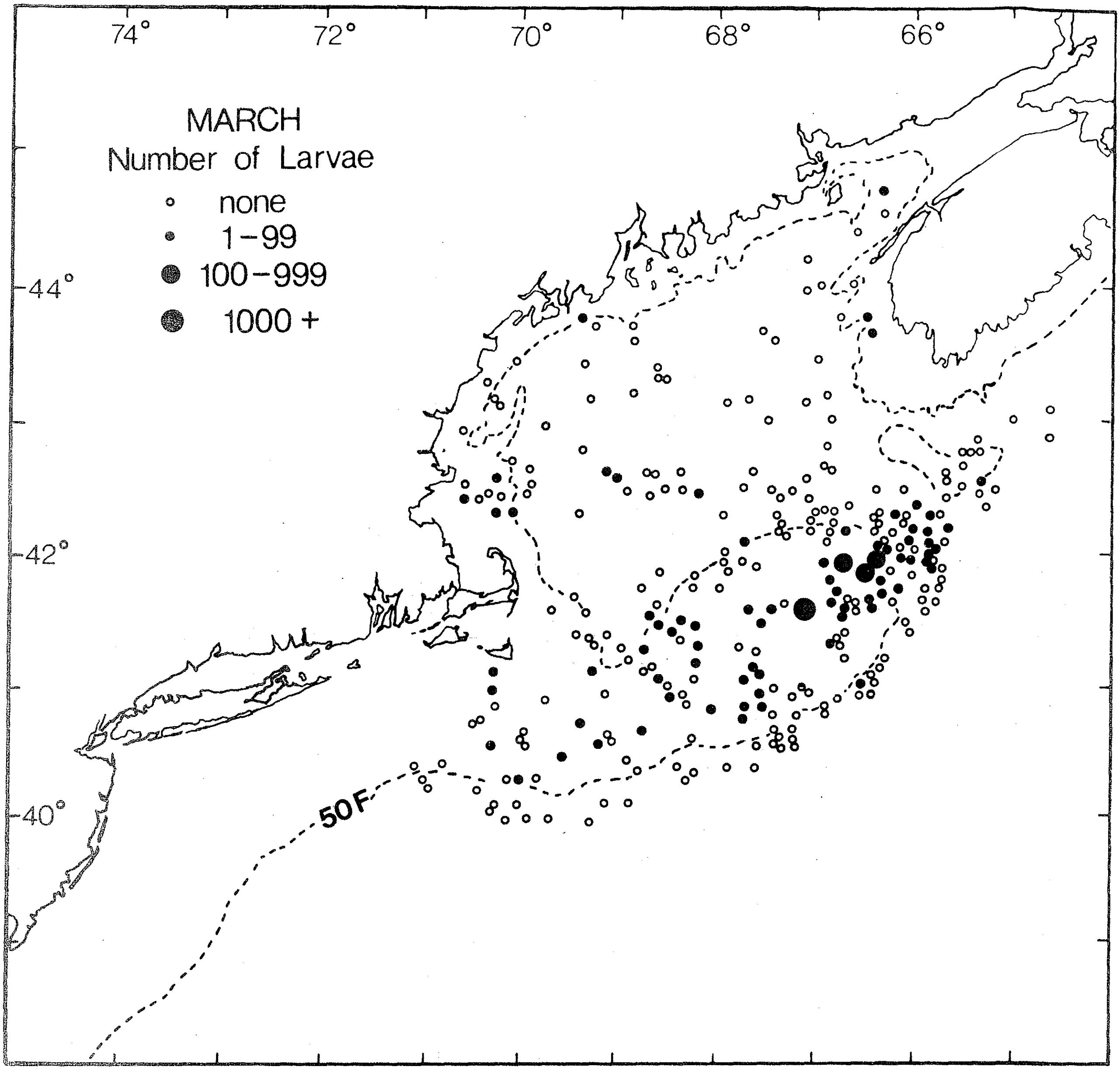


Figure 24. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in March 1967-1970 (from Boyar et al., 1973).

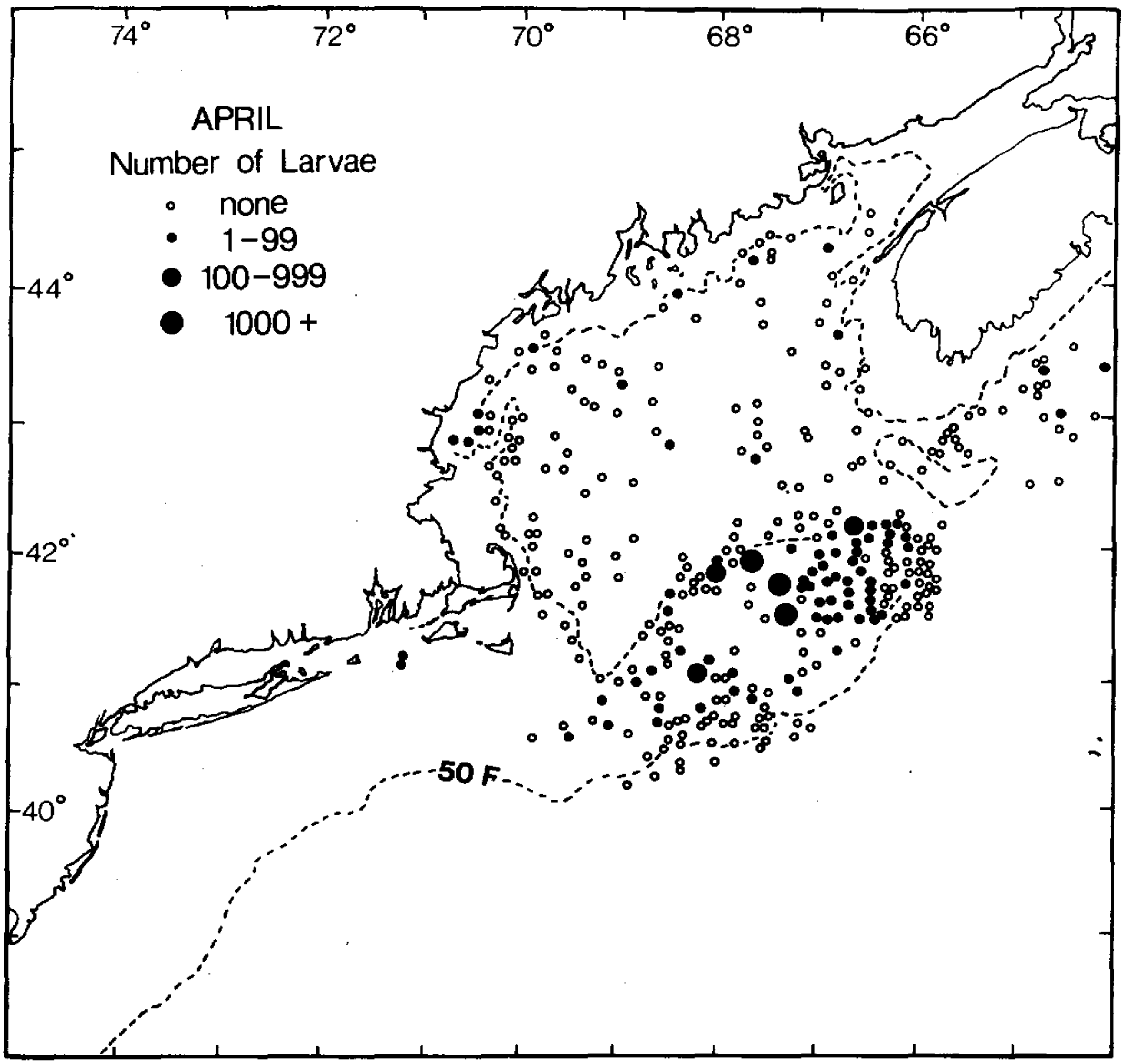


Figure 25. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine in April 1965-1970 (from Boyar et al., 1973).

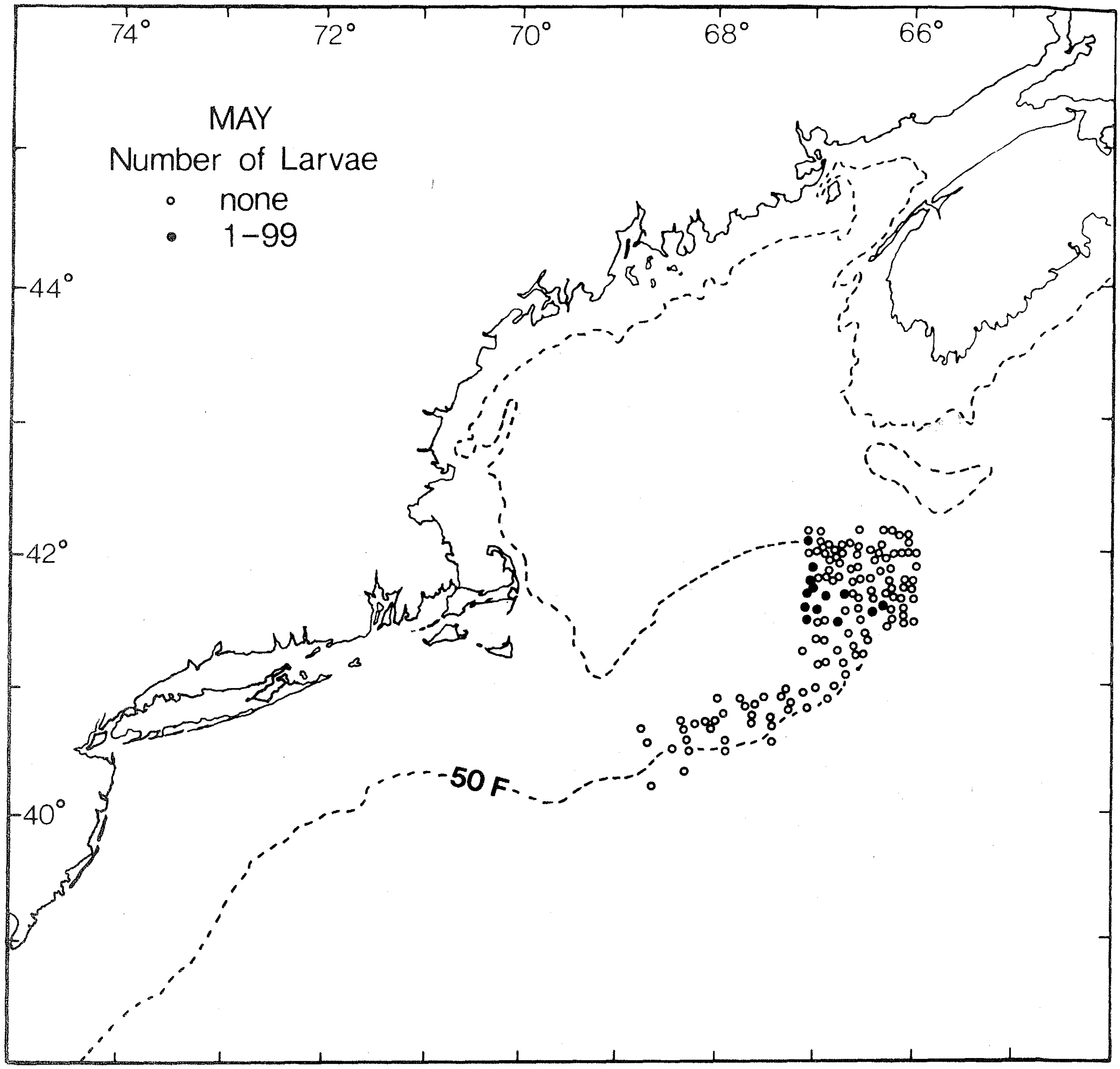


Figure 26. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine area in May 1968-1969 (from Boyar et al., 1973).

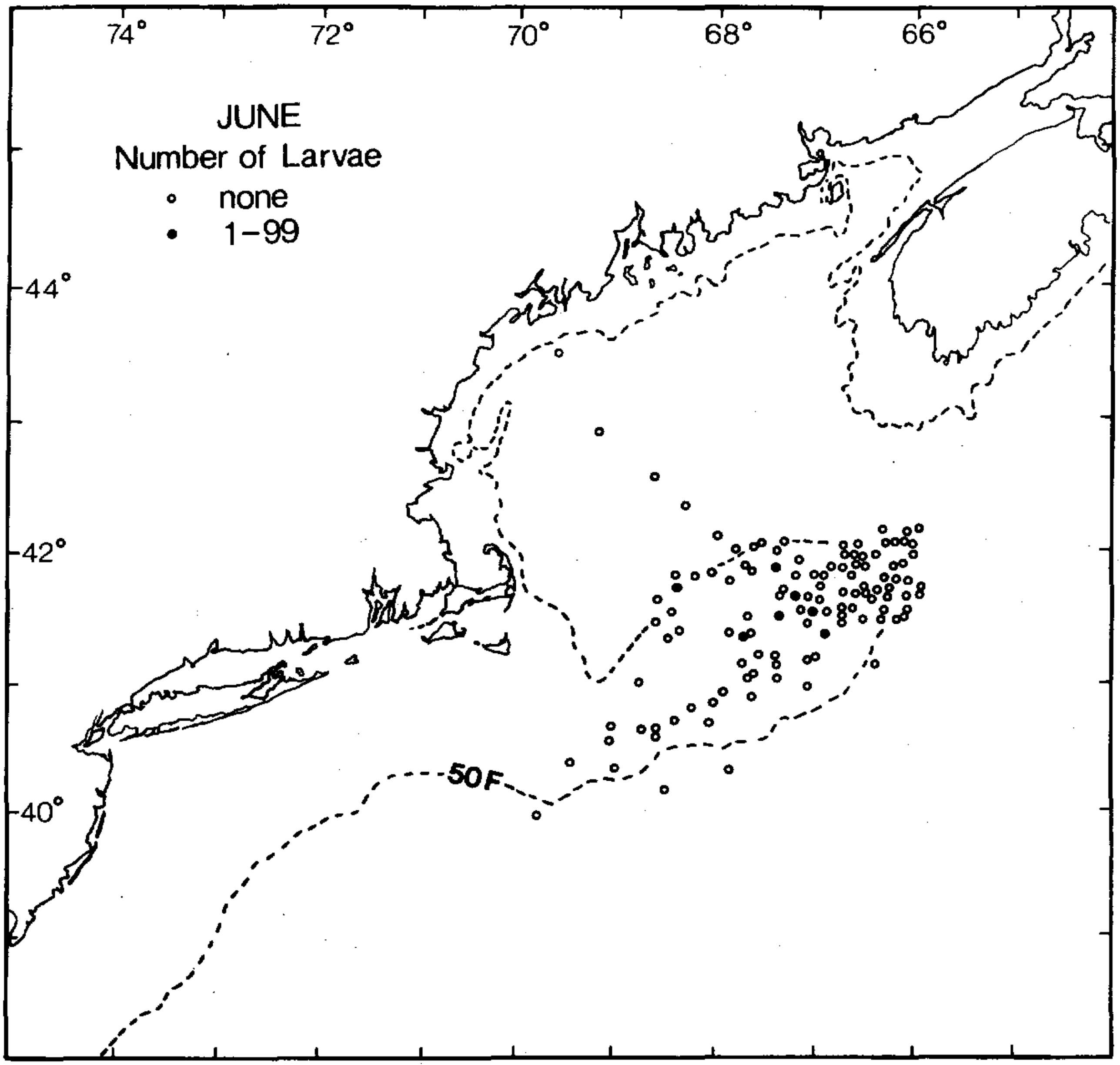


Figure 27. Plankton stations showing absence and presence of larval herring in the Georges Bank-Gulf of Maine in June, 1965-1970 (from Boyar et al., 1973).

Studies of the localized movements of larvae in coastal and estuarine waters by Graham et al. (1972) and Graham (personal communication) have provided useful insights. Principal findings have been:

(a) Larvae sampled within 10 miles (50 fathoms) of shore move shoreward all along the Maine coast. They hold their positions in winter and move into the estuaries in March, April and May.

(b) Larvae make diurnal vertical migrations that result in movement into estuaries that would be counter to existing near-surface current systems (For example, they move up the Sheepscot Estuary in Maine using tidal currents, against a net outward flow at the surface).

(c) Additional larvae from an unknown spawning source, possibly Georges Bank or Nova Scotia, entered the Maine coastal area each spring, but this group of larvae declined in abundance after 1971. (Anthony and Waring, 1978, point out that this coincides with the period when recruitment declined on Georges Bank).

A number of authors have speculated about the apparent shoreward and estuarine movements of larvae and post-larvae (Parrish and Saville, 1964; Cushing, 1967; Iles, 1970). Use of coastal and estuarine waters as nursery areas has been observed in the North Sea and the Gulf of Maine, but the universality of the phenomenon is still uncertain, particularly for progeny of spawning on offshore banks.

4.4 JUVENILE AGGREGATIONS AND MOVEMENTS

The movements of juveniles prior to recruitment into the adult fishery are only partially understood. The simplest assumption in the absence of data would be that post-larval and juvenile herring would exist in the area where they were spawned, or at least be retained within the system where they were spawned. This may be true for some of the stocks, but there is some evidence from tagging that movement and intermingling of juveniles can occur.

Information about seasonal movements of juveniles in Maine waters has recently been summarized (NERFMC, 1978, Appendix 1). One-and-two-year-old fish move inshore in spring, and are fully recruited to the sardine fishery. Peak catches in western and central sectors of the Maine coast occur in June and September and in the eastern sector in July. During the summer little lateral movement occurs along the coast; movements of schools seem random within any localized area. In late autumn juveniles move out of nearshore waters, and results of recent tagging studies (Speirs, 1977) suggest a south-westward movement of at least a part of the population in winter. Earlier results of parasitological surveys (Sindermann, 1957a, 1957b) indicated little eastward movement of juveniles from the western coastal sector, but the possibility of greater westward movement of fish that had spent their first year of life in the eastern and central coastal sectors.

The spawning source of juveniles from the Gulf of Maine coast and the western Bay of Fundy is still not clear. Spawning stocks in the Gulf of Maine (Jeffrey's Ledge, Stellwagen Bank, Isles of Shoals, Matinicus) would be logical contributors, but they may not be sole contributors.

The behavior of schools of New Brunswick juveniles is similar to that of those on the Maine coast, with migrations inshore in summer, but with little except random localized movements during the summer period. Winter movements southwestward may be more extensive, although Stobo et al. (1975) concluded from tagging results that a large part of the Bay of Fundy juvenile population overwintered off the mouth of the Bay. Some juveniles tagged in Canadian waters have been recovered in the Gulf of Maine, and even at Cape Cod.

The source of the New Brunswick juvenile stock remains an enigma. There is some evidence that the Nova Scotia spawning stock does not contribute significantly to the New Brunswick juvenile population. Based on limited evidence, Iles (1971) concluded that late larval stages from Nova Scotia spawning occurred only in the eastern Bay of Fundy; and there are differences in vertebral counts between juvenile aggregations on the Nova Scotia and New Brunswick sides of the Bay of Fundy (Tibbo, 1968). Iles (1970) pointed out that on the basis of vertebral numbers, New Brunswick juveniles were more like the Georges Bank spawning stock than the Nova Scotia stock, and suggested a transport mechanism for larval and post-larval drift from

Georges Bank in the Gulf of Maine counterclockwise eddy across the mouth of the Bay of Fundy. The conclusion reached by the Herring WG Report (1972) was that juveniles caught on the western side of the Bay of Fundy and along the Maine coast are derived from, and contribute to, stocks other than the Nova Scotia stock (probably the Gulf of Maine stock complex). Recent recoveries from the 1977 Maine tagging program (Graham, personal communication) have raised some questions about this statement. Recoveries from eastern Maine tagging were made in New Brunswick and Nova Scotia as well as from the western Gulf of Maine. Longer-term recoveries are clearly needed.

It has been suggested that the offshore banks may be over-wintering areas for juvenile herring, but evidence is not substantial. Surveys of the strong 1970 year class by the USSR in 1972 disclosed a wide distribution of juveniles from Emerald Bank southward over Georges Bank to south and west of Long Island. Juvenile (age 2) herring had been taken occasionally on Georges Bank before that time, but not in the large numbers reported by the Soviets in 1972. Largely because of the 1972 findings, juvenile surveys were instituted in 1973, but not many age 2 herring have been seen on Georges Bank, until the winter of 1977-78, when juvenile herring were again found there in appreciable numbers -- an observation which may indicate good survival of the 1975 and 1976 year classes. (This conclusion is also supported by high catches of these year classes in the juvenile fishery on the Maine coast).

A significant observation may have been made by Boyar (1968) and subsequently overlooked. He reported juvenile herring on Georges Shoals -- an extensive area avoided by commercial and research vessel operations. This shallow water area obviously should be searched for juvenile aggregations. It may be that this is a limited nursery area, and only in exceptional years would juveniles be found in deeper areas of the Bank which are normally fished. Even with this possible insight, there is still great uncertainty about the location of the extensive nursery grounds necessary for the large Georges Bank-Nantucket Shoals herring stocks. The coastal waters of southern New England are another logical possibility, although it seems that abundant juvenile herring in such inshore waters in earlier years would have been observed and reported (as they were in estuaries of the southern portion of Cape Cod in late spring and early summer of 1978). The possible existence of an isolated or unsampled group of juveniles on Georges Bank or elsewhere was not considered likely by Sissenwine (personal communication), who determined mortality rates for pooled Georges Bank, Jeffrey's Ledge and southern Nova Scotia stocks, and found them inconsistent with the concept of an unsampled population somewhere in the area.

4.5 ADULT STOCKS -- MOVEMENTS AT OTHER THAN SPAWNING PERIODS

Adult herring participate in extensive seasonal movements, which have been best defined for the Georges Bank stock. Three phases are apparent: (1) a late summer-early autumn spawning migration of ripening fish; (2) a rapid post-spawning migration to warmer waters to the south for overwintering; and (3) a spring-early summer feeding migration.

The Soviets have followed adult herring from Georges Bank after spawning. They found that post-spawners moved southwest to off Chesapeake Bay in November, and overwintered there. The larger and older fish seemed to move furthest south. Feeding migration back to Georges Bank began in May or early June, and to shallower spawning sites on the northern edge in September. The waters off Cape Cod seem to constitute a mixing area, with different groups passing at different times of the year.

It has been hypothesized that some fish from the southwestern Gulf of Maine stock overwinter in the Middle Atlantic Bight with fish from the Georges Bank stock (Ridgway, 1975), but otherwise the movements of the Gulf of Maine stock at times other than the autumn spawning season are incompletely understood. It is possible, according to the Herring WG Report (1972) that "some of its members move south and west after spawning, joining the overwintering Georges Bank stock in Division 5ZW (south of Cape Cod) and Subarea 6, although the U. S. and USSR biochemical and serological data indicate that its members cannot contribute more than 10% of the herring in this area". Some tagged adults from the southwestern Gulf of Maine stock have been found at least as far east as Mount Desert Island on the Maine coast (NERFMC, 1978). Adults from the Gulf of Maine stock which overwinter south of Cape Cod may move through Great South Channel and the Cape Cod Canal to summer feeding grounds along the Maine coast (NERFMC, 1978).

On the Nova Scotia coast, spawning begins in August and continues to October; post spawners migrate offshore, then move northward or southward (even to Cape Cod). Tagging 3-year-olds disclosed that 40% moved northward up the Scotian Shelf to the Chedabucto area while the rest moved southward to the Gulf of Maine and even beyond. Adults fished on the Scotian Shelf in winter are presumably members of the Nova Scotia stock, which spawns in autumn off southern Nova Scotia (Herring WG Report, 1972), and which is distinct from the Gulf of St. Lawrence stock. Nova Scotia spawners which move south undoubtedly form part of the mixed stocks taken in the United States winter-early spring adult herring fishery in southern New England. A return migration begins in the spring, and some adults reach the Bay of Fundy by June.

It seems clear that stock intermixture is a seasonal phenomenon. Recent attempts to place quantitative boundaries on seasonal movements have been made (NERFMC-1978). Their estimates of the distribution and intermixture of the three stocks are presented in Table 4. It should be pointed out that these estimates are assumptions for certain modeling exercises, to test the robustness of decisions, and are not necessarily indicative of actual movements. As an added complication, the possibility should be mentioned that with reduction in stocks, migration patterns may be changing, so that it may not be possible to categorize movements of a given stock easily. Anthony (1977) has summarized general information about movements of adult stocks (Figure 28).

Table 4. Percent Distribution of Spawning Stock in Area by Period (from NERFMC, 1978).

Period	Stock (generalized)	Exploitation Area 4xW	5Y	5Z/SA6
1 (December-March)	Lurcher	50	30	20
	Jeffrey's	0	50	50
	Georges	0	0	100
2 (April-May)	Lurcher	60	35	5
	Jeffrey's	10	75	15
	Georges	0	10	90
3 (June-July)	Lurcher	60	40	0
	Jeffrey's	30	70	0
	Georges	5	20	75
4 (August-November)	Lurcher	90	10	0
	Jeffrey's	0	100	0
	Georges	0	0	100

Note: This hypothetical stock intermixing matrix was developed by NERFMC for application of a management model, but it is based on assumptions and available data. Thus the percentages may be subject to a large degree of error, and should not be taken as an indication of real knowledge about stock movements and intermixing.

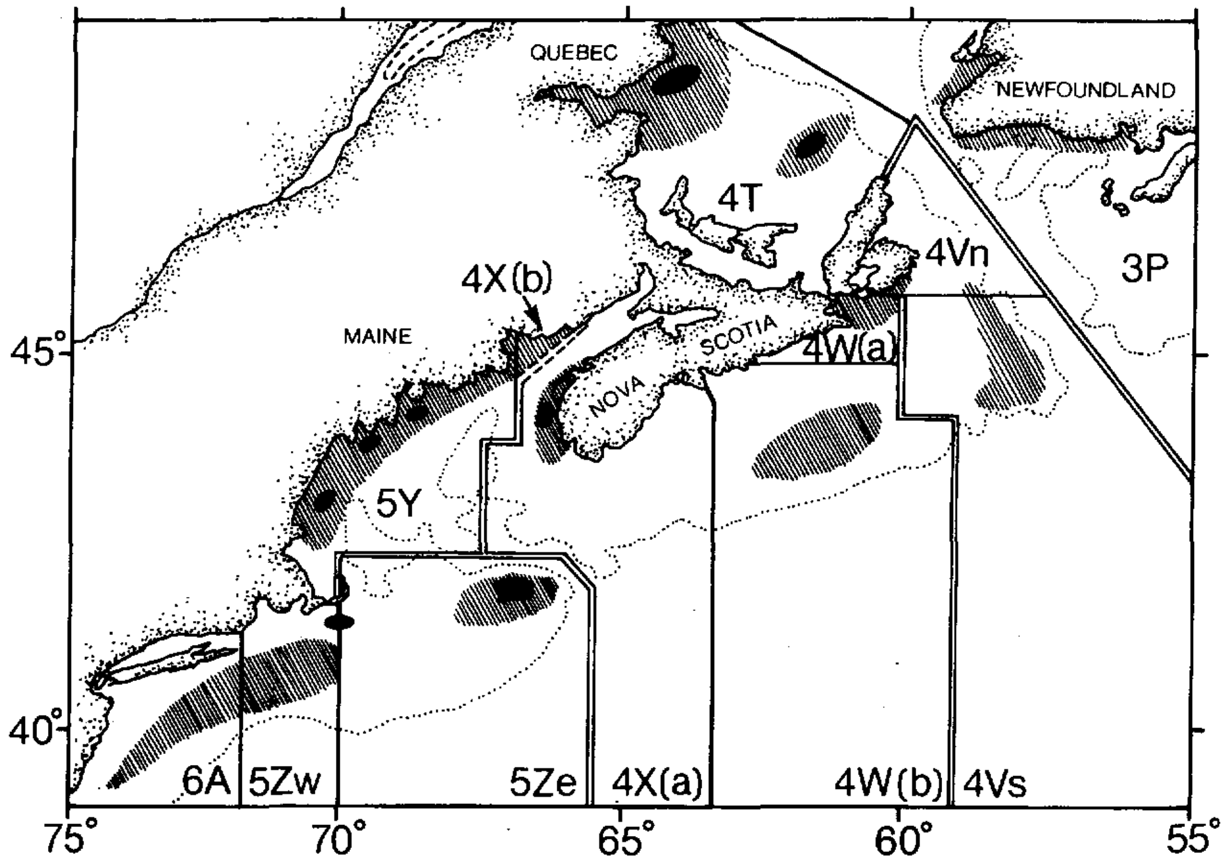


Figure 28. Adult herring stocks of the western North Atlantic (from Anthony, 1977b).

4.6 METHODS OF STOCK SEPARATION AND CONTRIBUTION OF EACH TO STATUS OF KNOWLEDGE OF STOCKS

Attempts to differentiate stocks of herring began almost a century ago, with the classical work of Heinke in the 1880's -- the first indication that herring of the Northeast Atlantic should not be considered as a homogenous unit, but rather should be divided into so-called "stocks" based on differences in meristic and morphometric characters. Since that beginning, great amounts of effort have been invested in attempts to identify and define subunits of populations often called "unit stocks", on the basis of morphological, physiological, and behavioral characteristics. The results have rarely been conclusive, as Møller (1971) pointed out, because the characteristics used were dependent upon both genetic and environmental influences for their expression -- and because little effort was made to separate and define these influences. The unit stock concept was defined principally on the basis of phenotypic characters, subject to environmental modification. This leads quickly to confusion when migrations and mixtures of groups occur.

Concern about intermixture (or lack of intermixture) of herring stocks of the western North Atlantic has existed for decades, but has only recently been of pressing importance, with the desire of NERFMC to manage stocks by restricting fisheries which occur throughout the year in some instances. For immediate management needs, some assumptions about intermixing must be made. These have to be based on available data, which are incomplete.

Methodology used in stock separation includes (1) morphometrics and meristics, (2) age and growth comparisons, (3) tagging, and (4) biological tags -- biochemical and parasite. One important generalization is that several methods of stock identification should be used concurrently where feasible, since each method supplies a distinctive perspective on the problem, and any concensus based on use of several methods is likely to be closer to reality than conclusions based on use of a single method. The following paragraphs summarize the status of knowledge using each method.

4.6.1 Morphometrics and Meristics

Stock separations have traditionally been based on morphometrics (measurements of various body parts such as head length, snouth length, orbit diameter, post-orbital length, pectoral and pelvic lengths, and pre-anal length), and meristics (counts of several segmentally repeated body parts such as vertebrae, fin rays, gill rakers, and keeled scales). There have been several successful attempts to use morphometrics for herring stock separation. Popiel (1955) used head length/body length ratios to separate groups of Baltic herring, and Muzinic and Parrish (1960) differentiated herring spawning in the northern and southern North Sea on the basis of head length/body length proportions. Pope and Hall (1970) used linear discriminant function analysis of eight morphometric characters to separate two European herring stocks

(Buchanan and Kobberground), despite the fact that Burd (1969) had earlier been unable to discriminate among three other European stocks (Dogger, Flamborough and Sandettie) using the same characters.

Among herring of the Northwest Atlantic, Jean (1967) was able to separate two groups of herring from the Gulf of St. Lawrence based on four morphometric characters. Parsons (1975) found that spring and autumn spawning herring from Newfoundland and adjacent waters differed in morphometric characters, and that significant differences in some or all morphometric characteristics existed when spring spawned or fall spawned fish from different areas were compared.

Parsons also pointed out that even though morphometric differences were found between autumn spawning herring from the Magdalen Islands and southwest Newfoundland, tagging results demonstrated that herring which overwinter in southwest Newfoundland waters are part of a stock complex which spawns and feeds in the southern Gulf of St. Lawrence. This led Parsons to the conclusion that statistically significant morphometric differences cannot always be considered to be valid indicators of stock discreteness. Undoubtedly, seasonal influences on morphometric characteristics in intermixing zones account for some of the differences seen.

In a number of studies with other species (Ahlstrom, 1957; Royce, 1957) the general conclusion has been that statistically significant morphometric differences could be found commonly -- even between closely related populations. Also, groups considered distinct on the basis of morphometric studies were found to intermix considerably when tagging was done.

Meristic characteristics -- especially vertebral and fin ray counts -- have been widely used in attempts to distinguish stocks of herring. The general finding has been that average counts increase with latitudinal decrease in temperature (Rounsefell and Dahlgren, 1932; Tester, 1937; McHugh, 1942; Bückmann, 1950). The assumption is that if herring remain in, or return to, their original spawning areas, and if several spawning areas have different temperature regimes, then the fish should have meristic counts typical of that environment and distinct from one another. Counts should be higher in colder waters.

Meristic studies of European herring have generally emphasized use of vertebral and keeled scale numbers to distinguish stocks, although there are a few reports of successful use of fin ray counts as well. Schnakenbeck (1927) used pectoral fin rays to separate several stocks, and Dutt (1958) found that autumn spawners in the western Baltic had significantly higher pectoral fin ray counts than spring spawners.

In Canadian studies, meristic data subjected to discriminant function analyses have demonstrated that spring and autumn spawning components of the southwest Newfoundland-southern Gulf of St. Lawrence stock complex constitute distinct populations, with only slight interchange between them (Parsons and Hodder, 1971a; Parsons, 1972b). Use of linear discriminant function based on three meristic characters enabled correct classification of from 79-91% of individuals to their respective spawning groups.

A later analysis by Messieh (1975) confirmed the hypothesis that spring and autumn spawning populations separate at onset of spawning, but mix during feeding.

Another study of meristics of herring from the southern Gulf of St. Lawrence, southern Newfoundland, and Banquereau Bank (Forest and Briand, 1975) indicated intermixing of the autumn spawning component of the stocks, but three stock complexes could be distinguished in the spring spawning component, using vertebral, anal fin ray and dorsal fin ray counts.

In United States waters, Anthony and Boyar (1968) used vertebral and fin ray counts in attempts to distinguish stocks of herring. They found that (1) differences in meristic counts among the years of sampling were significant, indicating a change in the distribution of herring or in environmental factors for a particular year for a given area, (2) differences in vertebral and right pectoral ray counts suggested that two stock complexes existed -- a Georges Bank-Cape Cod (South Channel) complex, and a Maine-Nova Scotia complex, and (3) the magnitude of differences in mean meristic counts among areas was greater in the 1958 year class than in the 1960 year class, but significant differences were not observed in later year classes.

Recently, Anthony and Waring (1978) reexamined conclusions from meristic data and pointed out additional findings:

(1) Adults (age 4+) of the 1958-1963 year classes from the Maine coast had right pectoral fin ray counts averaging 18.50, which was significantly greater than the average for Georges Bank adults (18.08). Right pectoral fin ray and vertebral counts of adult herring from the western Gulf of Maine were intermediate between eastern Maine-Nova Scotia and Georges Bank-Cape Cod.

(2) More importantly, right pectoral fin ray counts of Maine coast juvenile herring from the 1960-1963 year classes agreed closely with right pectoral fin ray counts of adults of the same year classes spawning on Georges Bank several years later, and were significantly different from the adult herring found along the Maine coast. These data suggested to the authors

that the juvenile herring found along the Maine coast could belong to the Georges Bank stock, since the Georges Bank-Cape Cod area is the only known area in the western North Atlantic with herring with low pectoral fin ray counts.

(3) The possibility of intermixing in Maine coastal waters of herring spawned on Georges Bank and on the Maine coast is suggested by a change at age in pectoral fin ray counts of juveniles from the Maine coast. Counts increased progressively with age, suggesting that herring with low counts leave the coast as they get older -- possibly to recruit to the Georges Bank stock.

This new information is fascinating, but, unfortunately, beginning with the 1964 year class, fin ray counts began to increase, and no significant differences between Georges Bank and other stocks could be detected (up to the time when meristic studies were discontinued in 1971). Anthony and Waring attributed this to decrease in water temperature at spawning time in the late 1960's. They also pointed out the interesting time relationship among (1) increase in meristic counts, (2) decline in water temperature, and (3) decline in year class strength -- suggesting that low temperatures at spawning may have caused an increase in mortality.

It seems relevant to point out in this discussion of meristic data that despite the enormous investment in sample collection and analyses, there is still some uncertainty about just where in ontogeny the meristic characters become fixed. Hempel and Blaxter (1961) concluded on the basis of laboratory studies that herring myotome counts are determined before hatching, but Tester (1938) and Bückmann (1950) had earlier provided some evidence that vertebral number was not fixed until after hatching. Even the lengths at which fin rays are formed during the larval stage is open to some question; Bigelow and Schroeder (1953) gave 15-17 mm and Blaxter (1962) gave 13-14 mm as lengths when the dorsal fin was formed (Anthony and Boyar, 1968). Since temperature is clearly an important determining factor; since the temperature at the bottom and at the surface may be markedly different; and since temperatures during spawning time may vary annually, these uncertainties must be added to those already discussed.

4.6.2 Age and Growth

Different populations, inhabiting different environments, might be expected to have different growth rates, so size at age can be a discriminating factor for distinguishing the populations. With herring, length at age has been most useful in separating spring-spawned from autumn-spawned components of stocks. Autumn spawned fish in the Gulf of St. Lawrence have slightly higher length-at-age values than do spring spawners because in the first full year of growth after metamorphosis they have more months of higher temperatures and abundant food (Parsons and Hodder, 1974).

Examination of length frequency distributions in the three adult stocks of concern to this paper, did not disclose significant differences in mean lengths (Boyar, 1967). However, a study of juvenile herring from the Maine coast indicated that, regardless of the year class, herring from western Maine grow significantly faster through age 2 than do herring from eastern Maine (Anthony, 1971).

4.6.3 Tagging

The use of artificial tags to determine movements of fish is a technique almost as old as is fishery biology as a science. Herring have been tagged successfully for almost half a century, beginning with the internal tags applied to Pacific herring (*Clupea pallasi*) by Dahlgren (1936); Hart (1937-1946); and Stevenson (1955). Early reservations about tagging were (1) herring are too delicate and lose scales too readily to withstand tagging, (2) herring flesh is too soft to retain tags for extended periods, (3) the volume of catches makes prohibitive the number of individuals that must be tagged, and (4) mass handling of herring catches makes tag recovery difficult. European experience with herring tagging since World War II has been that herring can be tagged successfully, but success depends on the condition of the fish, the "shedding" properties of the tag, and the effectiveness of the tag recovery procedure -- all of which contribute to the overall "efficiency" of each tagging experiment (Parrish and McPherson, 1963).

Herring tagging in the western North Atlantic has not been extensive until recently, and the one earlier large-scale tagging (of juveniles in Passamaquoddy Bay) was only marginally successful (McKenzie and Skud, 1958; McKenzie and Tibbo, 1961). Beginning in the late 1960's, and continuing to the present, tagging of adult herring in Canadian and United States waters has been conducted sporadically, beginning with stocks in the Gulf of St. Lawrence (Winters, 1970, 1975; Beckett, 1971). Subsequent studies have used external tags (Floy anchor-type) applied by cartridge-fed tagging guns (Dell, 1968), and the technical feasibility of the method has been demonstrated by Stobo et al. (1975), and Stobo (1976). A cooperative international tagging effort was planned at the annual meeting of ICNAF in 1976, with participation by Canada, FRG, USSR, Poland, and USA. A number of tagging operations have resulted from this international initiative, and important new information about movements, intermixing, and mortality is emerging. The Maine Department of Marine Resources conducted extensive tagging of juveniles in 1976, 1977, and 1978, at thirteen coastal locations.

Concerning juveniles, earlier tagging in Passamaquoddy Bay, hampered by poor tag retention, high handling mortality, and non-reporting of tags, indicated only limited movements (less than 50 miles) of sardine-size herring for several months after tagging. Preliminary results of recent tagging by the Maine

Department of Marine Resources has helped to substantiate the concept of limited movements of juveniles. Tagged fish moved distances of up to 50 miles in one year; movement was mostly in winter; and many tagged fish seemed to return to the area in which they were originally caught. It should be pointed out, though, that most recaptures occurred soon after tagging, and there were few returns after a significant period at large. Despite the preliminary nature of the findings, the general picture that is beginning to emerge is one of gradually increasing distances covered as fish get older; longer-term recoveries from the 1976 and 1977 tagging of juveniles should clarify this picture.

Recent Canadian tagging operations beginning in 1973 -- mainly with adult fish (Stobo et al., 1975; Stobo, 1976) -- indicate that adults tagged near traditional Nova Scotia spawning grounds within a reasonable proximity of the normal spawning period (August-October) overwinter outside the Bay of Fundy region. Some move north and may be taken in the Chedabucto Bay winter fishery, and some move south to the New England coast where they may be taken in the U. S. winter fishery.

Several taggings at Grand Manan and off Nova Scotia have been particularly instructive. Adults in substantial numbers moved across the Bay of Fundy, and several of the tagged fish moved westward to locations on the Maine coast. A few moved as far as Jeffrey's Ledge, Georges Bank, and Narragansett Bay. Stobo (1976) concluded that the westward movement indicated a substantial stock intermixture problem that needs additional consideration in future assessments.

Canadian tagging of juveniles has resulted in the general observation that New Brunswick juveniles have a greater relationship to Maine coastal populations than to those of Nova Scotia. Juveniles seem to feed in summer in the Bay of Fundy, then migrate southward along the eastern Maine coast in winter -- some moving as far south as Cape Cod.

Preliminary results of the Cooperative International Herring Tagging Program have been reported by Burns (1977) and Almeida and Burns (1978). Adults were tagged using chartered purse seiners in autumn 1976 on Georges Bank and Jeffrey's Ledge, in spring 1977 near Jeffrey's Ledge and in Great South Channel, and in autumn 1977 east of Cape Cod. Tag returns from the 1976 augumn operation were small, but a few fish tagged on Georges Bank were recovered in Cape Cod Bay and northwest of the tagging site, and one return from the Jeffrey's Ledge tagging came from Cape Cod Bay. Herring tagged in spring 1977 on Jeffrey's Ledge were apparently part of a northward migrating population, since returns during the summer came from the Maine coast, Grand Manan, and southwest Nova Scotia. However, returns from autumn came from Jeffrey's Ledge near the tagging site. Adults tagged in spring 1977 in Great South Channel were apparently also part of a northward migrating group which may have overwintered in the Middle Atlantic Bight, since some returns in autumn 1977 came from as far away as New Brunswick and southwestern Nova Scotia. It should be noted though that a number of returns in late summer and early autumn were from ripening and spawning fish in northern Massachusetts waters.

Thus far the tag returns are too few to formulate detailed hypotheses, but they do suggest substantial intermixing of Nova Scotia-Gulf of Maine stocks -- probably beyond that previously considered likely -- and the possibility of extensive migrations of adult fish. Tag returns also suggest that herring have definite migratory routes at various phases of their life history, and that there may be some element of homing to spawning sites.

Tag returns also suggest rather strongly that in the early years of the Georges Bank fishery, when winter catches were made south and west of the Bank, they may well have been overwintering fish from the Nova Scotia or Gulf of Maine spawning groups -- which could have affected assessments by causing an overestimate of Georges Bank stock abundance, and underestimates of other stocks (Anthony and Waring, 1978).

An independent analysis of tagging results to date and observations from the commercial fishery by the New England Regional Fishery Management Council (NERFMC, 1978) produced the following tentative conclusions about movements and intermixing of stocks:

1. A component of the Nova Scotia stock moves out of the Bay of Fundy in the fall and travels along the western Gulf of Maine as far south as southern New England.
2. A component of the coastal Maine juveniles, primarily three-year-olds, moves south in the fall to at least Massachusetts Bay.
3. The Georges Bank stock moves south after spawning in the fall and not into the Gulf of Maine in significant numbers.
4. A component of overwintering adults in the return spring migration moves from western Georges Bank and Jeffrey's Ledge along the coast of Maine to the Bay of Fundy.
5. The coastal Gulf of Maine area, particularly the southwestern part, is an area of heavy stock overlap during the winter and spring.

The NERFMC report properly emphasized the points that <u>any interpretation of tag recovery data must take into account the location, intensity, and seasonality of the fishery</u> -- which can at times be very localized, and the need for more tagging of spawning adults on the spawning grounds. (Planned international tagging of spawners on Georges Bank in autumn of 1977 was not possible because of the scarcity of fish).

A generalized hypothetical seasonal sequence of movements of adults of each of the three stocks is shown in Figure 29. The Georges Bank stock moves southward after spawning; overwinters in the Middle Atlantic Bight; and returns northward in spring. The Jeffrey's Bank stock movements are more problematic; possibly involving overwintering south of Cape Cod and summer feeding in the northern or offshore parts of the Gulf of Maine (including the Bay of Fundy). The Nova Scotia stock moves principally northward to Chedabucto Bay for overwintering, but a component may also move southward as far as Cape Cod.

The limited numbers of fish tagged, the short span of years during which intensive tagging has been carried on, and the very small number of returns do not permit conclusions about mortality rates.

4.6.4 Parasite Tags

Parasites have been used successfully as "natural tags" for the study of stocks and movements of marine fish for more than three decades. Such use is dependent on a number of factors: (1) parasites of fish often exhibit remarkable geographic variations in abundance, (2) some parasites, particularly

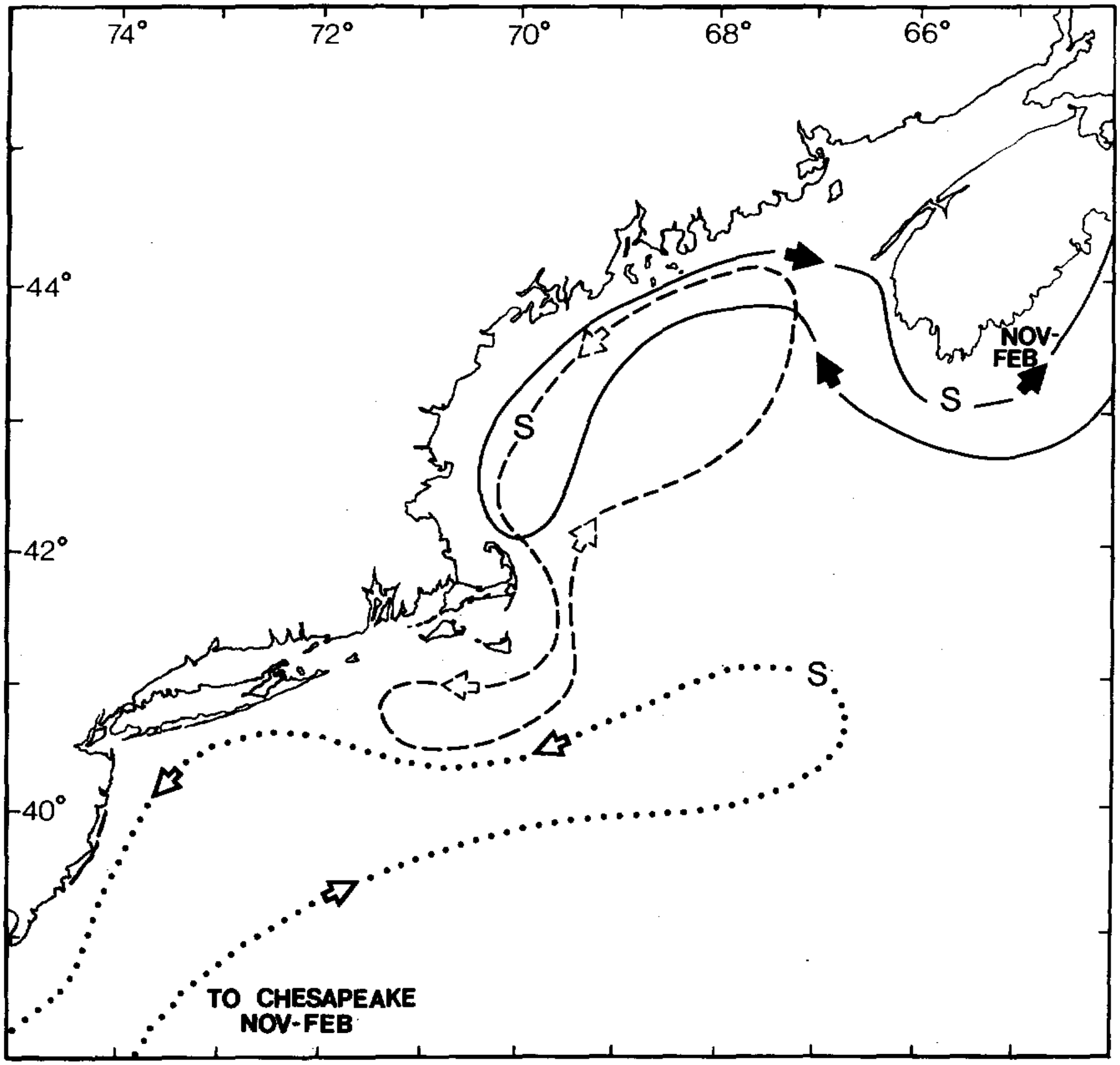


Figure 29. Hypothetical seasonal movements of three stocks of herring.

encysted larval helminths, are conspicuous and may persist in the host for several years in some instances, (3) encysted parasites are often relatively non-pathogenic, and probably do not materially reduce the likelihood of survival of the host. Parasite surveys have the added advantage of being relatively inexpensive when compared to tagging programs; such surveys may provide preliminary insights useful in planning tagging programs.

Early studies of parasites of adult herring (Sindermann, 1957a, 1961a) disclosed two encysted larval helminths -- a trypanorhynchan cestode and an anisakid nematode -- with geographic variations in abundance. The larval cestode was relatively abundant in Georges Bank and southern New England samples, rare in Nova Scotia samples, and absent in the Gulf of St. Lawrence. Conversely, the larval nematode was much more abundant in Nova Scotia samples than in Georges Bank and southern New England -- indicating only limited interchange between the two areas.

Subsequent studies of the larval nematode (Boyar and Perkins, 1971; Parsons and Hodder, 1971b; Lubieniecki, 1973) demonstrated its utility. Boyar and Perkins found that during eight years of sampling (1962-1969) the worms were at least twice as abundant in samples from Nova Scotia as they were in samples from Georges Bank and the coastal Gulf of Maine, and were more abundant in coastal Gulf of Maine samples than in Georges Bank samples. Lubieniecki found lower nematode incidences in samples from the Middle Atlantic Bight than those reported from more northern waters of Nova Scotia and Newfoundland. Parsons and Hodder found that the nematode was more abundant in Nova Scotia and Banquereau samples than in those from the southwestern Newfoundland and the southern Gulf of St. Lawrence. Similarities in incidences between winter samples from southwestern Newfoundland and spring-autumn samples from the southern Gulf of St. Lawrence were considered to be supporting evidence that the fish form part of a single stock complex, as did similarities in incidences between northeastern Nova Scotia samples and those from the Banquereau-Cape Sable area.

Among juvenile herring, a remarkable geographic discontinuity was found in the occurrence of a myxosporidan protozoan which causes intramuscular cysts. The parasite was common in one-and two-year-old fish from the western Maine coast, rare in fish from the central coast, and absent on the eastern coast in several years of sampling (Sindermann, 1957b, 1961a). The conclusion reached on the basis of distribution of this parasite (and that of the larval nematode discussed earlier) was that there was little eastward movement of juveniles along the Maine coast but possibly a greater westward movement of juveniles that had spent their first year of life on the eastern Maine coast. It is interesting that subsequent tagging studies have led to the same general conclusion.

4.6.5 Biochemical/Serological Identification of Stocks

Various attempts have been made to systematize and define subdivisions of species for management purpose (Muzinic, 1960; Parrish, 1964). One of the best definitions is that proposed at the 1957 ICNAF/ICES/FAO Scientific Workshop in Lisbon .... "a unit stock may be considered as a relatively homogeneous and self-contained population, whose losses by emigration and accessions by immigration, if any, are negligible in relation to the rates of growth and mortality ...". Other more pragmatic definitions of stocks were discussed in section 4.1.

Environmentally-modifiable phenotypic characters have been widely used to define unit stocks -- characters which often varied with year to year changes in environmental factors. Only recently, with the advent of biochemical/serological approaches to stock separation, have there been attempts to introduce concepts of population genetics. The unit concept in population genetics (a Mendelian population) was defined as "...a reproductive community of individuals which share in a common gene pool" (Dobzhansky, 1950). With this definition, differences between subpopulations of a species exist as differences in frequencies of certain genes in the common gene pool.

An excellent attempt to integrate the unit stock concept of population dynamics with the unit concept in population genetics was made by Møller (1971). He concluded that the two concepts can be equated -- that unit stocks can be considered equivalent to Mendelian populations, with the only point of difference that which relates to the effects of environment on genotypes of individuals. This is probably an oversimplification, neglecting such modifying forces as the dynamic state of the gene pool and disruptions of population stability by overexploitation. Nevertheless, the insertion of population genetics into thinking about unit stocks is an important and long-overdue step.

Biochemical/serological techniques progress in a stepwise fashion:

(1) Recognition of systematic individual differences in occurrence of particular phenotypic characters;

(2) Proposal of a genetic system that would explain the individual differences seen;

(3) Determination of the frequencies of each genotype in a spawning population;

(4) Determination of the closeness of fit of observed genotypes to those expected according to the Hardy-Weinberg law of genotype distribution in large randomly mating populations;

(5) Breeding and rearing experiments to confirm the proposed genetic basis for the system. (This step is often difficult to do with many marine species, and is usually ignored);

(6) Determination of frequencies of each genotype in other spawning populations;

(7) Tests for significance of any observed difference in gene frequencies between populations. (If samples are drawn from a mixture of populations, the observed frequencies will differ from those expected under Hardy-Weinberg rules, with an excess of homozygotes);

(8) Repetition of the entire process for other groups of variable characters (Two of three independent genetic systems are probably a minimum required to show differences between stocks -- depending on the degree of differences between gene frequencies and the complexity of the system, since multiple allele systems have more discriminating capacity than two-allele systems).

The biochemical/serological characters used are those which have simple Mendelian heritability, and are usually grouped in two-allele or multiple-allele systems.

Frequencies of alleles in some genetic systems may be remarkably similar throughout the range of a species (as is, for example, the C-blood-group antigen in Atlantic herring). Frequencies of alleles in other systems may vary significantly from one breeding population to another -- and these are the systems useful in stock identification.

Essentially, then, these techniques attempt to identify existing gene pools within a species and to determine whether there are significant quantitative differences in genotypes when samples of two or more breeding components of the species are compared.

Biochemical/serological studies of herring began in the mid-1950's, initially concentrating on blood group antigens (Sindermann and Mairs, 1959), but soon shifting to electrophoretic demonstrations of multiple enzyme fractions (Ridgway et al., 1970, 1971; Lewis and Ridgway, 1972; Odense et al., 1966a, 1966b). The blood grouping work proved to be inconclusive, after promising early results, because of the intrusion of physiological variables into the test reactions observed; the enzyme electrophoresis led to the description of several multiple-allele systems which were used in large-scale tests on many samples of herring from different geographic areas (Odense et al., 1966a, 1966b; Naevdal and Danielsen, 1967; Naevdal, 1969; Ridgway et al., 1971).

Odense et al. found differences in genotype frequencies among three Canadian herring populations; Naevdal et al. found genotype differences in Norwegian and North Sea herring; and Ridgway et al. found that gene frequencies in Georges Bank herring were different from those in western Maine and Nova Scotia herring. Ridgway et al. also examined samples from immature herring and found that gene frequencies in several enzyme systems of immature fish from Passamaquoddy Bay and western Maine were different from those of Georges Bank, but similar to those of adults spawning in southeastern Nova Scotia and western Maine.

CHAPTER 5

5. HERRING STOCK ASSESSMENT

CONTENTS

5.1 INTRODUCTION

Activities that can be categorized as "fishery resource assessment" or "stock assessment" include estimation of recruitment and year class strength, estimation of stock size (actual, minimum and optimum), estimation of fishing mortality, and the determination of effects of various exploitation rates on stock size.

As generalizations, there are three basic aspects of stock assessments:

(1) Determination of the abundance and age composition of each unit stock.

(2) Determination as to whether fishing mortality is great enough to affect stocks (for this we must have some measure of stock abundance).

(3) Prediction of stock levels in future years with respect to particular catch strategies.

Resource assessment efforts are thus divided between determination of the current status of stocks, and projections of future population size based on stock management decisions; the projections are obviously the more difficult aspect.

Assessments are dynamic; they depend on a constant flow of data from the fisheries and from resource surveys; they are constantly upgraded and often modified as new data become available; they require the use of assumptions; and they represent best estimates, not absolutes.

Critical to good fishery assessments are complete catch statistics and correct determination of ages of fish represented in catches. Reduced to simplest terms, some of the basic steps in assessments that relate to statistics and ages include the following:

(1) collect complete statistics on catches -- monthly or annually;

(2) determine length frequencies in catches;

(3) from the length frequencies and aging studies, calculate the numbers of fish of each age in the catch;

(4) set up a table which shows numbers of fish of each age group (year class) in the fishery for each year;

(5) from the table, the decline in numbers for each year class provides information about fishing mortality;

(6) by knowing the catch and the fishing mortality rate, the abundance of the year class can be estimated;

(7) by adding up the calculated abundances of each year class for any given year, an estimate of total stock size, by numbers and weight, is achieved;

(8) applying a range of fishing mortality rates and natural mortality rates to that size permits estimation of total mortality and determination of allowable catches, depending on the management strategy (maintenance, rebuilding at various rates) that is selected.

This simplified stock assessment procedure has been modified rather extensively for herring assessments after much discussion in ICNAF Herring Working Group meetings. The stock assessment procedure used for herring, as summarized by Sissenwine (personal communication) is as follows:

(1) collection of catch statistics;

(2) determination of length frequencies in the catch;

(3) determination of age-length key;

(4) estimation of the age composition of the catch for each year by application of the age-length key to the length composition of the catch; and

(5) application of virtual population analysis (VPA) to age composition of the catch data. Virtual population analysis is used to estimate fishing mortality rate by age for each year for which catch data are available, and to estimate strength of year classes at each age for each year. (Unfortunately, estimates of the fishing mortality rate and stock size by virtual population analyses are only reliable historically. That is, virtual population analysis typically is not a reliable method of estimating the size of year classes or fishing mortality rates for periods more recent than 3 to 4 years ago).

(6) Because of the difficulties mentioned in (5), historical estimates of population size or fishing mortality rates are related to some independent set of data (data not used in the virtual population analysis). Typically, stock size is related to relative abundance of a particular species in

research vessel surveys (as is the case with cod and haddock). Once such a relationship has been determined it may then be used to estimate stock size for the current year. Unfortunately, for herring research vessel surveys, data do not appear to be adequately related to estimates of stock size as indicated by virtual population analysis. On the other hand, the catch rate of juveniles in the sardine fishery appears to be strongly correlated with the strength of year classes as recruited to the adult fishery. Based on this qualitative relationship, the strength of incoming year classes is predicted and this information is used to assess the current status of the stocks.

(7) Projections of future stock size for specific levels of catch can then be determined by application of the catch equation. Thus managers may judge the impact of specific levels of catch on trends in stock size.

Some of the background analyses that contribute to meaningful assessments are: estimates of natural mortality (M); estimates of fishing mortality (F); estimates of abundance and recruitment; determination of growth rates (essential for determining surplus production -- along with estimates of recruitment and actual mortality); determination of catch per unit effort (which may in some instances be of lesser value if quotas are in effect); and construction of yield models.

Estimates of year class strength can be obtained from modified catch per unit effort data from the juvenile fishery (up to the processing saturation point, since underestimates result if markets or processing facilities are saturated). Generally, estimates of year class strength based on juvenile catch rates depend on the assumption of a constant exploitation rate in the juvenile fishery.

Sources of data for all these analyses have been tabulated in Table 4.

The best possible information about the size of the recruiting year class is very important in estimating stock size and allowable catches for fully exploited populations. Herring are recruited to the adult fishery principally at age 4, although to some extent at ages 3 and 5. Recruitment of herring to the adult fishery takes place at older ages in the Gulf of Maine; full recruitment does not occur until beyond age 5. The key observations on the subject of recruitment and stock size were made by Anthony (1972):

> "Due to fluctuations in year class strengths of Atlantic herring, I feel that any management of a herring fishery must be based on good estimates of recruitment by individual year classes, and management should be based on individual year classes if possible". But he also stated: "Stock and recruitment analyses are very difficult to interpret for clupeoid populations, due to normal fluctuations in year class abundance".

TABLE 4

SOURCES OF DATA FOR ASSESSMENTS		
METHOD	PARAMETERS MEASURED	CONCLUSIONS
research ship surveys of adults	abundance distribution	estimates of relative stock size
egg and larval surveys	spawning location and intensity early drift and survival of larvae	estimates of year class strength larval survival (if surveys are sequential)
juvenile surveys	distribution and abundance of 0, 1, 2 age groups	estimates of relative year class strength
pre-recruit (age group 3) surveys (from sardine and offshore purse seining)	distribution and abundance of age group 3	estimates of relative recruitment
age and growth studies	age and size	proportional representation of each year class in the catches; changes in growth rates
statistics from the fishery	catches effort year class representation locations of catches	yields compared to estimates of stock size, and estimates of previous stock sizes
biological studies	fecundity age at recruitment and first spawning	changes in age at recruitment and at first spawning

Estimates of recruitment should be based, ideally, on the following sequence of observations and analyses for each year class:

(1) egg bed surveys;

(2) larval surveys;

(3) juvenile surveys;

(4) juvenile fishery statistics;

(5) age group 3 recruitment;

(6) analysis of contribution of the year class to the fishery for as long as it is represented;

(7) hindcasts of the total contribution of the year class to the fishery.

The precision of the estimates increases from (1) to (5) (Figure 30). However, it should be pointed out that only items (1) through (4) are useful for predicting the strength of year classes in time to affect management decisions. It should also be pointed out that the steps carry disproportionate weights in terms of levels of precision of estimates. It is doubtful that steps (1) and (2) will give any reasonable estimate of trends in recruitment at the present level of precision of such surveys. Steps (3) and (4) may provide much better estimates. Steps (5) through (7) are essential to attempts to relate indices to actual estimates of abundance.

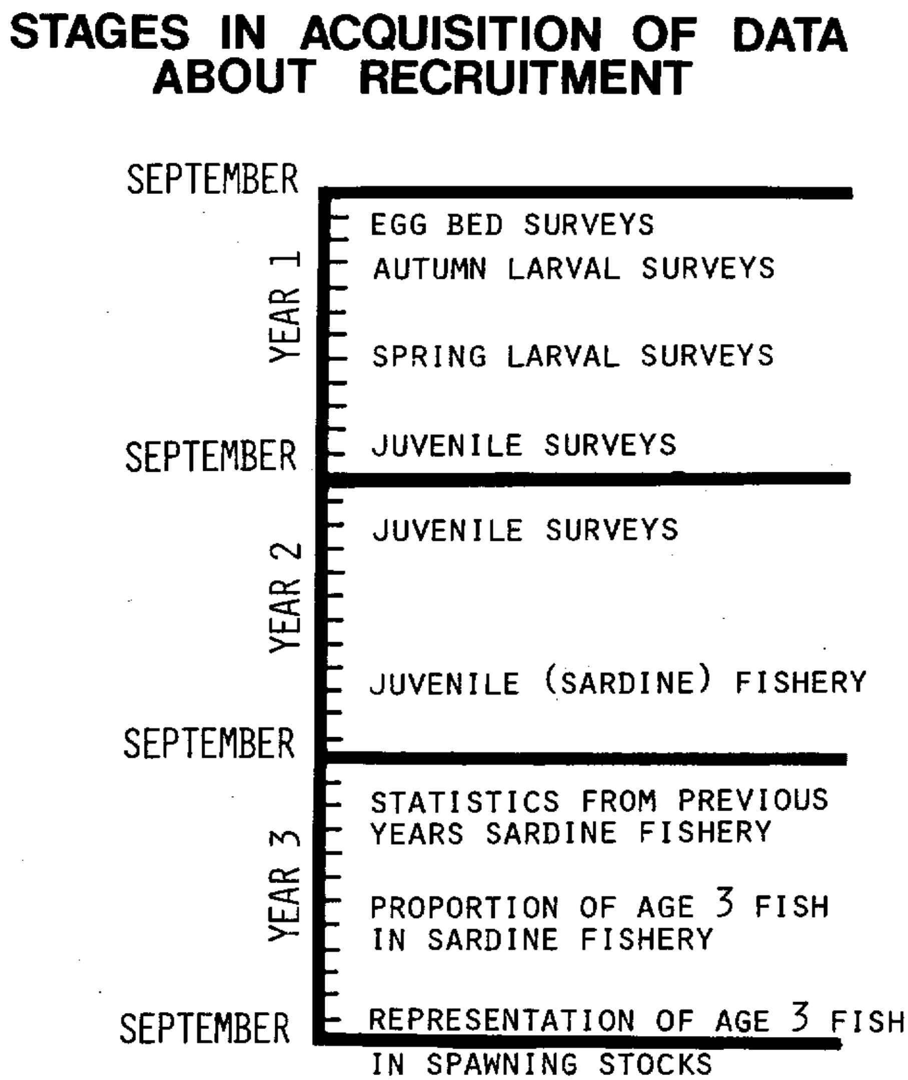


Figure 30. Sequence of steps in acquisition of data about recruitment of each year class.

The reality of efforts in recent years to determine recruitment to herring stocks of the western North Atlantic has been:

(1) Egg bed surveys have been conducted only sporadically in selected areas.

(2) Larval surveys were conducted sporadically beginning in the late 1950's, and annually in autumn-early winter since 1971. Spring larval surveys began in 1975. The longest time series is for selected stations on the Maine coast and particularly the Sheepscot Estuary, where annual larval surveys have been conducted by Graham since 1963.

(3) Juvenile surveys (age groups 2 and 3 primarily) began on Georges Bank in 1973. Surveys were conducted in March-April with bottom trawls -- which are less than ideal sampling tools for juvenile herring, although they may be useful at certain times of the year.

(4) Adequate juvenile fishery statistics have been collected for Maine and New Brunswick since the 1950's.

(5) Abundance of age group 3 has been determined from commercial purse seine catches on the Maine coast and from representation in catches of adult herring.

Some general findings have been that good year classes are generally good in all areas, and poor year classes are poor in all areas. Also, as fishing mortality increases, the total catch in any year probably depends more and more on recruitment levels (Anthony, 1972).

BASES FOR ESTIMATES OF ADULT STOCK SIZE

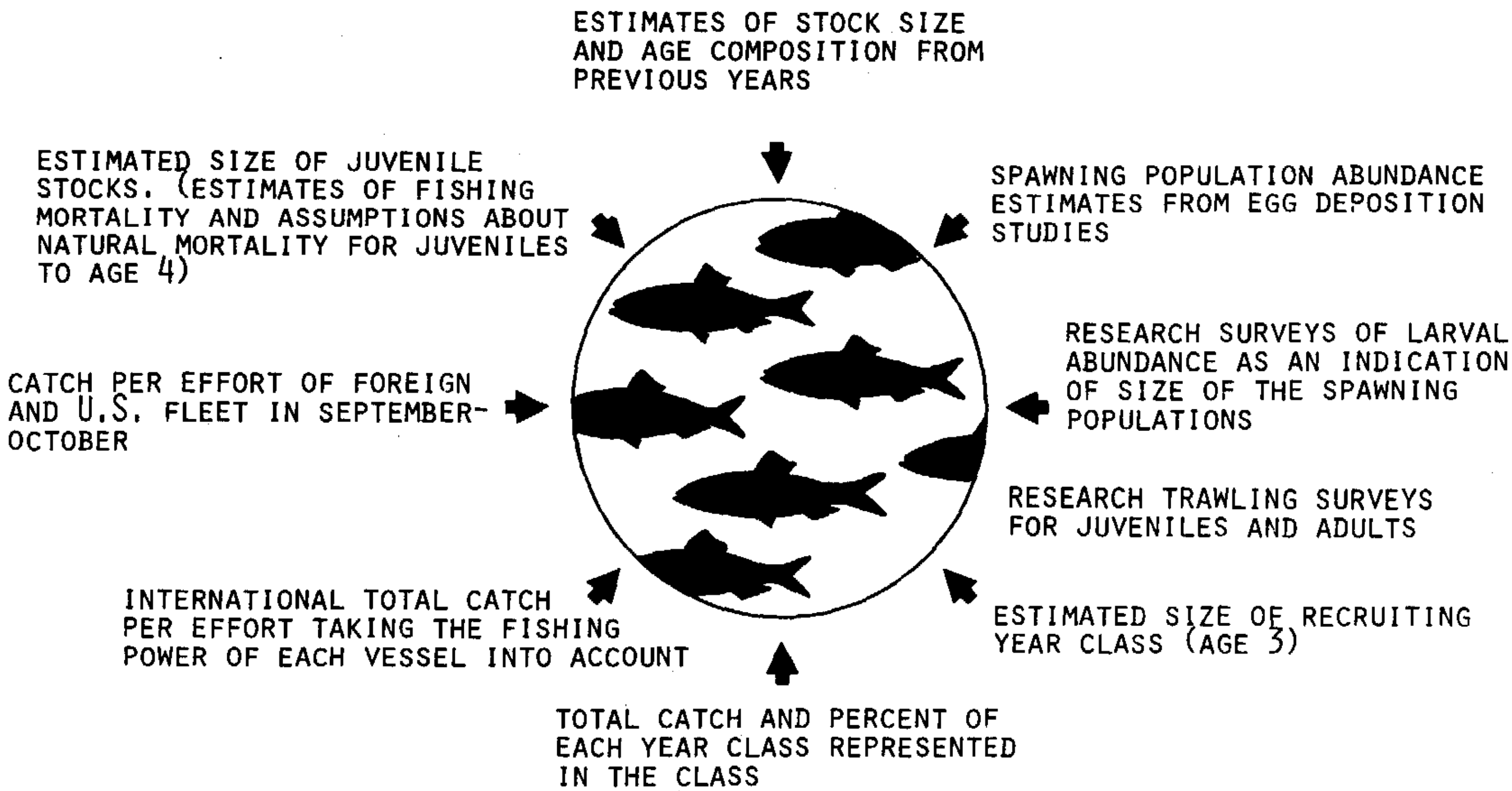


Figure 31. Background factors useful in estimating stock size. Actual calculations of estimated stock size may or may not make use of all of these items.

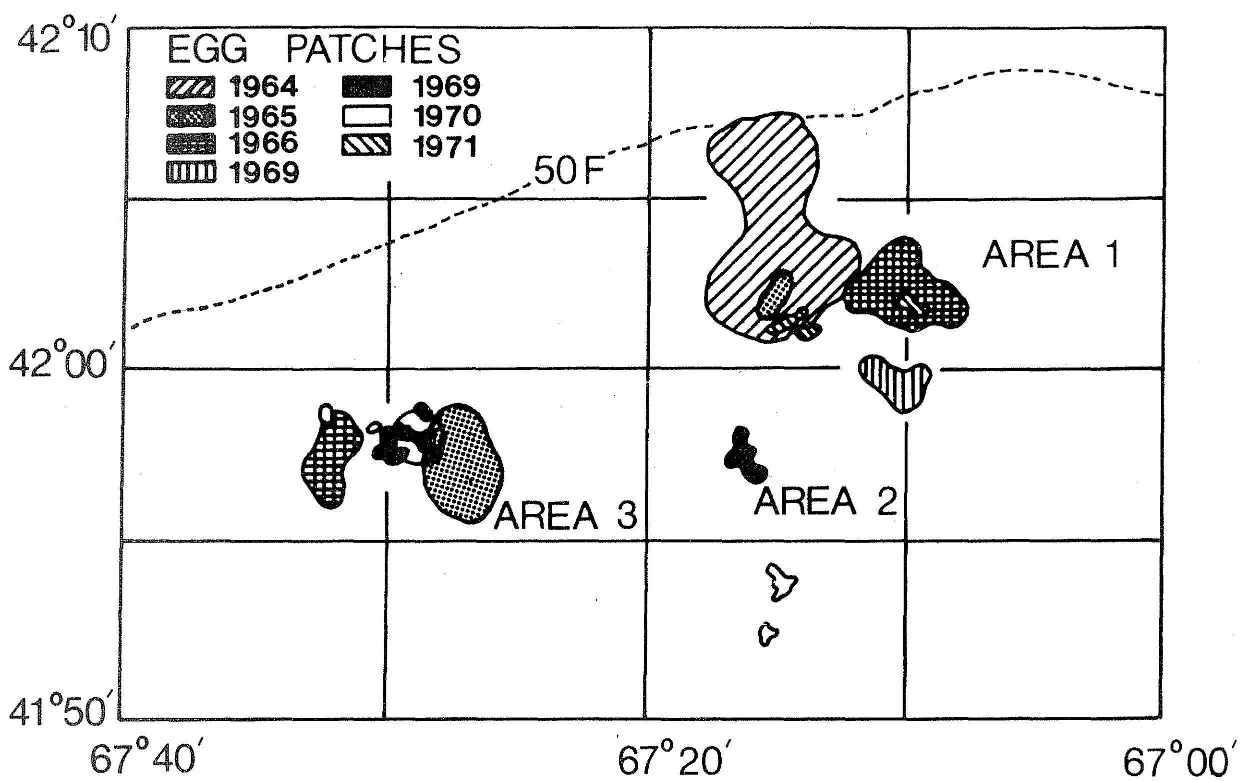


Figure 32. Estimates of sizes of herring egg patches on the northern edge of Georges Bank (from Anthony, 1972).

Estimation of the size of the recruiting year class is, of course, one important component in estimating stock size; other bases for estimating abundance of a particular stock are shown in Figure 31. (It is interesting that all these indices showed a strong decline in the areas of concern to this review from 1964 to 1971).

5.2 DATA ACQUISITION

There are three basic steps in stock assessment: (1) acquisition of data, (2) analyses of data for estimates of mortality, recruitment, and age composition of the population, and (3) integration of analyses to provide estimates of stock size and allowable catches, once the objectives of management have been stated by responsible officials.

Data useful for stock assessments come from many sources, including spawning surveys, larval surveys, juvenile surveys, trawling surveys for adults, and catch-effort statistics from fisheries. Data acquisition, which is the emphasis in this section, is tedious and expensive, but the accumulated data base has permitted the development of estimates which often approximate the real world. Some specifics about methodology are in the following subsections:

5.2.1 Spawning surveys

Surveys of the time, location, and intensity of spawning have been conducted sporadically in Canadian and United States waters for a number of years, principally as a approach to estimating the size of the spawning stock. The northern edge of Georges Bank has received most attention, and annual variations in location and abundance of the demersal herring eggs have been found (Figure 32).

Such surveys are labor-intensive, requiring multiple ship operations over an extended area in September-October.

5.2.2 Larval Surveys

Standardized autumn-early winter larval herring surveys began in 1971, principally on Georges Bank and adjacent areas. Spring larval surveys, to provide a comparison of larval abundance between autumn-early winter and spring, were instituted in 1975.

5.2.3 Juvenile Surveys

Largely because of the observation by the Soviets in 1972 of large numbers of age 2 herring in catches from Georges Bank, juvenile surveys have been conducted there since 1973. These have been bottom trawl surveys, conducted in March and April by vessels of several nations (FRG, GDR, Poland, Soviet Union, United States). They provide a fishery-independent measure of abundance of juveniles of age 2, but the general conclusion is that age 2 herring may only be found in offshore areas when the year class is very abundant.

5.2.4 Trawling Surveys for Adults

The Northeast Fisheries Center, NMFS, has been conducting spring and autumn trawling surveys from Nova Scotia to Cape Hatteras for well over a decade. While a bottom trawl is not an ideal sampling tool for a pelagic species such as herring, it does catch some adults as well as juveniles, and the relative numbers caught from year to year can provide an indication of abundance. Bottom trawls could provide good estimates of relative abundance if the sampling is designed for this purpose and intense enough to increase the precision of the current estimates. The present stratified sampling design is probably adequate to do this if sampling intensity could be increased and seasonal considerations taken into account.

5.2.5 Catch Statistics

Statistics from the juvenile (sardine) fishery have provided the best source of information about recruitment to adult stocks. When year classes are poor or mediocre, the juvenile fishery probably provides a reasonable estimate of recruitment to the adult fishery. However, the utility of juvenile catch statistics in estimating recruitment declines when a very good year class enters the fishery, since gear and processing components cannot respond quickly enough to rapid increases in supply. Despite this limitation, Anthony and Waring (1978) concluded that Maine juvenile catches can be used as a pre-recruit index of abundance and that they do indicate very good or very poor year classes, but are less useful in estimating abundance of intermediate-sized year classes. It should be noted, however, that the juvenile catches will no longer be a useful assessment tool if comprehensive management strategies are developed which apply to herring fisheries for all age groups.

Accurate catch statistics from the adult fishery are vital to the development of estimates of stock size. Determination of the numbers and relative proportions of each year class in catches provides information about year class survival, and about fishing mortality. Reliable aging methods are important.

5.2.6 Fishing Effort

Measures of fishing effort that are directly proportional to mortality are difficult to achieve for herring fisheries, since a wide variety of fixed and mobile gear is used. Fixed gear includes weirs, stop seines, and gill nets (drift nets). Mobile gear includes pair trawls, purse seines, mid-water trawls, and bottom trawls. Efficiency of the mobile gear far surpasses the fixed gear.

5.3 QUANTITATIVE METHODS USED IN ASSESSMENTS

Data acquisition is of course a continuous process, and even so, analyses must proceed with what is at best a limited sampling. This section is concerned with phase two of stock assessment activities -- the analyses of data to determine natural and fishing mortality, to estimate year class strength and recruitment, and to determine the relative representation of year classes in the population.

5.3.1 Determination of Natural Mortality

Herring and other fish die from a number of causes other than being caught by fishermen. Probably the principal cause of death is predation by fish (and to a lesser extent by marine mammals, and even fish-eating birds). Other causes are starvation, disease, stranding, and extremes of physical or chemical environmental factors.

The sum of all of these non-fishery related deaths is termed natural mortality (M), and of course its proper estimation is an important element in determining abundance of a population. Natural mortality is usually treated as a constant, but there is disagreement among quantitative biologists as to what the constant should be. The important point to be considered is the sensitivity of the conclusions of the assessment relating to the assumptions of natural mortality.

Anthony (1972) had identified the problem rather well, and has shown graphically how estimated stock sizes may vary drastically under different assumptions of natural mortality. He used three values of M: 0.2, 0.3, and increase with age. Using the increase with age factor for M, estimated stock size for particular years may be almost twice as great as estimates derived from use of the 0.2 factor for M (Figure 33), although the differences in estimates may be very small in other years.

Anthony pointed out that some European herring biologists believe that M is a constant 0.2 or less, though they agree that M may increase with age. Soviet and Polish biologists believe that M is much greater, and may reach 1.0 for fully recruited age groups. Anthony, in his calculations, assumed

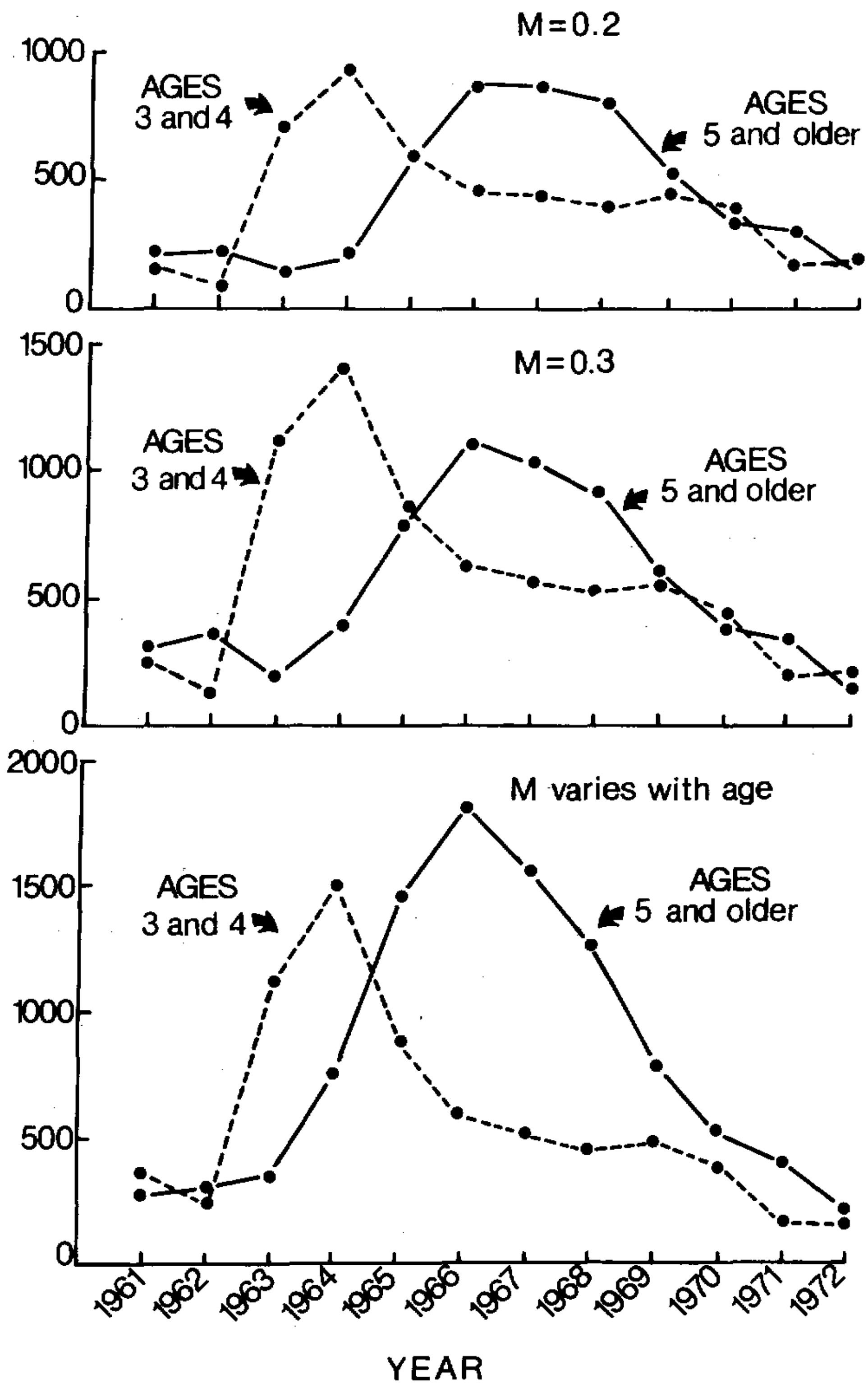


Figure 33. Stock size of recruits and fully recruited Georges Bank herring under three assumptions of natural mortality (from Anthony, 1972).

that M increased with age, and his calculated biomass changes (Figure 34) suggest that this is the case. His assumed values for M between ages 5 and 8 are: 5 = 0.15-0.32; 6 - 0.40-0.43; 7 = 0.47-0.55; 8 = 0.54-0.82.

Recent herring assessments by the Northeast Fisheries Center have assumed a constant natural mortality rate rather than a rate increasing with age, based on the observation that absolute estimates of stock size are very sensitive to natural mortality, but trends in estimated stock size are insensitive to estimates of natural mortality.

5.3.2 Determination of Fishing Mortality

Measures of fishing mortality (F) are:

(1) F(max) which is the instantaneous fishing mortality rate which produces the maximum yield per recruit at a specific age at recruitment to the fishery;

(2) F(msy) which is the exploitation rate at which the average long-term catch from a stock is maximal, and is a function of the total production processes within the stock (NERFMC, 1978);

F(max) and F(msy) may be the same in those situations where the average recruitment does not change directly in response to changes in stock abundance. F(max) is not useful for non-equilibrium fish populations, since it does not consider the

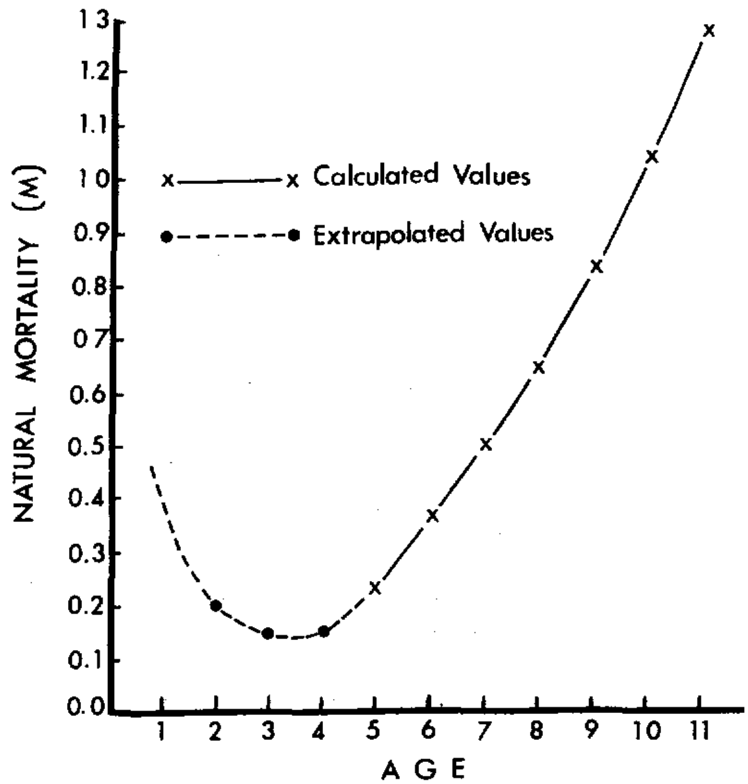


Figure 34. Changes of natural mortality with age (after Anthony, 1972).

magnitude of annual recruitment. The problem with F(max) occurs when recruitment is directly related to spawning stock size. In this case a strategy of fishing at F(max) leads to continuous decline in recruitment and eventual collapse of the fishery. Therefore a more restrictive system, setting F below F(max) would be justified for species such as herring. This is:

(3) F(0.1) which is the exploitation rate at which the change in yield per recruit with respect to mortality rate is one-tenth of that corresponding to the fishery beginning on virgin stock. (F(0.1) could result in only a small loss in average catch, but should achieve a higher stock size and greater stability of the stock because of the presence of a greater number of age groups, and higher catch per unit effort. Gulland and Boerema (1973) considered $F_{0.1}$ to have the following favorable characteristics: (1) it provides a high yield per recruit, and (2) it is closer to the economic optimum, while maintaining a spawning stock sufficient to provide reasonable recruitment.

Even though F(msy) is difficult to estimate or define, it is still possible to estimate a maximum equilibrium yield from pelagic stocks based on historical recruitment and the assumption that future recruitment will follow a similar pattern.

F(0.1) may be a level of fishing mortality that corresponds reasonably to F(mey), assuming long-term average recruitment. The MEY for the Gulf of Maine is estimated to be 15,000 MT.

$F_{0.1}$ determinations depend on definition of what a "virgin stock level" is, and are based on age at recruitment to the fishery, growth rate, and natural mortality rate. For herring and other pelagic stocks great annual fluctuations in recruitment occur so it is difficult to define what a long-term virgin stock level is. For example, the good 1960 and 1961 year classes built the Georges Bank stock size to a very high level of 1.2 million MT (estimated) in the mid-1960's -- a level which we may not see again. Such a level should not be considered a "virgin stock level".

As a general rule of thumb in herring fisheries management, Anthony (1977) feels that ..."to manage on a long-term sustainable basis, if you have a good estimate of what a long-term virgin stock size has been, you can take one quarter to one third of that virgin stock level on a sustained basis as a general management tool". While such a rule of thumb may be valid for herring, it cannot be applied to all fisheries. Its application to fisheries such as redfish or ocean quahogs, which concern species with very slow growth rates, would be disastrous.

Lett and Kohler (1976) in simulation studies considering recruitment, environmental perturbations, species interactions, density dependent growth to age 1, and growth and life expectancy, found that maximization of production occurs at exactly one-half the virgin stock biomass.

For some stocks in which there is large fluctuation in recruitment, maintenance of an equilibrium spawning stock biomass of about two-thirds the virgin stock should provide an adequate buffer against depletion in the presence of large fluctuations in recruitment (Doubleday, 1976; U. S. Dept. Commerce, 1977, p. 74).

Another approach to assessments for management purposes is to determine stock size and review the past history of that stock to see what the effects of specific exploitation rates have been on stock sizes in existence at those times.

The recent history of the Georges Bank-Gulf of Maine fishery has been one of dramatically increasing catches, so that F increased to levels approaching 1.0. Early (1972) stock assessments by ICNAF suggested that an $F_{0.1}$ value of 0.3 for herring of ages 3-9 could be used to provide an estimate of a total allowable catch that would provide reasonable yield per recruit and also maintain a spawning stock that could provide a reasonable level of recruitment (Anthony and Waring, 1978). These conclusions of course referred only to stock levels existent of that time. Advice given to ICNAF in 1973 (Redbook, 1973) was that fishing mortality in excess of 0.5 would place spawning stocks in jeopardy. Catches were severely restricted after that time.

Recent calculations of Georges Bank and Gulf of Maine stocks (NERFMC, 1978) indicate that fishing mortality rates corresponding to $F_{0.1}$ are 0.34 and 0.33 respectively (Figure 35).

5.3.3 Estimates of Year Class Strength and Recruitment

Information about year class strength begins to accrue from late autumn and winter larval surveys, spring larval surveys, juvenile surveys (age groups 0, 1 and 2), statistics from the juvenile fishery (age group 2), determination of the representation of the year class at age 3 in the juvenile fishery, calculations of extent of recruitment into the adult fishery at age 3, and the relative abundance of the year class as it moves through the adult fishery. The precision of estimates of year class strength of course increases as the fish approach recruitment into the adult fishery, but early estimates are important to management decisions concerning total allowable catches in any given year, both for juvenile and adult fisheries.

There are correlations between good and poor year classes among the three stocks considered -- which, as Ridgeway (1975) pointed out, might be explained by a general similarity in the ocean climates where the three stocks live. This correlation

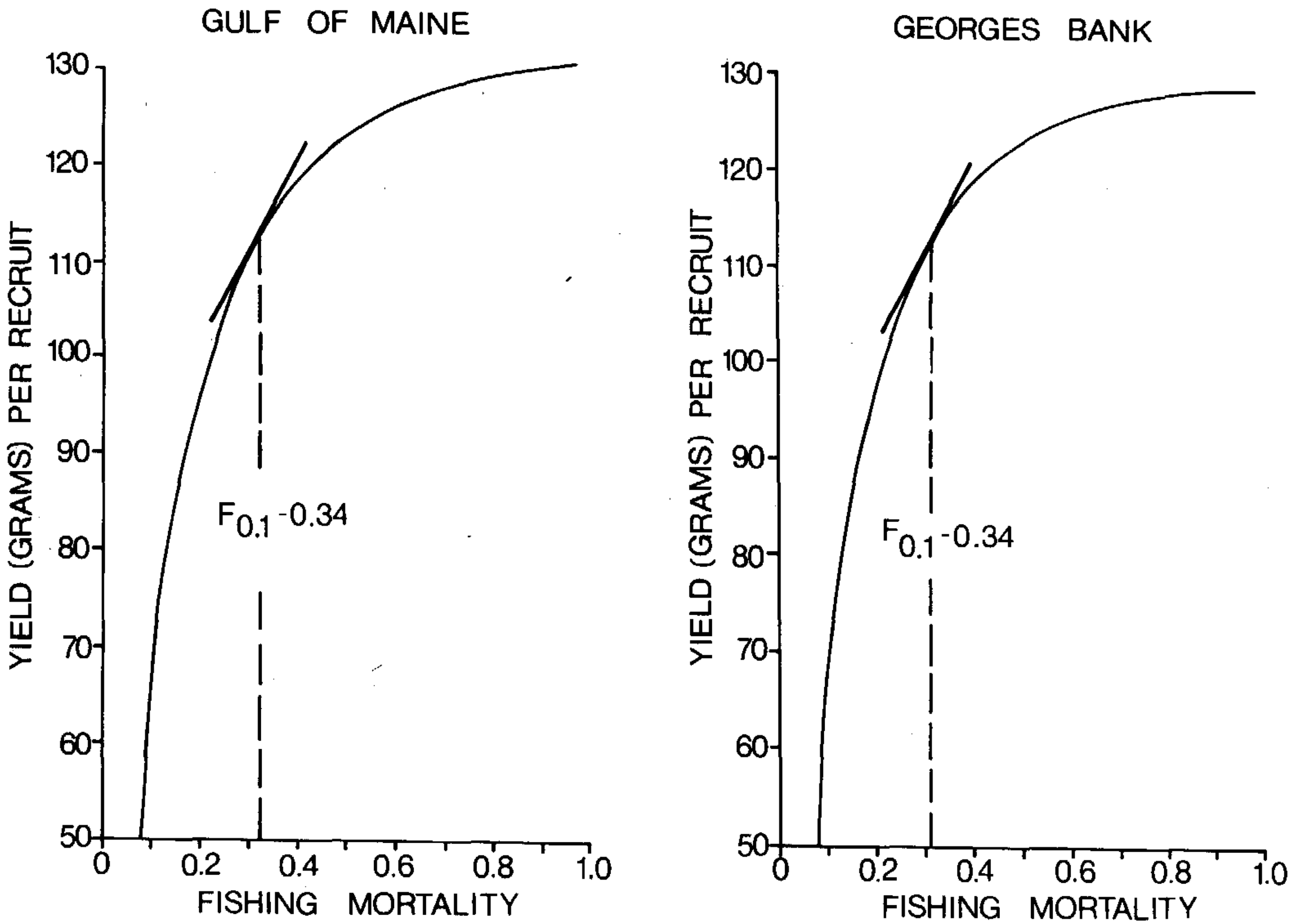


Figure 35. Beverton-Holt yield per recruit curves for Georges Bank and western Gulf of Maine herring (from NERFMC, 1978).

was considered close enough by Anthony (1972) so that he felt that recruitment indices developed for one stock (Gulf of Maine) could be applied reasonably to the others.

As might be expected, the correlation is not perfect. For example, the very good 1970 year class on Georges Bank was estimated in 1973 to be only fair (75% to 100% of the size of the reference 1966 year class) based on catches of age 2 juveniles on the Maine coast. Only when the year class began to be recruited into the adult fishery on Georges Bank, at age 3 and beyond, did its real strength become increasingly apparent (Figure 36). The final estimate made in 1975 was that the 1970 year class was twice the size of the 1966 year class.

It should be pointed out, however, that this discrepancy between initial and later estimates of the size of the 1970 year class does not detract seriously from the otherwise strong correlation between sizes of the year classes in the Gulf of Maine and Georges Bank. The 1970 year class now appears to be twice as strong as the 1966 year class in both areas.

Because important fisheries exist for age 2 herring in Maine and New Brunswick, as well as for age group 3 and older fish throughout the area of concern to this paper, estimates of year class strength must be made as precisely and as early in the life of each year class as possible. "Recruitment" or entry of year class into the fishery occurs at age 2 for Maine-New Brunswick juvenile stocks, but not until age 3 or 4 (or even later) for adult stocks.

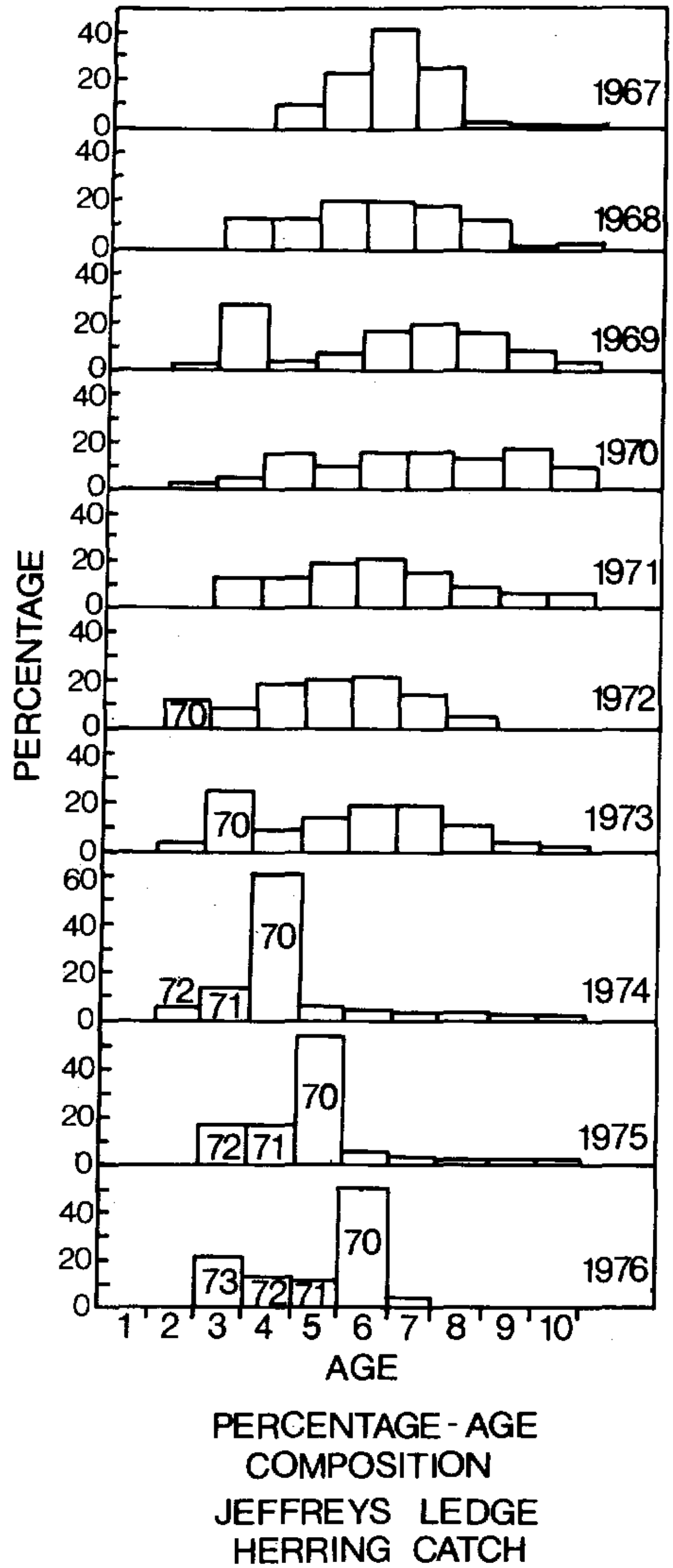


Figure 36. Representation of the strong 1970 year class in the fishery (from Anthony, 1977b).

Estimates of adult stock size depend to a large extent on the size of the recruiting year class in any given year. The level of recruitment of herring has been estimated from:

(1) autumn-early winter larval surveys, principally in the Georges Bank area, which began in 1971, and spring larval surveys, which began in 1975;

(2) juvenile surveys with bottom trawls conducted in March and April since 1973, principally on Georges Bank;

(3) catch-effort information from the juvenile fishery -- probably the best source of information about recruitment to the adult fishery, but not without shortcomings.

Estimates are reviewed and revised annually as the year class enters and passes through the fishery.

In making determinations of recruitment, the size of the poorest year class observed in the fishery -- the 1969 year class, estimated to be 550,000,000 fish at age 3 (Georges Bank stock) -- is used as a reference (this figure was revised in 1975 to 610,000,000 fish based on virtual population analysis). Each year class is assumed to be at this minimum size until data accumulate to modify the assumption. The assumption was made as a result of interaction between ICNAF scientists and managers, as an appropriate assumption for developing robust management strategies. However, the assumption seems to be too conservative, in that the 1971 and 1972 year classes appear to be even poorer than the reference year, perhaps by as much as an order of magnitude.

The optimum size for harvest of herring is between ages 4 and 5 for calculating maximum yield in terms of weight per recruit.

Errors on the low side in estimates of recruitment result in gains in terms of yield per recruit; errors on the high side result in too low an estimate of yield per recruit. A conservative original estimate of recruitment is safer, in that it could keep stock size at such a level as to increase the probability of good recruitment, and to decrease the probability of very low recruitment. If necessary, the estimate can be revised upward as data improve. It should be noted, though, that with the recent drastic reduction in fishing mortality rate, an estimate on the low side may in fact result in some additional loss in yield per recruit. This would not be true in areas where total fishing mortality rates are much lower.

Very poor recruitment of a single year class will not seriously affect the long-term size of the spawning stock, unless the fishery is intensive. However, if there is a series of very poor year classes, then stock size will decline -- and if the fishing mortality is high, the decline can be severe.

5.4 INTEGRATION AND ANALYSES

The final step in stock assessment is the integration of analyses for each variable, and the estimation of stock size and changes in stock sizes that would equate with different levels of catches, and an interpretation of what that stock size means relative to previous stock size. In simplest form, estimates of stock size are made from catch information, estimates of weights of fish at each age, estimates of fishing mortality, and assumed natural mortality. The specific technique -- called "virtual population analyses" (Gulland, 1965) or "cohort analysis" (Pope, 1971) is a calculation which provides estimates of stock size. It depends heavily on good catch statistics and reliable aging of fish, and it provides best estimates of mortality when the fishing mortality rate is increasing steadily; it decreases in precision with decreases in fishing mortality. Restrictive allowable catch regulations can cause problems in making estimates if current catches are expanded to total stock size using an estimate of fishing mortality rate. The measures, usually from the commercial catch effort data. that are often used to estimate fishing mortality rate may be greatly changed by restrictive regulations; compared to what they were in the years preceding. The effect of restrictive total catches on accuracy of virtual population analysis comes into play only because the accuracy with which one can estimate a year class depends on the cumulative fishing mortality rate. If fishing mortality rates are relatively high, then one has a good estimate of year class size when fish have been in the fishery only a very few years. If fishing mortality rates are low, then one has to go back a good many more years to sum the fishing mortality rate to such a level that the estimate of year class size can be considered accurate.

5.4.1 Estimates of Stock Size

Estimates of stock size in the adult fishery are based on the assumption that incoming year classes in the Gulf of Maine adult fishery begin to recruit at age 3 but are not fully recruited until age 7, while incoming year classes in the Georges Bank fishery begin to recruit at age 3, and are fully recruited at age 5. This means that the effects of variations in year class strength will be felt earlier on Georges Bank than in the Gulf of Maine.

In considering stock size, there are several terms that should be defined:

Optimum stock size: stock size as related to particular management goals, which could be "the stock size which should provide long-term maximum sustainable yields", or "that level of abundance which when fished at $F_{0.1}$ will be maintained, given long-term average recruitment". ICNAF has estimated optimum stock size for Georges Bank (Div. 5A and SA6) and Gulf of Maine (5Y) to be 500,000 MT and 100,000 MT respectively.

Minimum stock size: the stock size below which the likelihood of very poor recruitment is great. ICNAF has estimated minimum stock size for Georges Bank and Gulf of Maine to be

225,000 MT and 60,000 MT respectively. Minimum stock size in terms of the ICNAF management regime for herring is a stock below which there would be no fishing, and in only that sense it is minimum stock size. That is, ICNAF managers said that they did not wish the stock to fall below the best estimate of the size for which the likelihood of low or poor recruitment is large, and that would be the minimum stock size.

5.4.2 Estimating Effects of Management Actions

Once reasonable estimates of stock size and recruitment have been made, and management objectives clearly defined, the final step -- estimation of effects of management actions concerning allowable catches on stock size -- can be taken. Beginning with the assumption that the herring stocks considered in this paper are at or below minimum stock size, then the only viable management options are whether to maintain the stocks at their present low levels, or to allow stocks to rebuild. If rebuilding is the choice, then the rate of rebuilding will depend on the size of allowed removals by the fishery. (Another option, that of driving stocks further down, has been suggested as an experimental test of a fishery model developed for Gulf of St. Lawrence herring).

An essential consideration is surplus production of each stock, which is the increase in weight resulting from recruitment and growth of individual fish minus the weight of all fish that die of natural causes (other than fishing). An important aspect of surplus production was pointed out recently by Sissenwine (in a memo to NERFMC dated December 2, 1977). He stated:

> "For herring four years old and older, the growth rate of individual fish of each year class is less than the weight of fish dying from natural causes, so the older fish do not contribute any surplus production to the stock -- in fact the net decrease in biomass of fish greater than four years old must be offset by the net increase in biomass of younger fish before there is any net production".

To illustrate the point, Sissenwine went on as follows:

> "While the variation in assumed sizes of 1973 and 1974 year classes will have only minor impact on surplus production in 1978, the size of these year classes has a very significant effect on stock size.
>
> If these year classes are weaker than assumed then the stock is at an extremely low level and the probability of recruitment failure because of inadequate spawning stock is increased. (This applies to the Gulf of Maine and Georges Bank also)".

5.5 ASSESSMENTS MADE SINCE 1961 -- YEAR BY YEAR SUMMARY

Data relevant to stock assessments have been collected for the three stocks considered in this paper -- Georges Bank, Gulf of Maine, and Nova Scotia -- with varying intensity since the early 1960's, and even earlier for the juvenile stocks of Maine and New Brunswick. However, it was not until about 1970, when concern about the status of stocks intensified, that adequate assessments were made. This section attempts to summarize the history of assessment activities, principally under ICNAF, on an annual basis.

5.5.1 Georges Bank Stock Assessment: Year Class Strength, Recruitment, Stock Size, Allowable Catches, Actual Catches

Exploitation of the Georges Bank herring stock by distant water fishing fleets began in 1961; catches peaked in 1968 at 374,000 tons. An accumulated biomass and two strong year classes (1960 and 1961) resulted in a maximum stock size in 1967 of 1.14 million tons, but mediocre recruitment during much of the 1960's (Figure 37) and intensive fishing (exceeding surplus production) reduced the stocks to low levels by 1972 (Figure 38), when ICNAF regulation began.

Since the inception of multinational fishing for herring on Georges Bank in 1961, data were collected that provided information about the amount of catches, the relative representation of year classes in the fishery (Table 6) and the amount of fishing effort applied. These data were augmented by survey collections, so that a reasonable base for assessments was developed. Estimates of year class strength, recruitment, and stock size were prepared annually under the aegis of ICNAF, and are summarized in the following pages.

GEORGES BANK RECRUITMENT

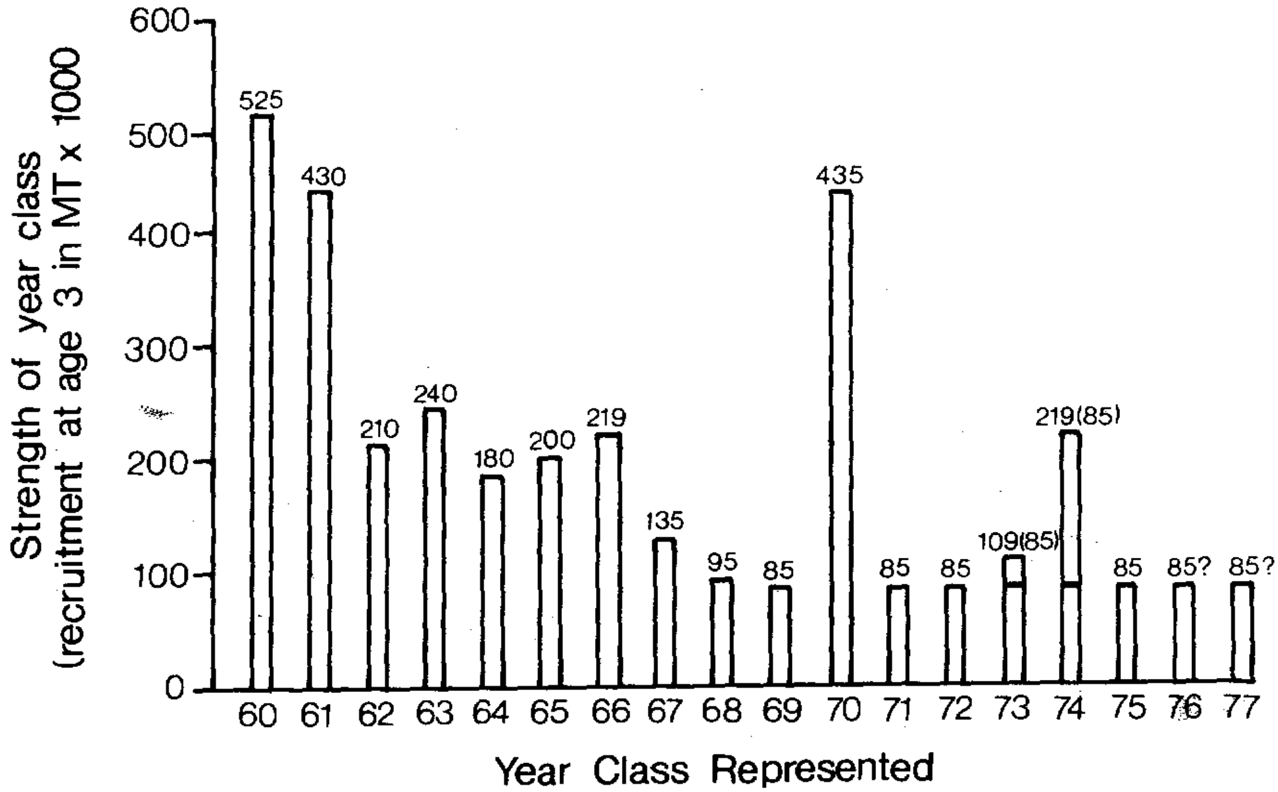


Figure 37. Estimated annual recruitment to Georges Bank stock 1960-1977 (modified from Anthony, 1977b).

Note: Figures in parentheses for 1973 and 1974 are original estimates, which were revised upward based on strength of these year classes in the Maine juvenile fishery. Indications are now that the 1975 and 1976 year classes are lower than assumed by ICNAF assessment committees.

This graph shows that year class strengths have varied by as much as a factor of seven (in terms of biomass at age 3).

GEORGES BANK STOCK SIZE

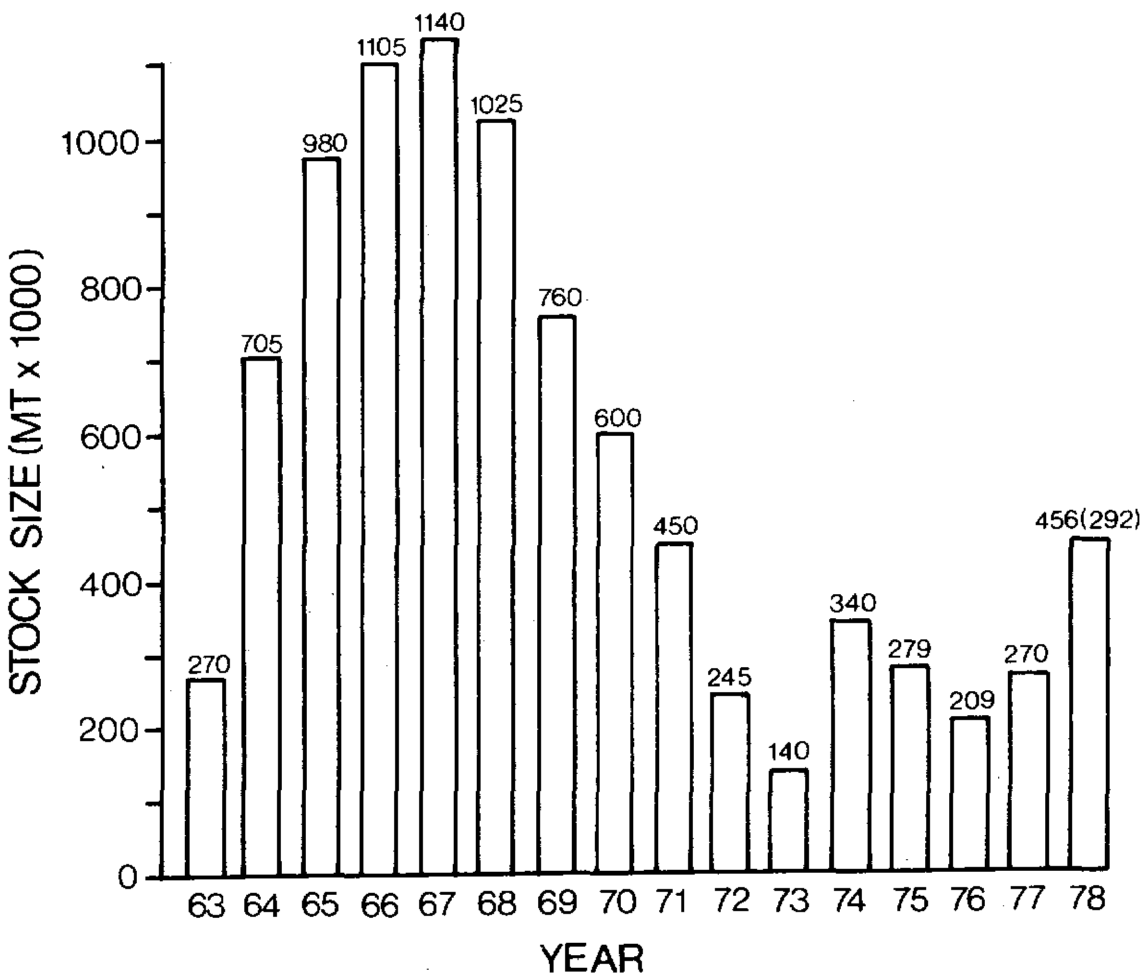


Figure 38. Estimated Georges Bank stock size, 1963-1978 (age 4+ at beginning of year) (modified from Anthony, 1977b).

Note: 1977 stock abundance is based on revised assumption of 1973 year class abundance -- from 85 to 109.

1978 stock abundance based on revised assumptions of 1973 and 1974 year class abundance -- from 85 to 109, and from 85 to 219.

Value in parenthesis for 1978 is the estimated stock size based on original estimates of strengths of 1973 and 1974 year classes (85 + 85).

Even the value in parentheses may be an overestimate, in view of the remarkable low 1977 catch. NERFMC 1977 (Dec.) has assumed a conservative 1978 stock level of 199,000 MT -- and even this may be optimistic, in view of the vanishingly small 1977 catch (<1,000 MT).

Table 6. Georges Bank stock size (millions) at age (from Anthony, 1977b).

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11	Age 12	Age 3 and older Numbers (10^{-6})	Age 3 and older Weight (MT(10^{-3}))	Age 4 and older Numbers (10^{-6})	Age 4 and older Weight (MT(10^{-3}))
1961		666.5	449.9	629.4	274.7	51.6	13.1					2085.2	396.8	1418.7	303.5
1962			533.2	327.5	359.7	166.9	29.7	4.4				1421.4	310.6	1421.4	310.6
1963		3718.3	733.8	397.3	178.1	23.9	9.6					5061.0	792.2	1342.7	271.7
1964	1867.6	2901.4	2872.1	541.0	193.5	84.6						6592.6	1111.9	3691.2	705.7
1965	2112.5	1514.2	2239.0	2142.9	326.7	70.2	37.7					6330.7	1195.5	4816.5	983.5
1966	1585.3	1729.2	1230.4	1801.6	1661.3	244.4	46.0	22.5				6735.4	1346.8	5006.2	1104.8
1967	1754.9	1297.6	1404.2	976.0	1313.9	1106.7	141.2	25.4	16.6			6281.6	1325.0	4984.0	1143.3
1968	1909.5	1435.2	1056.2	1094.8	701.4	848.9	563.0	70.9	10.7			5781.1	1228.9	4345.9	1028.0
1969		1561.1	1127.9	744.1	592.3	363.1	303.3	156,4	38.3			4886.5	981.3	3325.4	762.8
1970	854.7	969.9	1211.7	732.7	358.5	233.3	126.7	76.0	20.8			3737.6	737.4	2767.7	601.6
1971	758.7	688.4	680.4	584.4	355.3	182.8	107.0	57.0	35.4			2690.9	545.4	2002.5	449.0
1972	3843.7	609.5	262.7	307.9	221.0	131.8	55.7	42.0	34.1			1664.7	331.4	1055.2	246.1
1973	756.8	3121.7	467.3	115.6	58.5	38.0	17.4	4.9	8.1			3831.5	580.6	709.8	143.6
1974	745.1	610.6	1627.4	141.9	36.7	18.0	10.3	3.4				2448.3	427.6	1837.7	342.1
1975	955.0	608.3	463.8	786.0	54.1	18.4	9.2	5.2	0.9			1945.9	364.3	1337.6	279.2
1976	1908.2	780.6	487.7	310.7	197.7	13.0	3.7	2.1	0.5	0.6		1796.5	318.0	1015.9	208.7
1977 1/		1561.0	631.9	393.0	237.4	37.6	6.1	1.0	0.6	0.1	0.2	2868.9	488.6	1307.9	270.1

1/ Stock size calculated from the relationship $N_{1+1} = N_0 e^{-z1}$

1976

This seems to be a good year class based on following criteria; abundant in 1977 Maine juvenile catches at age 1; present in numbers in the spring 1978 offshore young herring survey; most abundant year class ever observed by Graham in Sheepscot estuary autumn larval surveys. Canadian biologists also report the 1976 year class as abundant on the New Brunswick and Nova Scotia coasts. The only negative finding was that larval abundance on Georges Bank in December 1976 was the lowest ever observed (ICNAF Redbook, 1977).

1977

Herring larvae were almost completely absent in plankton collections from Georges Bank in late autumn 1977. Only one patch was found, on Nantucket Shoals, and the 1977 index for Georges Bank and Nantucket Shoals combined was the second lowest on record, intermediate between the 1971 and 1976 indices (Lough, 1978).

Estimates of year class strength have received recent critical scrutiny -- especially the estimates for the 1973 and 1974 year classes. Several significant statements have been made: (1) "The diminishing catches due to ICNAF quotas have in recent years provided less accurate base for determining the 1971-1974 year class strengths, since the analytical technique used to assess year class strength and fishing mortality rate (cohort analysis) is most accurate under conditions of increasing exploitation" (NERFMC, 1978, p. 13). (2) The unexpectedly low catches in 1977 (less than 1,000 MT) suggested that the 1973 and 1974 year class abundances were overestimated, possibly badly so -- or that those year classes may not have recruited to the spawning stock, or that some change in distribution had occurred, or that the maturation rate may have been retarded. A herring working group report (November, 1977) suggested that the conventional year class size for poor year classes (610 million fish or 85,400 tons at age 3) should be assumed for the recruiting 1974 year class in 1978 -- but that in view of the almost total absence of herring on Georges Bank in 1977 this conventional level of recruitment (equal to the poorest observed for the Georges Bank fishery) may not be conservative any longer.

5.5.1.2 Stock Size and Allowable Catches -- Georges Bank

Recruitment, stock size, total allowable catches, and actual catches for Georges Bank have been summarized by Anthony (1977) (Table 7). The strong 1960 and 1961 year classes resulted in a high level of abundance in the mid-1960's, and produced high catches, building to a peak of 373,000 MT in 1968. Estimated stock size dropped from 1968 to 1972, to a low of 146,000 MT at the end of 1972. In 1973 the strong 1970 year class was recruited as 3-year-olds; this caused a temporary resurgence of estimated stock size (Figure 39). Subsequent year classes (except for 1974) have been poor to mediocre, but an effective TAC of 150,000 MT beginning in 1974 should have slowed the rate of reduction in estimated stock size. Still further limitations on catch (60,000 MT in 1976, 33,000 MT in 1977) were expected to permit rebuilding of stocks, but catches (43,000 MT in 1976, <2,000 MT in 1977) indicated that stock size had been overestimated, although inability to catch herring may have been partially related to peculiarities in the "windows" in which fishing on prespawning and spawning fish was permitted.

Table 7. Management Scenario - Georges Bank Herring (from Anthony, 1977b)

Year	Year class	Recruitment at age (000 tons)	TAC(000 tons) Recommended by scientists	TAC(000 tons) 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	- -	- -	134 319	1051
1968	1965	222	-	-	373	795
1969	1966	236	-	-	306	615
1970	1967	149	-	-	247	457
1971	1968	104	-	-	263	253
1972	1969	96	50-90	150	174	146
1973	1970	496	83-135	150	199	359
1974	1971	85	150	150	146	285
1975	1972	85	90-150	150	146	204
1976	1973	85	60	60	≃28	234
1977	1974	>85	50	33	≃28	260

Optimum stock level - 350-500 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 and 1977

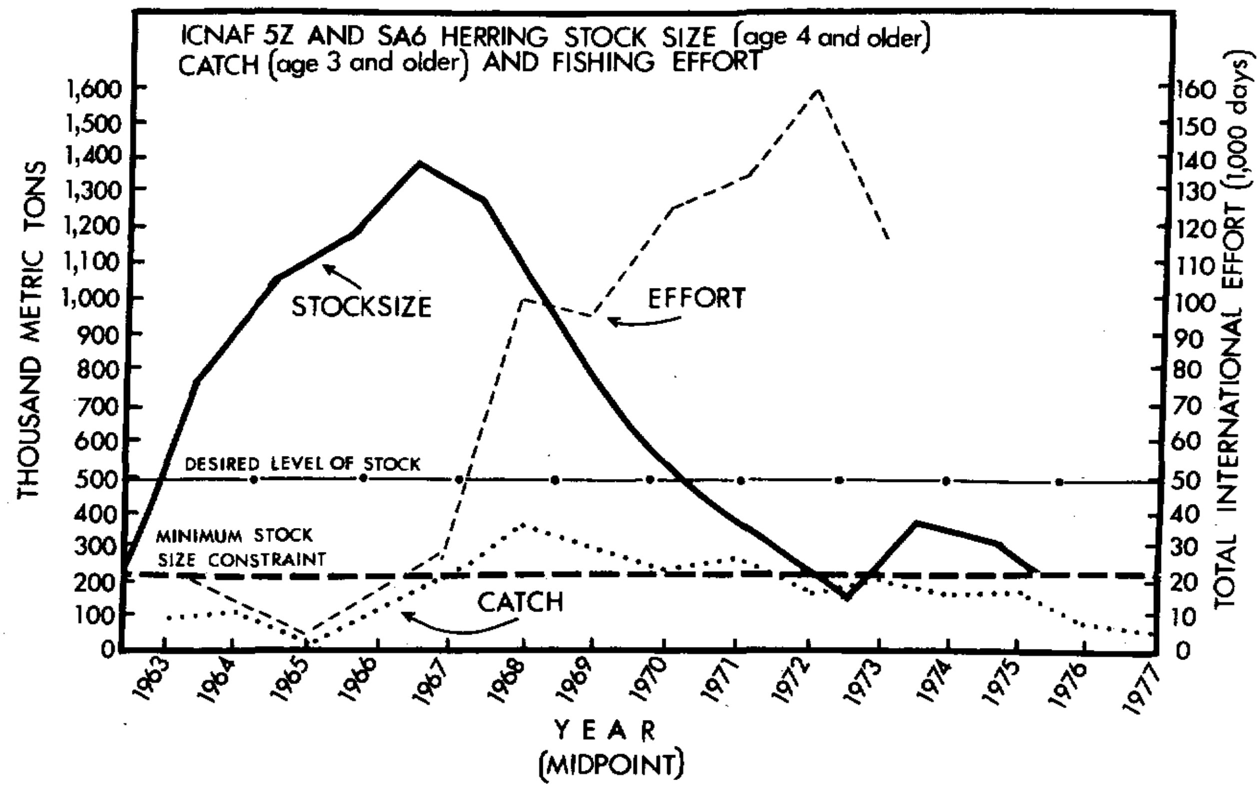


Figure 39. Trends in stock size, catch and effort for the Georges Bank fishery (5Z + SA6) (from NERFMC, 1978).

F(max) for Georges Bank and other U. S. herring stocks cannot be defined, since there is no apparent maximum as fishing mortality is increased (using the Beverton-Holt yield per recruit relationship). Maximum equilibrium yield based on fishing at $F_{0.1}$ is estimated at 100,000 to 150,000 MT corresponding to an optimum spawning stock size of 500,000 MT*. ICNAF has recommended a minimum spawning stock size of 225,000 MT to assure continued recruitment.

The present stock size estimates for Georges Bank are critically dependent on assumptions about the strengths of the 1973 and 1974 year classes -- assumptions which cannot be considered reliable because of the extremely low (1,000 MT) catches on Georges Bank in 1977. If optimism about the 1973 and 1974 year classes is unfounded, and they are in fact equivalent to the poor 1969 year class, then the revised estimate of stock size at the beginning of 1978 is 319,000 MT. However, in view of negative findings from survey cruises, a "prudent" and conservative estimate by NERFMC (1978) is 199,000 MT.

---

*The 500,000 MT optimum stock size for Georges Bank was determined by the ICNAF Herring Working Group in 1973. It is based on the average stock size and age at maturity in the 1960's, which was known to give good recruitment and which was also about the stock size that produced the good 1970 year class (Anthony and Waring, 1978).

If the conservative estimate of NERFMC for stock size at the beginning of 1978 (199,000 MT, based in part on a conservative estimate of the size of the 1975 year class) is correct, then stock restoration measures are required. Levels of allowable catch to provide stock recovery are estimated to be:

1978 TAC 16,000 to 26,000 MT	= 10% to 15% increase which would allow stock to reach minimum recommended level by 1979
1978 TAC 46,000 MT	= 0 (zero) increase

If the assumption of a stock size at the beginning of 1978 of 292,000 MT is made then

a 1978 TAC of 40,000 MT will provide a 10% increase in stock size, and

a 1978 TAC of 67,000 MT will maintain present stock size (zero increase).

The principal question at the moment concerning the collapse in 1977 of the Georges Bank fishery is "Have we allowed the stock to get so low that there has been very poor recruitment?" If this has happened, it may be very difficult to rebuild the stock, even in the total absence of a fishery. Survival and recruitment of the 1975 and 1976 year classes will be a major determining factor.

The conservative estimate of stock size (age 4+) for 1978, made early in 1977, was 200,000 MT, but qualitative evidence from the 1977 fishing season suggests otherwise. Concern has been expressed in a number of informal documents that the Georges Bank stock may have collapsed. Dr. R. L. Edwards, Director of the Northeast Fisheries Center, in a memo dated Nov. 3, 1977 to the Director, NMFS, stated:

"The most startling information, however, is that developing concerning the 5Z stocks. Every captain and chief scientist of the foreign research vessels that work with us have reported "no herring". The consistency of this message was broken only once by a report from a Canadian seiner that, one time only, wrapped 100,000 pounds on the northeast peak of Georges Bank.

The annual fall surveys for sea herring in the waters of southern New England-Georges Bank-Gulf of Maine were conducted from 8 September through November 1977. Four research vessels worked at various times so far within this time frame and have used various types of fishing gear. The ANTON DOHRN (FRG) used a bottom and pelagic trawl; the WIECZNO (Poland), a bottom trawl, the YUBILEINIY (USSR), a purse seine and the DELAWARE II, a bottom trawl.

Considerable zig-zag cruise tracks (as opposed to stratified random) were used by the vessels (except for the DELAWARE II) and a relatively complete coverage was made of Georges Bank and its contiguous waters. All the vessels monitored their echo sounders (or fish finders) 24 hours per day. Very little herring were observed or obtained in the "so-called" window. No quantity of herring was detected or collected elsewhere, on Georges Bank or Jeffrey's Ledge, or in such inshore areas as off Nantucket. No spawning fish of any significant quantity were collected from historical spawning areas. The largest single catch obtained by all the vessels was 1,500 specimens of which 645 were tagged. These herring were obtained by the YUBILEINIY on 24 September approximately 14 miles east of Nauset, Massachusetts. We had acoustic experts on the ANTON DOHRN.

No larval herring were obtained by the WIECZNO in October on Georges Bank. Concentrations of herring larvae were collected by the WIECZNO and ARGUS in the Great South Channel, close to where the YUBILEINIY had made its catch of 645 fish".

A draft US-Canadian herring working group report (also dated November, 1977) expressed serious concern about the Georges Bank stock:

"The Georges Bank herring fishery appears to have collapsed during 1977 and there is no reason for optimism in 1978. The 1970 year class, which has supported the fishery since 1973 has been finally fished out. The 1971 and 1972 year classes (which were assumed to be poor) and the 1973 year class were expected to maintain the herring fishery in 1972. Judging from the failure of the 1977 fishery, the 1971 and 1972 year classes may no longer exist in fishable quantities. Research surveys were conducted almost continually from September 1 to November 1 in the Georges Bank area north to Jeffrey's Ledge and almost no fish were found. The 1977 fishery was conducted in a "window" area from August 15 to September 30 by vessels from several nations. Virtually no herring were caught. Even if distributional changes were, in part, responsible for the lack of fish in the window area, spawning on Georges Bank was apparently very limited. There was some spawning in the Nantucket Shoal area but the amount will not be known until the herring larval surveys are completed. New estimates of the abundance of the 1971 and 1972 year classes at age 3 were obtained from cohort analysis using average F levels. The resulting calculated sizes for the 1971 and 1972 year classes were considerably lower than previously assumed. Therefore, the herring stock biomass on Georges Bank at the start of 1978 is probably very small and any fishing during 1978 would have to be supported by the 1973 and 1974 year classes. If stock rebuilding or maintenance is desired, then removal should be restricted to the lowest possible level during 1978".

5.5.1.3 Actual Catches -- Georges Bank Stock (Div. 5A and SA6)

Herring Catches in ICNAF Division 5Z and Statistical Area 6 by all nations since 1960 have been summarized in Table 8. Catches from Georges Bank stock in 1976 were 43,500 MT, and estimated catch for 1977 was about 1,000 MT. The U.S. fishery in Division 5A-SA6 had averaged 3,200 MT in the period 1972-1976; this compares with an average 14,000 MT in the Gulf of Maine (5Y) for the same period. The U.S. fishery on the Georges Bank stock is primarily off Rhode Island, New York, and Connecticut, with no directed fishery on Georges Bank.

5.5.2 Gulf of Maine Stock Assessment: Year Class Strength, Recruitment, Stock Size, Allowable Catches, and Actual Catches

The intensive foreign fishery for adult herring began somewhat later (1967) in the Gulf of Maine than on Georges Bank (1961), and reached its peak somewhat later (1972) than did the Georges Bank fishery (1968). Catches in the Jeffrey's Ledge adult fishery began at 7,800 MT in 1967, increased to 31,900 MT in 1968, and averaged 38,500 MT from 1969 to 1972. By 1972 the accumulated biomass had been reduced, and from 1973 to 1977 catches depended on surplus production, averaging 18,700 MT. Assessments, particularly as they concern year class strength and recruitment, were facilitated by the existence of the juvenile fishery for sardine-size herring in Maine and New Brunswick, with its own good statistical system instituted in the late 1940's (Scattergood and Trefethen, 1952).

5.5.2.1 Estimates of Year Class Strength -- Gulf of Maine

Annual Summary:

1970 -- the size of this year class at age 3 was estimated at 64,000 MT (535 million fish), the largest year class in recent years (since adequate assessments began). The previous dominant year class was 1966, calculated at 32,000 MT (276 million fish) at age 3, so the 1970 year class was twice this size*.

---

*For reference purposes in ICNAF discussions, stocks of agreed year class sizes, 1966 and 1969, have been used for projections.

Table 8. Catch of herring in ICNAF Divisions 5Z and SA6, 1960-1976 (from Anthony, 1977b)

Year	USA	Canada	FRG	GDR	USSR	Poland	Japan	Bulg.	France	Iceland	Norway	Romania	Others	Cuba	Total
1960															67,655
1961	105														152,242
1962	101					277									97,968
1963	322														131,438
1964	489					35									42.992
1965	1,191					1,447						1,982			142,704
1966	4,308			1,133	120,113	14,473						2,677			142,882
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	4,511				898			267,374
1972	2,782 (4,000)	53 (6,800)	27,703 (31,600)	40,016	52,340 (48,200)	49,275 (49,400)	1,722 (1,200)	2,355	500			2,156 (600)	(8,200)		174,190 (150,000)
1973	4,627 (5,250)	5,083 (5,050)	31,501 (31,600)	53,326	52340 (48,200)	49,275 (49,400)	1,722 (1,200)		2,784			297 (1,300)	(8,000)		(150,000)
1974	3,385 (6,955)	217 (2,980)	23,530 (23,900)	31,530 (31,440)	41,541 (41,725)	39,312 (39,000)	2,442		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	146,085 (150,000)
1976	735 (12,400)	(1,000)	8,759 (9,200)	7,831 (9,300)	11,790 (12,190)	10,517 (11,000)	873 (1,100)	89 (900)	1,110 (1,100)			74 (800)	(10)	298 (1,000)	42,135 (60,000)

Note: National allocations in parentheses.

1971 -- the size of this year class was estimated in 1974 to be equivalent to the poor 1969 year class (9,000 MT [64 million fish] at age 3*). The estimate was revised upward in 1976, and it is now considered to be 9-12,000 tons (78 million fish) -- somewhat greater than the 1969 year class but still poor.

1972 -- equivalent to 1971, based on poor catches in the juvenile fishery, and poor performance in the adult fishery.

1973 -- at age 2 this year class was estimated (from the juvenile catch) to be no more abundant than 1972 (64 million fish), but the large catch of age group 3 fish taken in 1976 (111 million fish -- the largest since 1969) caused this estimate to be revised upward to 16,000 MT (134 million fish) at age 3 -- one half the reference 1966 year class. Poor catches of this year class on Jeffrey's Ledge in autumn 1977 suggest that this estimate may be optimistic.

---

* For reference purposes in ICNAF discussions, stocks of agreed year class sizes, 1966 and 1969, have been used for projections.

1974 -- This year class was earlier estimated to be poor (equivalent to the 1969 year class), but it was abundant as age group 2 fish in the 1976 Maine sardine fishery (310 million fish were taken), so the estimate was revised upward drastically. The 1974 year class is now assumed to be equal to the reference 1966 year class (32,000 MT or 269 million fish) at age 3. Poor catches of this year class on Jeffrey's Ledge in autumn 1977 suggest that this estimate may be optimistic.

1975 -- based on larval surveys and juvenile catches at age 1 (1976), this year class was assumed to be poor (equal to the poor 1969 year class -- 9,000 MT or 73 million fish) at age 3. However, the catch of juveniles on the Maine coast in 1977 was 27,800 MT, which provides a basis for greater optimism about the size of this year class.

1976 -- larvae of the 1976 year class were more abundant on the Maine coast than any other year class in an 18-year time series. This year class was strongly represented as age 1 fish in the 1977 sardine fishery and as age 2 fish in the 1978 sardine fishery.

1977 -- Larvae were very abundant on the Maine coast in autumn 1977, and there were numerous reports of abundant 0-age-group herring (brit) along the Maine and Massachusetts coasts in spring of 1978.

5.5.2.2 Stock Size and Allowable Catches -- Gulf of Maine

Stock size on Jeffrey's Ledge was fairly high from 1967 to 1971 (150-100,000 MT), and was composed of accumulated year classes (average age of 7 years). The intensive fishery began in 1967 and increased greatly in 1968. By 1971 the accumulated stocks had been removed, and the estimated stock size declined sharply until the good 1970 year class was recruited, beginning in 1973 (Figure 40). Absence of substantial recruitment since that time has resulted in a new decline in stock size (Table 9); the catch in 1976 was still composed of over 50% representation from the 1970 year class and this year class was still strongly represented in the 1977 adult fishery. Catches of adults in 1976 and 1977 far exceeded TAC; this should accelerate the rate of decline.

A minimum stock size for the Gulf of Maine of 60,000 MT has been recommended by ICNAF (1976a), and and optimum stock size of 80,000-120,000 MT has been

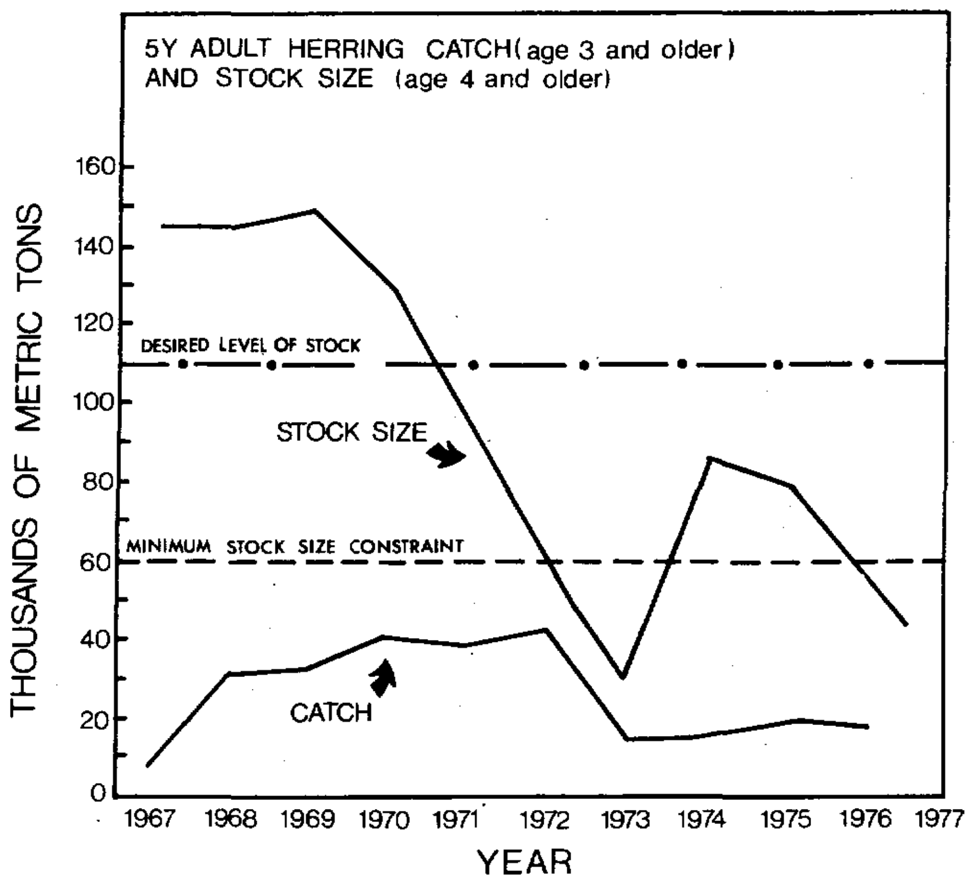


Figure 40. Trends in stock size and catch for the Gulf of Maine fishery (5Y) (from Anthony, 1977b).

Table 9

Gulf of Maine (5Y) Adult Herring Fishery:

Summary of Stock and Recruitment Assumptions
(From NERFMC, 1978)

Year	Stock Size (age 4+) beginning of year (MT)	Recruitment at age 3 (MT)	Year Class Represented
1969	140,900	32,000	1966
1970	130,800	18,300	1967
1971	100,900	14,000	1968
1972	66,200	8,800	1969
1973	31,100	64,200	1970
1974	40,100	9,400	1971
1975	80,700	9,300	1972
1976	60,600	16,000	1973
1977	52,800 1/	32,300	1974
1978	67,600 2/	8,800 3/	1975

1/ Based upon revised estimates of 1973, 1974 year classes (see text).

2/ Assumes 20,000 MT catch for 1977 in 5Y.

3/ Pending further data, the 1975 year class is assumed to be equal to the relatively poor 1969 year class at age 3.

suggested in recent NMFS assessments. Spawning stock size for 1978 has been estimated at 67,600 MT, so even exploitation at $F_{0.1}$ will result in stock decrease peculiar to a given year, instead of maintenance or rebuilding. Levels of allowable catch have been proposed to provide various rates of stock recovery in 1978:

10% rate of increase = 1,000 MT TAC

zero increase = 7,000 MT TAC

However, Sissenwine (Dec. 22, 1977) stated that the failure of the Georges Bank 1977 fishery suggests a more conservative estimate of stock size in the Gulf of Maine.

The optimistic earlier assumptions about strength of the 1973 and 1974 year classes were based on the juvenile fishery; if the conservative view of their strength is applied to the current stock level in the Gulf of Maine (as it was to Georges) then the projected stock size at the start of 1978 would be less than half the estimated value of 67,000 MT.

Sissenwine also pointed out that "the surplus production of adult herring fisheries in 1978 is primarily dependent on the size of the incoming (1975) year class, therefore the calculated surplus production is not significantly affected by the assumptions made about the 1973 and 1974 year classes".

The 1978 surplus production (age 3 and older) in the Gulf of Maine is estimated at 7,000 tons, but this may be optimistic, as was suggested by the report of a U.S.-Canada herring working group dated November, 1977:

"The total catch for the adult 5Y fishery in 1977 through July was about as predicted, (19,000 tons) and the catches of the 1970-1973 year classes were also as expected. The catches during this fall fishery on the spawning grounds were far less than expected and studies of herring spawning during 1977 did not indicate the presence of any spawning concentrations on Jeffrey's Ledge. The catch of the 1974 year class during 1977 was only 449 tons through July whereas a catch of 2,680 tons was predicted. Due to the poor performance of the 1974 year class in 1977, a more conservative approach for 1978 would be to assume that the 1974 year class is equal to the conventional year class size at age 3 for poor year classes of 78 million (9,400 tons) fish. This would reduce the estimated stock biomass (age 4+) at the start of 1978. The June assessment projected that a 1978 catch of 7,000 tons could be taken with no change in biomass and 1,000 tons could be taken to achieve a 10% increase in stock size. If the 1974 year class is no better than the conventional level for poor year classes, as more recent data suggest, then any allowable catch in 1978 could decrease the spawning stock size to very low levels with at least half of the stock comprised of the recruiting 1973 and 1974 year classes". Sissenwine (personal communication) disagrees with the final conclusion, pointing out that surplus production is nearly totally dependent on the strength of the 1975 year class, and therefore, overestimation of the 1973 and 1974 year classes would not affect the surplus production calculation. Thus a catch of 7,000 tons would still be possible in 1978 without any further decrease in spawning stock size.

5.5.2.3 Actual Catches -- Gulf of Maine

Herring catches in ICNAF Division 5Y by all nations since 1957 have been summarized in Table 10. Catches for 1976 totalled 49,400 MT (of this 30,200 MT were taken in the Maine juvenile fishery, which is not usually included in the assessment). The estimated catch for 1977 is 46,700 MT, of which the Maine juvenile catch is 27,800 MT. The adult catch in 1977 thus greatly exceeded the recommended total allowable catch of 7,000 MT. The estimated domestic catch (EDC) for 5Y under a strategy aimed at 0% recovery in 1978 is 9-11,000 MT (NERFMC, 1978), and at 10% recovery 1,000 tons, with foreign allowable catch zero.

Table 10. Catch of herring in ICNAF Division 5Y. (from Anthony, 1977b).

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						56,295	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 (others =	100 500)				62,416	42,918 (30,000)
1973	16,400	5,201 (19,750)	21,601	5,014 (4,000)	690 (1,000)	5,284	69 (others =	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	16,864 (10,750)	32,046	4,500 (4,200)	57 (500)	(500)	(others =	71 71)			38	36,655	21,530 (16,000)
1976	30,195	19,204 (6,000)	49,398	921 (990)							10 (10)	50,399	20,125 (7,000)
1977	32,357	17,891	50,248									50,248	17,891

Because of delay in development and implementation of a Fishery Management Plan for herring, the fishery will be unregulated during the first half of 1978 -- which may result in intensive fishing of Gulf of Maine stocks. This can be mitigated by restrictive quotas (3,000-4,000 MT) for the autumn-early winter period of 1978 (NERFMC, Herring O/S Comm., Feb. 78).

The Draft Fishery Management Plan for herring (NERFMC, 1978) issued in April, 1978, proposes a quota of 4,000 MT for autumn 1978, and 4,000 MT for winter-spring 1979.

5.5.3 <u>Nova Scotia Stock Assessment: Year Class Strength, Recruitment, Stock Size, Allowable Catches and Actual Catches</u>

The fishery for adult herring off Nova Scotia (principally Bay of Fundy and the southwestern coast) expanded enormously beginning in 1964, and by 1968 had reached 230,000 MT -- a level that declined only slightly through 1975.

Assessments of Nova Scotia adult herring stocks have a shorter history than those of other stocks considered in this paper. The peak of production was also reached later (1975) than for either of the other stocks. Stock size has been considered in the past to be roughly equivalent to that of Georges Bank.

5.5.3.1 Estimates of Year Class Strength -- Nova Scotia

Unlike the situation in the Gulf of Maine and Georges Bank stocks, where size of juvenile catches on the Maine coast is used as an indicator of year class strength in both stocks, the Canadians find no clear relationship between success of the juvenile fisheries of New Brunswick (ICNAF Div. 4XB) and size of year classes in the Nova Scotia adult fishery. Since the adult fisheries are largely dependent on recruits, the size of incoming year classes is very important, and the absence of independent estimates of year class strength is a severe limitation to any assessment (Miller and Stobo, 1977).

Estimates of the sizes of year classes have been derived from cohort analysis, as opposed to use of the catch equation, as follows:

1971 -- this year class was considered poor, based on extremely low contributions to the fishery during 1973-1975. Estimated year class size at age 2, based on cohort analysis was 782 million fish (minimum estimate during a range of starting F's was 504 million fish).

1972 -- estimated year class size at age 2, based on cohort analysis, was 1,261 million fish (minimum estimate using a range of starting F's was 592 million fish).

1973 -- estimated year class size at age 2, based on cohort analysis, was 1,881 million fish.

1974 -- year class size set at conventional level of 750 million fish at age 2, lacking any independent estimates of year class strength.

1975 -- year class size set at conventional level of 750 million fish at age 2.

1976 -- year class size set at conventional level of 750 million fish at age 2.

5.5.3.2 Stock Size and Allowable Catches -- Nova Scotia

The total allowable catch for 1975-1976 for Nova Scotia (Div. 4WX) was 129,600 MT, but the actual catch was only 114,400 MT. The total allowable catch for 1977 was set at 108,000 MT for Div. 4XWb, with an expected stock size (age 4+) of 399,000 MT at the beginning of 1977.

Total allowable catch for 1978 was set at 98,000 MT for Div. 4WX with resulting predicted stock size (age 4+) of 363,000 MT, of this 20,500 tons (21%) should be taken in 4Wa (Chedabucto) and remaining 79% (77,025 tons) from Div. 4XWb. This includes the inshore catch, and 11,000-15,000 tons has been the estimated inshore catch in the past. This stock size for the beginning of 1978 of 363,000 MT may be optimistic; the minimum year class estimates of the 1972 and 1973 year classes are below those used previously for the assessment. A revised assessment will be made using data from the 1977 Div. 4X fishery.

5.3.3.3 Actual Catches -- Nova Scotia

Catches from the Nova Scotia stock (Divisions 4X and 4Wb) averaged about 20,000 MT in the early 1960's (including juveniles and gill net fish) and rose to 114,000 MT in 1971; 116,000 MT in 1972; 135,000 MT in 1973; 140,000 MT in 1974; 145,000 MT in 1975; and 144,000 MT in 1976.

The total catch from Nova Scotia herring stocks (ICNAF Div. 4WX) in 1976 was 114,433 MT, plus and additional 29,858 tons taken in the New Brunswick juvenile fishery (ICNAF Div. 4Xb) for an overall total of 144,291 MT.

The 1977 catch in 4WX (based on preliminary figures as of Nov. 1977) should be about 117,000 MT.

5.5.4 <u>Pooled Area Assessments</u>

It is becoming increasingly apparent from recent tagging studies that except at spawning time, there is appreciable movement and in some instances intermixing of Georges Bank, Gulf of Maine and Nova Scotia stocks, and that some adult fisheries exploit these intermingled stocks. To cope with this problem, recent assessments (in 1975 and 1977 -- Anthony, 1977, W. H. Lab. Ref. 77-16) have combined all areas from Chedabucto Bay south, and have included juvenile as well as adult fisheries. Such assessments have been called "pooled area" or "combined" assessments, and they have provided another and possibly more realistic approach to analyses of herring data.

As Anthony pointed out, the total catch in this combined area increased during the 1960's to a peak of 692,000 tons in 1968, after which catches declined to 384,000 tons in 1973, 360,000 tons in 1974, 354,000 tons in 1975, and 248,000 tons in 1976 (the decline from 354,000 tons in 1975 to 248,000 tons in 1976 was due at least in part to a reduction in total allowable catch on Georges Bank from 150,000 tons to 60,000 tons).

5.5.4.1 Pooled Area Assessment -- Year Class Strength

Assumptions about year class strength were similar to those made for Georges Bank and the Gulf of Maine: 1970 year class twice the size of the 1966 at age 3 (7,301 million fish); 1971 year class as poor as 1969 at age 3 (1,584 million fish); 1972 like 1971; 1973 year class equal to one-half the 1966 at age 3 (1,825 million fish; 1974 year class equal to 1966 at age 3 (3,656 million fish).

5.5.4.2 Pooled Area Assessment -- Stock Size and Allowable Catches

Stock size for 1977 was determined by applying the survival rates in 1976 to the 1976 stock size (Anthony, 1977). Assumptions were that the Nova Scotia catch would be 77,000 MT, Chedabucto Bay 20,000, New Brunswick juvenile 20,000, Gulf of Maine juvenile 20,000, Gulf of Maine adult 20,000, Georges Bank 28,000 -- for a total of 185,000 MT. Anthony then averaged fishing mortality rates by age for the years 1965-1975, which gave recruitment selection factors for ages 1-5 which were applied to age groups in the stock for 1977 (assuming a total catch of 185,000 MT) to derive a 1978 stock size (age 4+) of 862,000 MT.

Since there are seven principal fisheries involved (in recent years), each with different recruitment rates and mean weights at age, catch compositions must be determined separately. Survival rates were applied to the assumed 1978 abundance to provide an estimate of 1979 stock abundance of 907-990,000 MT. Projected changes in abundance are influenced by ratios of catches of juveniles to those of adults.

The pooled area assessment provides guidelines about total fishing mortality, but this mortality must be apportioned to spawning populations according to their size (for example, the Georges Bank spawning component has been historically 8 to 10 times larger than that of Jeffrey's Ledge).

Combining juvenile and adult fisheries, an equilibrium total annual catch of 240,000 tons could be taken from a stock size of 1.7 million tons if recruitment is poor, and 377,000 tons if recruitment is fair (Anthony, 1977).

Problems with pooled area assessments (as pointed out in a U.S.-Canada working group report, 1977) are (1) historically, sizes of year classes in Canadian waters (Div. 4XW) have been estimated at age 2 while those of Georges Bank and Gulf of Maine have been estimated at age 3, and (2) catches of juveniles in Maine and New Brunswick can lead to early overestimates of year class strength, since fish may appear abundant as age 2 in one area and as age 3 in the other a year later -- implying substantial movement between the two areas, and leading to double counting.

The solution of course (if annual projections are desired) is to carry out annual combined assessments for all stocks, such as were attempted in 1975 and 1977. The working group report emphasized the enormity of the undertaking, since detailed information must be obtained on a timely basis from seven fisheries: (1) winter purse seine fishery in 4W, (2) summer and fall adult purse seine, weir and gill net fisheries in 4X, (3) juvenile weir fisheries in Maine and New Brunswick, (4) the early juvenile purse seine fishery in the Bay of Fundy, (5) the stop seine and purse seine fisheries along the Maine coast, (6) the trawl fishery in the Gulf of Maine, and (7) the international fishery on Georges Bank and southward.

5.5.4.3 Actual Catches -- Pooled Areas

Combined catches in 1976 from the three stocks of concern to this paper were 236,000 MT; while the estimated 1977 catch was only 165,000 MT, due to declines in the Nova Scotia and particularly the Georges Bank catches.

In summary, it seems that assessment of herring stocks of concern to this document has gone through several phases:

(1) The pre-regulation phase, before 1972, when assessments were made to determine status of stocks under increasingly intensive but unregulated exploitation, and voices of alarm were heard.

(2) The ICNAF management phase (1972-1976), when TAC's were determined, then debated by assessment scientists of several nations, then often ignored by the regulatory body, so that catches consistently exceeded surplus production.

(3) The panic phase, brought about by the decline and apparent collapse of the Georges Bank stock in 1976 and 1977. This coincided with assumption of extended fishery jurisdiction by United States and Canada, and the imposition of severe catch restrictions. It also produced a reappraisal of the validity of herring stock assessments, since it became fully apparent to the United States fishing industry (possibly for the first time) that assessments would form the basis for regulation of <u>their</u> catches, as well as those of foreign fishermen.

It is somewhat unfortunate that the basic methodology used in stock assessment until 1972 -- cohort analysis -- is somewhat more difficult to perform when severe catch restrictions are imposed. If there is a reduction in fishing mortality, then it takes longer for a year class to be essentially fished out and, therefore, longer before the cohort analysis in and of itself gives an estimate of year class strength. Furthermore, if one is using the catch equation to expand catch to size of year class in the current year, the estimates after that year may be made difficult by changes in fishing practices resulting from regulations imposed.

Current stock assessment is almost totally a matter of estimating annual recruitment, since there is little accumulated stock of older year classes. The fishery has become more and more dependent on recruiting year classes since the late 1960's, and annual determination of the strength of recruitment became (and will continue to be) the bulk of the assessments (Anthony and Waring, 1978).

CHAPTER 6

EVALUATION OF THE ADEQUACY OF EXISTING INFORMATION ABOUT HERRING

CONTENTS

6.1 INTRODUCTION

It is not difficult to become pessimistic, when examining the nature of existing information about herring stocks of the western North Atlantic, about whether it will ever be feasible to collect and interpret enough data on a timely basis to provide sufficiently precise information for effective long-term management of the fisheries. This is particularly true if we examine the histories of other herring fisheries, and the attempts to understand the population and ecosystem dynamics of the stocks that have been exploited.

An important aspect of attempts at understanding the stocks of concern to this paper is the relative intensity of effort per unit area that has been invested for the past several decades, and continues to be invested. Research on herring of the western North Atlantic was pursued vigorously by the Atlantic Herring Investigation Committee of the Fisheries Research Board of Canada beginning in the late 1940's; by the Atlantic Herring Investigations of the U.S. Bureau of Commercial Fisheries beginning in the early 1950's; by the International Passamaquoddy Fisheries Board, beginning in the late 1950's; more recently by United States, Canada, and distant water fishing nations as members of the International Commission for the Northwest Atlantic Fisheries; and most recently by United States and Canada in response to needs developed under extended fisheries jurisdictions.

Much information has been acquired, particularly that relevant to stock assessments. Much remains to be learned. In this chapter critical and persistent problems will be examined, hypotheses related to the problems will be presented, and available information will be summarized.

6.2 CRITICAL AND PERSISTENT PROBLEMS

In examining the history and present status of the herring fishery in the Northwest Atlantic, a number of critical problem areas emerge. It is interesting that most of these were apparent a decade ago, and that, while some insights have been gained, the problems persist. Most of the problems are common to many exploited species; a few are unique to the herring stocks under consideration. Critical problems can be described and discussed as:

1. Accuracy of stock assessments (especially an accurate determination of stock size and mortality rates), and validity of the conceptual basis for assessments.
2. Stock-recruitment relationships -- the amount of data and the complexity of analyses required for understanding.
3. Discreteness of stocks (extent of intermixing).
4. Determinants of year class strength.
5. Spawning source(s) of juveniles fished in coastal waters.
6. Criteria for predicting recruitment.
7. Use and adequacy of models.
8. Pooled area assessments.
9. Ecosystems interactions.

Obviously, these categories overlap to a large extent, but it still seems worthwhile to examine the problems separately.

The format of this chapter will be to describe each problem adequately, then to propose a hypothesis, and then to review available information that would support or refute the hypothesis. This should lead logically to a consideration of necessary research and analyses in the following chapter.

Much information about herring of the western North Atlantic has accumulated, particularly during the past two decades. While definitive answers to persistent problems have proved elusive, there is now enough data available to propose a series of somewhat rational hypotheses, and to evaluate supporting information. With this approach, it should then be possible to make better determinations about directions and intensities of future research.

6.2.1 Accuracy of Stock Assessments and Validity of the Conceptual Basis for Assessments

The Problem: Herring populations fluctuate drastically, and for exploited stocks, great dependence is placed on success of each year class. There are many aspects of recruitment, mortality, and migrations that are poorly understood. Therefore, is it feasible to carry out assessments that can be accurate enough to enable management of the herring fishery at some long-term equilibrium yield? This fundamental question leads to a host of subsidiary questions:

What is the population size, and what are recruitment and mortality rates for each geographic subunit?

Are the assumptions made about natural mortality valid, and how sensitive are the conclusions to the assumptions?

Can recruitment be determined with any degree of adequacy before the year class enters the fishery?

Even if it were possible to carry out accurate stock assessments, would not social and economic pressures make management at a long-term equilibrium yield difficult or impossible?

How closely do existing fishery models approximate reality?

What degree of accuracy in assessments is really necessary for satisfaction of the goal of effective long-term management of stocks?

What data base is required to provide increased accuracy of assessments?

Possibly the real problem is not with accuracy per se, but with the conceptual basis for assessments. We have used methods of stock assessment that seem robust in terms of the data available, but we may have gone beyond our knowledge about responses of marine productive systems. Possibly more conservative methods should have been followed, or should be in the future. Assessments must be tailored to current status of knowledge about the dynamics of fish stocks; with persistent uncertainties about discreteness of stocks, mortality rates, and stock-recruitment relationships, possibly the best approach would be pooled area assessments and allocations based on socioeconomic factors.

The Hypothesis: Precision of estimates of stock size and recruitment can be improved if necessary, once the degree of required precision is stated by fishery management groups. With the imposition of restrictions on catches, fisheries-independent criteria must be developed. October-November international larval herring surveys (for spawning stock abundance estimates) could be expanded in terms of area covered, and trawling surveys could be intensified, even though neither approach will fully satisfy data needs for good stock size estimates.

Information Available: Assessments of the herring stocks of concern to this paper have been conducted since the late 1960's. The data base has improved steadily since that time, although there are still problems with age determinations, adequacy of sampling of the commercial catch, and others.

Estimates of stock size have been based on a number of measurements: total catch, catch per unit of effort, juvenile surveys, extent of egg deposition, and larval abundance. With imposition of severe catch restrictions, total catch is no longer as useful as it is for unrestricted fisheries, and catch per unit of effort must be reevaluated. However, catch of age 2 fish in the juvenile fishery still remains unregulated, and therefore, may still be used as a good criterion for estimating strength of incoming year classes.

With the disappearance of accumulated stocks as a result of intensive fishing, herring stock assessment has become largely a matter of predicting the level of recruitment. Several measures of recruitment are available, but the precision and accuracy of abundance estimates based on them should continue to receive attention. At low abundance levels, accurate sampling is of great importance.

6.2.2 Stock-Recruitment Relationships

The Problem: What is the relationship between spawning stock size and the magnitude of subsequent recruitment of off-spring into the fishery?

The Hypothesis: Year class abundance is independent of spawning stock size over a wide range of abundance levels; only when spawning stocks are severely reduced because of over-exploitation would a direct relationship of stock size and year class abundance develop. This was the conclusion of Lett (1976) for Gulf of St. Lawrence herring, and it may apply to other herring stocks as well. It is quite possible that the Georges Bank spawning stock is now at or below that critically low point, in view of the absence of larvae in 1976 and 1977, and the failure of the fishery in 1977.

Information Available: From evidence obtained thus far, a direct relationship of spawning stock size and recruitment has not been clearly demonstrated. Good and poor year classes seem to have little obvious relationship to numbers of spawners, and environmental factors -- biotic or abiotic, particularly those that exist during the first winter of life -- may well determine abundance of any given year class.

Anthony (1972) who has considered this critical problem area in great detail, has made several significant statements:

"Since both the Georges Bank and Jeffrey's Ledge fisheries are highly dependent on recruitment, the development of stock-recruitment relationships is of utmost importance".

The fact that stocks are highly dependent on recruitment means that improved understanding of stock size is critical to hard management decisions about what level of spawning stock should be left in the population or what level the spawning stock should be rebuilt to. It is unlikely that any such development of stock recruitment relationships can be done in time to assist managers in their current dilemma.

Examining the sardine pack versus 3/4/5-year cycles, Anthony stated "If a stock-recruitment relationship exists .... in Maine Atlantic herring, the parents spawning for the first time probably will be more nearly related to their offspring than parents spawning in any other year".

Anthony's general statement about spawning stock and recruitment (relevant to the situation in 1972) was: "Whether a stock-recruitment relationship exists or not, a good year class cannot be produced if the spawning stock is too low, even when environmental factors are favorable. It is likely that the present (1972) very low spawning stock on Georges Bank is considerably smaller than that required to give a high probability of a good year class occurring when environmental conditions are favorable". This generalization is not completely satisfactory, since a definition of when a spawning stock size is "too low" is not given.

In examining the matter of the point in stock exploitation where depletion becomes severe, little is available in the way of specific information. Recruitment is often considered independent of population size down to a poorly-defined minimum number of spawners -- below this point a direct relationship exists. It seems possible that the virtual disappearance of the northern stock of Pacific sardines on the California coast in the 1940's and 1950's may have resulted from events (overfishing and environmental changes) which depleted the population below some critical point. Although a comparison may be premature, we may have witnessed the same kind of event with the collapse of the Georges Bank spawning population in 1977.

The minimum stock size provided by ICNAF at its 1974 special meeting was 225,000 MT for Georges Bank and 60,000 MT for the Gulf of Maine. It should be noted that these are arbitrary reference points, very poor recruitment could occur either above or below these points.

We know that at one point in recent history (1969) almost a million tons of herring were caught, so the herring population of the western North Atlantic was at that time at least of that size. The carrying capacity of the environment at that time was adequate to support that many tons of herring. With greatly reduced populations, it may be that at least part of that capacity is being diverted to other species with similar if not identical ecological requirements -- comparable to the apparent replacement of California sardines by anchovies.

The matter of stock-recruitment relationships was recently summarized succinctly by S. Clark and E. Anderson (memo March 11, 1977): "There is no defined stock-recruitment relationship for any of the herring stocks; rather, the broad spectrum of biotic and abiotic factors present and interacting in the ocean environment is likely more influential in determining recruitment strength than the size of the spawning stock when it is near average levels. Simulation studies on herring stocks (Lett, 1976) have indicated that recruitment is independent of stock size over a fairly wide range and that a stock-recruitment relationship emerges only when the stock is at extremely low levels. Unfortunately, it is difficult to define this critical low level".

One final thought on stock recruitment relationships was provided by Graham (personal communication). Herring stocks during the history of the species have faced catastrophes from natural causes and recovered. Populations may react by changes in behavior, or increase in recruitment from a small stock. The stock-recruitment relationship, in this sense, is dynamic, and a short-term static relationship would not exist.

6.2.3 Discreteness of Stocks

The Problem: How discrete are stocks of herring in the western North Atlantic? Attempts to distinguish spawning aggregations on the basis of morphometrics and age and growth characteristics have been inconclusive. Limited tagging of adults has provided only limited information so far. The nature and extent of intermixing of all stocks, at all times of the year, must be understood. Management decisions can be based on concepts of a single unit stock, partially intermingled stocks, or completely intermingled stocks. The incorrect choice of alternatives may jeopardize rebuilding or continued productivity of certain stocks.

The Hypothesis: Considering only the Georges Bank, Gulf of Maine, and southwest Nova Scotia herring, separation of stocks in the sense of genetic distinctions among them, may not exist. The degree of intermixing, and the consequent gene flow, among various spawning populations, may be great enough so that genetic differences do not exist, or that the magnitude of such differences may be too small to be detected.

Put in population genetic terms "A single gene pool may cover a wide geographical area with relatively great environmental differences over the whole range, and this may result in phenotypic differences between groups of individuals in different localities" (Møller, 1971). When extensive intermixing of groups with phenotypic differences occurs, we are then left with a complex and confusing situation.

Information Available: Anthony (1977) and others feel that there are three principal stocks -- Georges Bank, Gulf of Maine, and southern Nova Scotia. Anthony has summarized what he considers the best evidence for the existence of separate stocks in the area of concern to this paper as follows:

1. Differences in abundance of spawning populations have been maintained, in relative terms, over time (Georges Bank stock, for example, was perhaps ten times greater than Jeffrey's Ledge, and this relative proportion persisted -- which would not be the case

if the stocks were not separate). Similarly, the Nova Scotia stock was about equal in size to the Georges Bank stock, and much greater than Jeffrey's Ledge -- and the proportions have been consistent with time.

2. Differences in meristic counts of adults in spawning aggregations have been detected. Adults from Nova Scotia and Maine had significantly higher pectoral fin ray counts than adults of the same year class from Georges Bank (for 1958 through 1963 year classes). Beginning in 1964, with decrease in water temperature, fin ray counts increased for all stocks, and earlier differences between stocks disappeared.
3. Persistent differences have been observed in growth rates between adults spawning on Georges Bank and those spawning off Nova Scotia -- differences which would not be detectable if significant intermingling of spawning stocks existed during much of the year.

Recent tagging results indicate that Nova Scotia fish can move into Maine waters, and juveniles from Maine move southward to below Cape Cod. There is as yet little evidence for intermingling of Gulf of Maine and Georges Bank adult stocks, but much more tagging of spawning populations needs to be done.

It seems reasonable to conclude at present that clear indication of genetic diversity among the three stocks does not exist, but that some environmentally-mediated morphological differences suggest three poorly differentiated subgroups of herring, with extensive intermixing for feeding and overwintering.

An important persistent question is "Does a relationship exist between Canadian catches in Division 4XWB (Bay of Fundy and southern Nova Scotia) and U.S. catches in the Gulf of Maine -- or between stock sizes in the two areas? The Nova Scotia fishery started expanding in the late 1960's and expanded rapidly; stock size did not begin declining until 1971. The stock size in the Gulf of Maine also stayed fairly high until 1971. Another persistent question is "What is the extent of intermixture in the Block Island area in winter, and what are the spawning populations from which such fish are derived?

6.2.4 Determinants of Year Class Strength

The Problem: What are the factors which affect year class abundance, and size of recruiting year classes? Two major aspects of this problem are spawning intensity and subsequent mortality at each life history stage. There is some suggestion that size of spawning populations or size of egg beds do not correlate with success of the resulting year class. There is some evidence (at least in coastal waters) that winter mortality of larvae is extensive, so autumn larval surveys may not be a reliable criterion of year class abundance. There have been repeated attempts to correlate year class survival with autumn and winter temperatures, but a clear relationship has not emerged. Other environmental factors, biotic or abiotic, have been found to influence survival, but relationships are complex.

The Hypothesis: Enough environmental and fisheries data are now available from the western North Atlantic to begin a multivariate examination of factors responsible for year class success or failure. Inability to make such correlations with other herring stocks in the past may have resulted from inadequate environmental data; the intensity of observations during the past decade in the area of concern to this paper makes the likelihood of success greater. We now have enough data for enough years to begin an analysis of integrated effects on survival.

Information Available: Continued attempts to improve the data base for stock assessments during the past decade have resulted in good data on year class abundance (as measured by catches of adults). Hydrographic and meteorological data are also available, as is information about other environmental influences (zooplankton abundance, predator abundance, competitor abundance). The data base for the area of concern is probably better than any that has been available for other herring stocks and fisheries.

It should be noted though that adequate systematic larval monitoring began in 1971, and three years are required before any measure of year class success appears in the adult fishery. The time series for assessing this important possible relationship is thus still short. The time series of data on zooplankton, predator, and competitor abundance is probably still inadequate to be correlated with strength of recruiting year classes, and these variables are probably the key to understanding what determines year class strength of herring. A significant problem is the relatedness of data collection. Large data bases from various sources can be considered statistically, but if the data are not collected as part of an integrated sampling plan, then only long-term changes are likely to be observed.

6.2.5 Spawning Source(s) of Juveniles Caught in Coastal Waters

The Problem: What are the spawning sources of juveniles fished in coastal waters, and to which spawning population(s) do they contribute? Attempts to answer this question by comparison of morphometric and other characteristics of juveniles and adults have been inconclusive; limited tagging of juveniles has not been helpful because of limited tag retention; and attempts to follow larval drift from spawning sites have been inconclusive. Thus effects of exploiting age groups 1, 2, and 3 in the coastal juvenile fishery on recruitment into the adult fishery are undetermined, and, conversely, the effects of exploiting spawning stocks on the abundance of juveniles is equally unknown.

Another and more pragmatic way of phrasing this problem would be "Is there any relationship between declines in the Maine juvenile fishery and those of adult stocks on Georges Bank, in the Gulf of Maine, and off Nova Scotia?"

The Hypothesis: Because of annual fluctuations in success of spawning and in larval drift as a consequence of water temperatures and ocean currents, populations of juveniles in coastal waters may be derived from more than one spawning source, and the source may vary in percent contribution from year to year. Juvenile stock maintenance in a given area would thereby be a mechanical process, depending principally on larval drift from spawning areas and subsequent movements of juvenile schools.

Movements of juveniles increase with increasing age, and become more purposeful (feeding and spawning). Recruitment to spawning aggregations at age 3 to 5 is a consequence of such purposeful movements.

Information Available: There is some evidence that the declines in the Maine juvenile fishery and those of the adult stocks on Georges Bank, in the Gulf of Maine, and off Nova Scotia were not interdependent (Figure 41). The juvenile fishery began declining in eastern Maine in the 1950's and continued coastwide through the 1960's, reaching bottom in 1969-1971 -- and the decline was apparent before the Georges Bank and Jeffrey's Ledge fisheries began. (Decline in adult stocks began after 1968 on Georges Bank, and after 1971 on Jeffrey's Ledge).

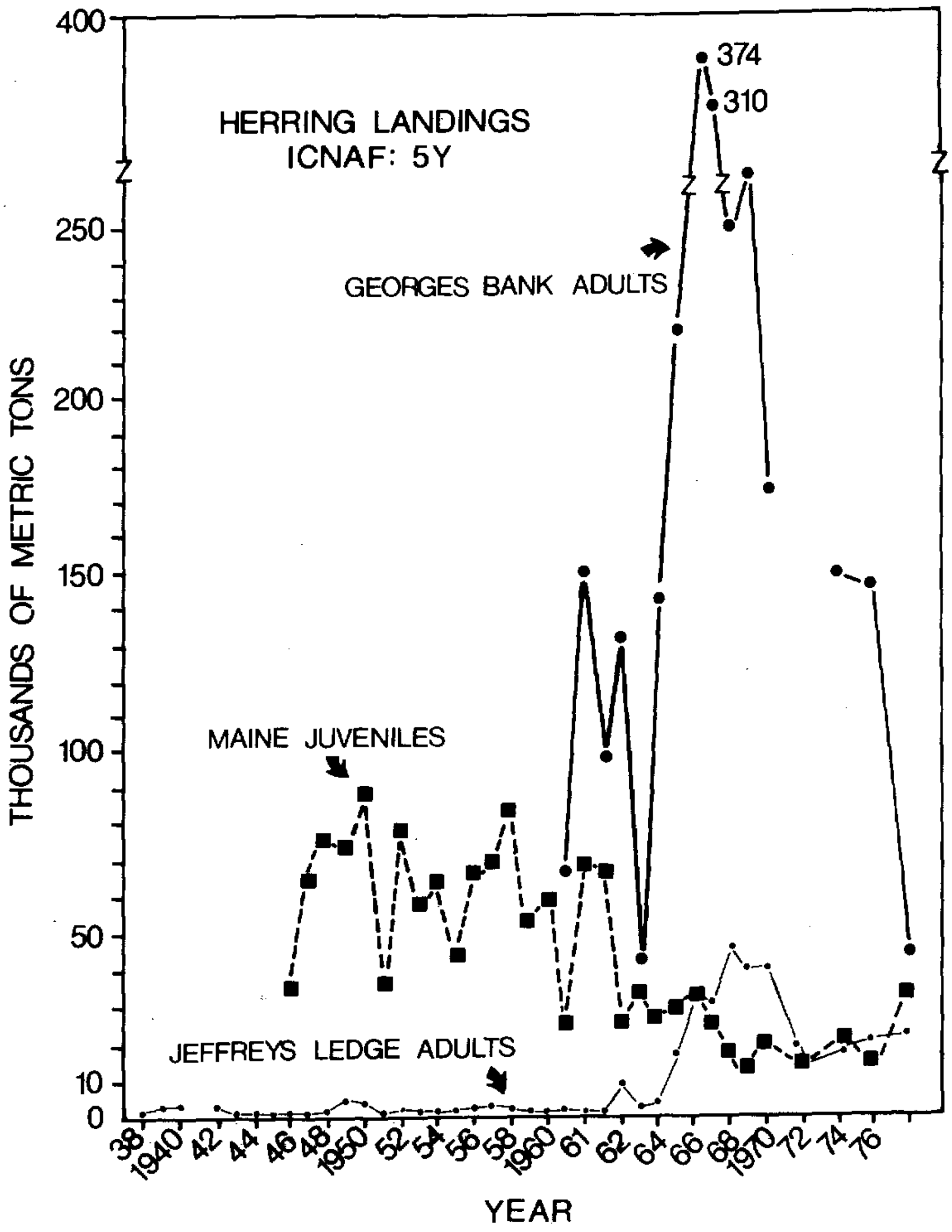


Figure 41. Annual herring landings: Georges Bank adults, 1960 to 1977; Jeffrey's Ledge adults, 1938-1977; Maine juveniles, 1946-1977. (From NERFMC, 1978).

The relationship, if any, between juvenile herring on the Maine and New Brunswick coasts and adult stocks on Georges Bank is uncertain, but there is circumstantial evidence and inference that link Maine coast juveniles and Georges Bank spawners. Unfortunately, there is also circumstantial evidence that the success of the Maine juvenile fishery is independent of the size of the Georges Bank spawning stock.

On the side favoring the hypothesis that Maine coast juveniles do recruit to the Georges Bank spawning stock are these:

(1) Meristic studies (Anthony and Boyar, 1968) of the 1958-1963 year classes indicated that vertebral counts and right pectoral fin ray counts of Maine coast juveniles agreed with those of the same year classes spawning on Georges Bank several years later, and were different from adult herring found along the Maine coast.

(2) Larval drift studies of Davis and Morris (1976) indicated that larvae from Georges Bank were widely distributed over the center of the Gulf of Maine, and could have continued to move toward the Maine coast. The data supporting a conclusion about drift to the Maine coast is not convincing. Also, Graham has observed for a number of years that larvae from

an unknown source enter Maine coastal waters in spring, but that this wave of larvae diminished drastically after 1971, which is similar in timing to the decline in recruitment to the Georges Bank spawning stock.

(3) Good and poor year classes coincide in the Maine juvenile fishery and in the Georges Bank fishery; the relationship gave a multiple correlation coefficient of 0.90 (Anthony and Waring, 1978).

(4) Fishing directly on spawning grounds -- the act of fishing -- may cause recruitment declines, as well as decrease in size of spawning stock. Anthony and Waring (1978) pointed out that the most recent drop in catch of Maine juveniles after 1963 roughly coincided with increased fishing activity on spawning stocks of Georges Bank.

There are several lines of circumstantial evidence leading to the conclusion that the success of the Maine juvenile fishery is independent of the size of the Georges Bank spawning stock -- and that the Maine juvenile fishery was not a primary factor in the recent decline of the Georges Bank stock.

(1) Despite the largest recent catches of juveniles in the Maine and New Brunswick fisheries (104,000 MT in 1962 and 108,000 MT in 1963) the estimated Georges Bank stock rose dramatically beginning in 1964 (the western Gulf of Maine adult stock also increased substantially).

(2) The estimated Georges Bank stock size was at its peak in the mid-1960's, precisely at the time when the Maine juvenile fishery had begun dropping to very low levels.

(3) Georges Bank stock size declined beginning about 1969 to a very low point in 1973, despite the fact that the Maine juvenile fishery had been at a low level since 1964, and continued so until 1976.

(4) It can be demonstrated that juvenile fisheries reduce total yields significantly. An analysis by ICNAF (Redbook, 1975, p. 49) indicated that the yield per recruit would almost double if all herring were taken as adults. However, a later analysis of herring catches from northern Nova Scotia to Cape Hatteras by Anthony and Waring (1978) led to the conclusion that "the juvenile fishery did not play a substantial role in the decline of the Georges Bank stock".

Squarely in the middle of the relationship-no relationship problem is the matter of intermixing. Good and poor year classes agree in the Georges Bank-Gulf of Maine fisheries, suggesting a common cause of success or failure that is not the size of any single spawning stock. A possible explanation for this similarity in year class strength was proposed by Anthony and Waring (1978) -- extensive intermixing of herring from several spawning areas. This explanation would function for good or mediocre year classes, but not for poor ones, as the authors pointed out.

It is not inconceivable, and in fact the recent analysis by Anthony and Waring (1978) supports the idea, that offspring from Georges Bank spawning do use the Maine coast as a nursery area at ages 1 and 2, and then begin offshore movement, segregating from cohorts spawned on the Maine coast at that time. Soviet scientists have long held that a relationship existed between Maine juveniles and Georges Bank adults.

Some additional light may soon be shed on the problem of whether or not Maine juveniles recruit to Georges Bank as adults. The 1976 and 1977 year classes were strong as larvae and juveniles on the Maine coast, while those year classes were almost absent as larvae and juveniles on Georges Bank. The 1976 year class will begin contributing to spawning stocks as recruit spawners in autumn of 1979. If the recruit spawner contribution is strong on Georges Bank after indications of scarcity of the 1976 year class as larvae and juveniles offshore, then this would suggest recruitment from the Maine coast; if the representation of recruit spawners on Georges Bank is weak or absent in 1979, then this suggests the absence of such recruitment. Of course this line of reasoning is not totally conclusive, since there could be annual variations in larval drift, or Georges Bank recruits could come from Nantucket Shoals or other southern New England waters.

6.2.6 Criteria for Predicting Recruitment

The Problem: What are the best criteria for predicting recruitment into adult populations? Estimates of year class strength can be based on (1) surveys of egg deposition on spawning grounds, (2) larval surveys, (3) juvenile surveys (age groups 1 and 2), (4) success of the coastal fishery for juveniles, and (5) pre-recruits (age group 3) taken in the juvenile fishery (Anthony, 1972). As Anthony pointed out, the precision of the estimates should increase from (1) to (5), but in some years this has not necessarily been the case. Furthermore, the cost of conducting all five types of surveys on a long-term basis would probably be prohibitive, and there is the added question of the appropriateness of conducting surveys to assess stock abundance of a single species, as opposed to collective surveys that increase our understanding of the entire ecosystem and its dynamics.

The Hypothesis: Prediction of the extent of recruitment into adult populations should concentrate on independent surveys of age 1 and 2 fish. Enough information is available to suggest that correlations of year class strength with results of larval surveys are poor. This is to be expected if the survival curve of early life history stages is examined. After the inflection point of the curve is past, and mortality rates begin to stabilize, reasonable assessments of abundance, using several sampling methods and concentrating on one- and two-year-old fish, can be made.

Information Available: All of the five criteria for predicting recruitment mentioned under "the problem" have been employed for several years, but the extent and intensity of sampling has been variable, and often inadequate. Anthony (1977) has pointed out that we should look for the best measure of recruitment for management purposes, but if we are to understand factors affecting year class success we must do all five types of surveys. We probably must also examine mortality factors on a geographic and annual basis as well.

A recent review of criteria useful in estimating recruitment (particularly relevant to the Georges Bank stock) was made by Anthony and Waring (1978). The following paragraphs summarize some of their conclusions.

Concerning larval surveys, which have consumed tremendous amounts of effort and ship time regularly since 1971 and sporadically before then -- results in terms of providing an index of recruitment, have been at best equivocal. The very poor 1971 and 1972 year classes were so indicated by larval abundance in the ICNAF larval herring surveys. The 1973-75 year classes were represented at greater abundance as larvae than the 1971 and 1972 year classes (4 to 10 times as abundant in 1973 and 1974, according to Schnak, 1975), and catches of these year classes in the juvenile fishery supported findings from the larval surveys, in that they were better than the catches from the 1971 and 1972 year classes. The 1976 year class is an enigma. Larval abundance in December 1976 on Georges Bank was the lowest observed to that time (ICNAF Red-book, 1977) but larvae of the 1976 year class were more abundant on the Maine coast than any other year class in an 18-year time series (Graham, personal communication), and the 1976 year class was strongly represented as age 1 fish in the 1977 juvenile fishery and as age 2 fish in the 1978 juvenile fishery. Additionally, the 1976 year class appeared in the spring 1978 ICNAF Young Herring Survey (This is the first time since the strong 1970 year class appeared as age 2 in 1972 that numbers of age 2 herring have been taken in that survey).

It seems apparent that a longer time series is necessary before the utility and accuracy of larval surveys in forecasting recruitment can be determined. Even though the early spring larval surveys began only in 1975, it is apparent from the inshore data of Graham that these later surveys, after the period of winter mortalities, would be better choices as indices of recruitment than the late autumn surveys. The cost and the uncertainty of any larval survey suggest that other approaches may be preferable.

Concerning young herring surveys, there is already an indication that they may be useful in detecting very strong or very poor year classes, but not otherwise. It is early to draw conclusions, since they began in 1972, but they did detect the strong 1970 year class, and new information acquired in April 1978 detected a strong 1976 year class, which is considered strong on the basis of coastal larval sampling and presence in the autumn 1977 juvenile fishery and in the 1978 juvenile fishery.

The concept of the young herring survey seems sound -- sample with bottom trawls in February-March, when juveniles would be near the bottom and evenly distributed; and sample synoptically over a wide area of the shelf subdivided into statistical areas. The reality is less sanguine, since to be successful the survey must be done cooperatively with a number of vessels using standard gear operating in a predetermined area.

Although not designed as herring surveys, the NEFC groundfish surveys have been useful in estimating recruitment to the Georges Bank stock. Anthony and Waring (1978) examined the catch per tow of age 2 herring from the 1968-1974 spring groundfish surveys and found good correlations with abundance estimates from cohort analysis for age 2, using survey data from Georges Bank and waters north of the Bank. Predictions of abundance at age 3 from these analyses only provided estimates of very good or very poor year classes, according to the authors.

Concerning statistics from the juvenile fishery, agreement between size of catches of age 2 herring in the Maine sardine fishery (Figure 42) and subsequent representation in adult stocks suggests that such catches can be used as a pre-recruit index -- and possibly the most reliable one at present.

Anthony and Waring (1978) ran multiple regressions on age 2 and 3 catch data from the Maine juvenile fishery against recruitment of the 1960-1969 year classes to the Georges Bank fishery. A multiple correlation coefficient of 0.90 was obtained, although overestimates of abundance at age 3 of 82% and 64% were made for the 1968 and 1969 year classes, and the 1970 year class abundance at age 3 was underestimated by 58% (due possibly to low availability of that abundant year class to fixed gear).

Thus, as Anthony and Waring stated, while the relationship between catches in the 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. Good and poor year classes are indicated, but not those in-between. Also, correlation need not imply causation.

The reality is that estimates of recruitment are very subjective and qualitative -- that none of the pre-recruit indicators have been reduced to quantitative terms, so the weighting of these indicators is entirely subjective. Thus it is reasonably easy to distinguish a good year class from a poor one, but it is difficult

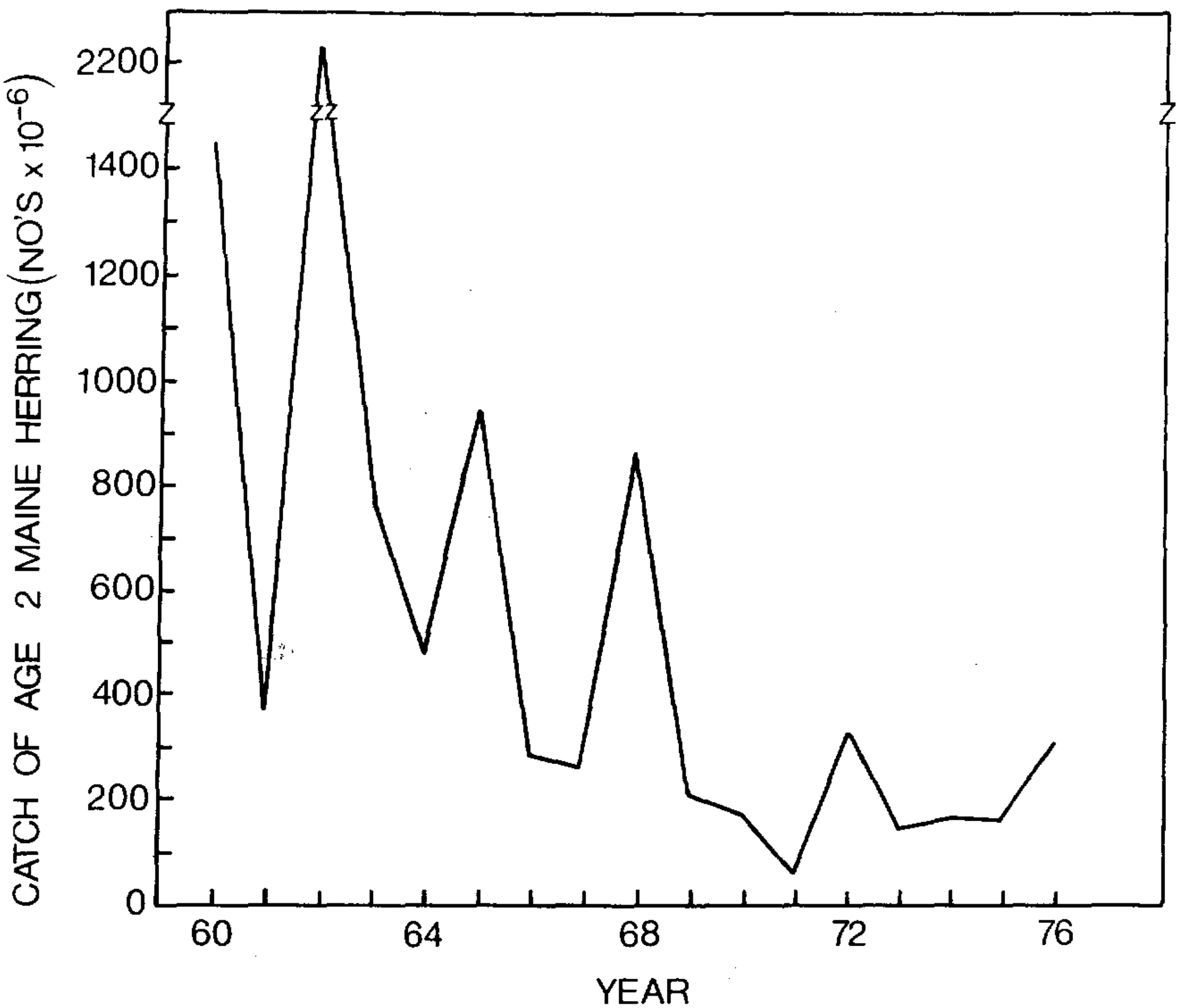


Figure 42. Catch of age 2 herring from Maine (from Anthony, 1977b).

to separate levels of poorness or goodness. We still do not have a reliable index of recruitment from pre-recruit surveys of various kinds. Surveys cannot cover sufficient territory, and the distribution of juveniles is not random.

6.2.7 Use and Adequacy of Models

The Problem: What should be the extent of investment in models, and what can we expect of models? Models can serve a variety of purposes, but their proper use must be fully understood, otherwise extremes of optimism or pessimism about their utility can develop. Generally, there are two levels of modeling: (1) the more utilitarian year to year fishery models, which depend for their accuracy on a constantly improving data base and best possible pre-recruit information; (2) the longer-term models to provide insights about basic questions such as stock-recruitment and success of year classes. These longer-term models depend on data and expertise available; they can point out inconsistencies in data; they can merge data sets; and they can provide longer-term information about the future of the fishery. (They are not, however, useful for short-term decisions about next year).

The Hypothesis: Modeling is important. We should emphasize a better data base for models, then divide effort into short-term year to year approaches and the longer-term models. One of the legitimate uses of research information is refinement of fishery assessment models and the production of better predictive models.

Information Available: Many fishery assessment models have been developed and used in attempting to understand the effect of fishing on the exploited stocks. The model with greatest previous utility with herring data has been virtual population analysis (cohort analysis) but with the advent of more and more stringent catch restrictions, a longer time period is necessary for its use.

Simulation modeling has been used in attempts to understand the relative significance of environmental variables which may affect year class strength, in Canada and more recently in the United States. Dr. W. Bossert of Harvard University has done and is doing exploratory work with simulation models; although he has not found correlations thus far, this kind of study should be encouraged.

6.2.8 Pooled Area Assessment

The Problem: Should herring stock assessments be conducted on a "pooled area" basis? Because of new evidence about movements and intermixing of stocks, and the changing nature of fisheries on those stocks, there seems to be a great need for pooled area assessments from Chedabucto Bay southward.

The Hypothesis: Because of stock intermixture, herring south of Chedabucto Bay, Nova Scotia, should be assessed using the pooled area concept. Translation into management practice would take the form of assigning a total allowable catch, then allocating by area and time on the basis of ratios of past catches in each area, with a mechanism to prevent overfishing in any area. An additional basis for allocation might be previous ICNAF catch quotas.

Information Available: A data base for pooled area assessment extending back to 1956 exists, if Canadian purse seine data is added (pooled area assessments obviously require Canadian cooperation). One international attempt at pooled area assessment was made by a joint United States-Canada working group in 1977. More are needed, hopefully on an annual basis.

6.2.9 Ecosystems Interactions

The Problem: What are the principal interactions of herring of all life history stages with their living and non-living environment, and how do these interactions result in success or failure of year classes?

This problem is in some sense a subset of 6.2.4 (Determinants of year class strength) but it seems to have an identity of its one in focusing on environmental interactions rather than on herring exclusively -- it attempts to locate herring properly in quantitative food webs and not as the focus of a production system.

The Hypothesis: Although complex, the reasons for year class success or failure, and for herring stock abundance or scarcity at a particular time, are not "random", and are amenable to systematic investigation.

A key factor here, obviously, the nature and extent of the data base available for analyses. Necessary components are physical/chemical environmental data; data on predator-competitor abundance; data on forage species abundance and distribution; and most importantly, the expertise with time available for analyses.

Information available: The data base for quantitative examinations of productivity, biomass, and species interactions is probably as good for the area of concern to this document as for any comparable ocean area in the world (with the possible exception of the North Sea). Information about Georges Bank is particularly complete, with a possible weakness in primary and secondary production. The extent and nature of the data base and the potential for exploitation of this data base are indicated in the recent paper by Grosslein et al. (1978). Additional studies of this kind, combined with ecosystem simulation modeling, should be fruitful.

In summary, these seem to be the relevant and persistent problems to be addressed in future research. They are not all unique to herring stocks of course -- in fact most of them are generic ones that appear in considerations of any exploited species. Some seem more amenable to solution than others, considering the existing information and the likelihood of additional data acquisition. Obviously the next step is to define what that additional data should be.

CHAPTER 7

7. RESEARCH REQUIREMENTS, OPTIONS, AND CHOICES

CONTENTS

7.1 INTRODUCTION

During the past three decades -- and particularly during the last one -- much has been learned about herring of the western North Atlantic, but persistent problems exist, and have been reviewed in the previous chapter. Research effort specifically addressed to herring during all this time has fluctuated in intensity, but in totality has not been large, and probably will not be in the future, so any proposal for future research must be realistic, and must focus on the most critical needs for assessment and management.

The cost of doing research on any species has been and will continue to be weighed against the economic benefits derived from the fishery on that species. Beyond this, research on a particular species must be prioritized against that required for other economic species, since total funds and personnel for research on all species are finite. Research priorities are of course based on a number of considerations, but the strongest will inevitably be "What information is really required for management?"

The decision to conduct research on a specific species must also be weighed in terms of its generic value for assessment activity and in terms of its value in producing better ecological understanding of the system as a whole. For this reason, research programs of the Northeast Fisheries Center during the past decade have typically not centered on species, because species specific programs tend not to be particularly valuable in terms of an overall understanding of the productive system.

There are at least three reasons for doing more research on herring:

(1) to meet pragmatic short-term management needs;

(2) to enable refinement of fishery assessment models and production of better predictive models; and

(3) to increase basic biological understanding of herring stocks and of their responses to exploitation and environmental changes.

The research ingredients needed to satisfy these needs are summarized in Figure 43.

Herring research for any of the above purposes must be based on a substantial foundation of continuous monitoring, which must have funding priority. However, since monitoring programs can become ends in themselves, and since monitoring programs can, without adequate controls, quickly expand to consume all available funding, the objectives and approaches to monitoring must be carefully selected and circumscribed -- so that the "right" information is collected on a long-term basis.

Research to meet pragmatic short-term management needs must have priority also, since critical decisions about allowable catches and geographic distribution of quotas should be made on the basis of the best scientific information available. Key research areas here are reliable estimates of stock size and distribution, and adequate recruitment estimates. Just as there must be some rational balance

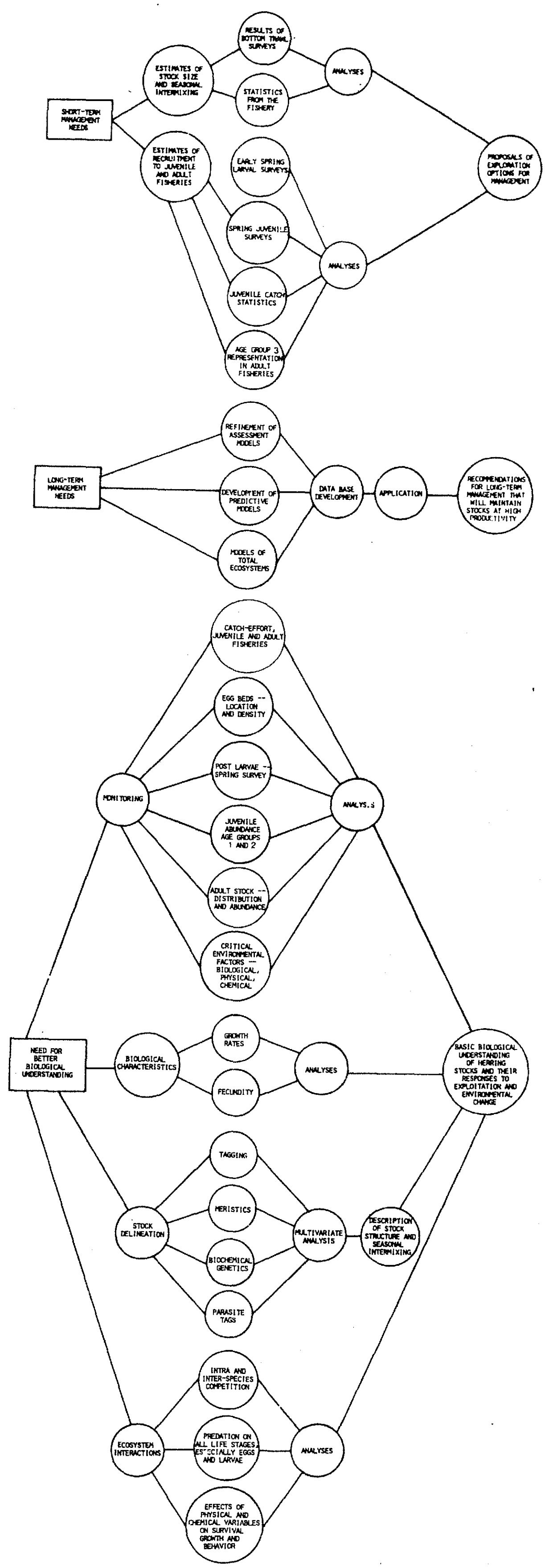


Figure 43. Research requirements to satisfy short- and long-term management needs and to increase biological knowledge of herring.

between monitoring and research, so also there must be a balance between research to meet short-term management needs, and longer-term research to enable refinement of predictive models, and to increase necessary basic understanding of herring stocks and their responses to fishing and other environmental pressures. Such a balance will be difficult to achieve and maintain, although the United States research oriented toward total ecosystem management is a promising indication of commitment to long-term goals.

This chapter will consider monitoring needs, research to meet short-term management needs, and research to meet longer-term goals -- and will then review how the proposed work will address the critical persistent problems identified in the previous chapter.

Essential information requirements for herring include research and analyses conducted under the following descriptors: stock assessment, stock identification, biology (including growth, reproduction and mortality), recruitment estimates, and environmental studies. Obviously these categories are overlapping to some extent and interrelated. The degree of interrelationship and the estimated relative proportions of effort required to obtain needed information is shown in Figure 44.

7.2 MONITORING

Monitoring of adult stocks must continue to be the mainstay of any sampling program. Data from catches (abundance, location, age, composition) as well as from fishery-independent surveys must continue.

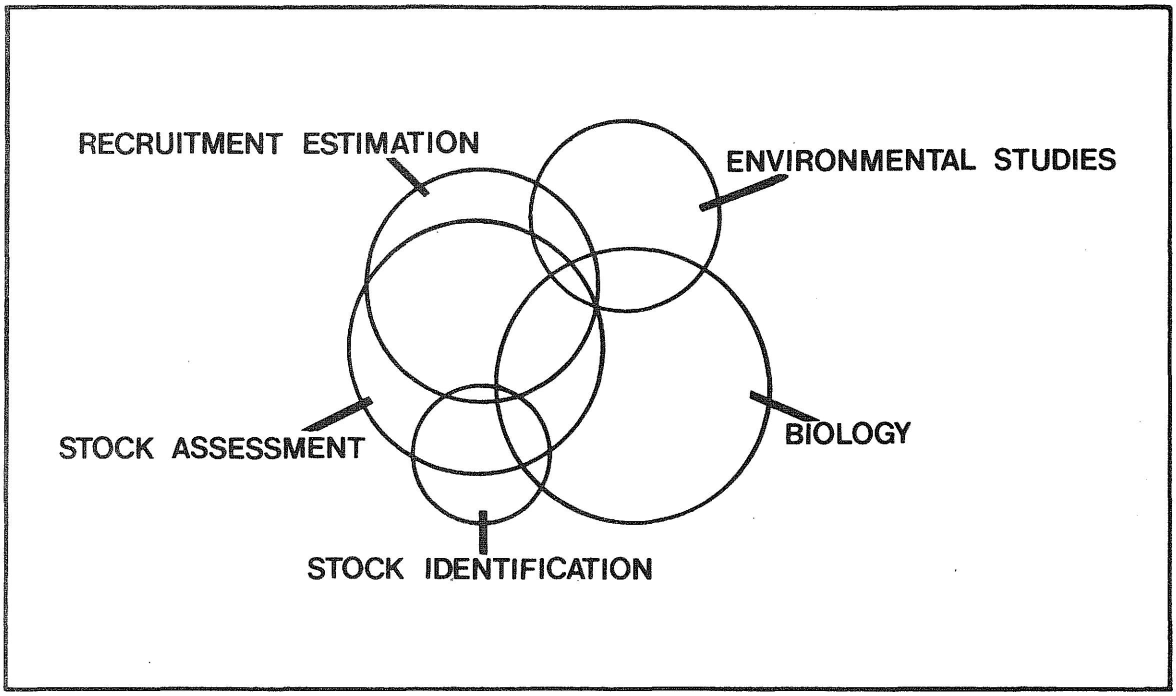


Figure 44. Interrelationships and relative proportions of research effort required to obtain essential information on herring.

Collection of catch-effort statistics from the juvenile and adult fisheries, regardless of the limitations of catch statistics, must continue.

Monitoring of catches must emphasize accuracy of catch information and catch-effort data, adequacy of sampling catches for age determinations, and timely reporting of catch information. Continuous data collections for determining abundance of significant predators and competitors must also be assured -- from surveys and catch statistics.

Collection of environmental data should have continuity, and should be limited to those parameters which may be important to survival, movements, growth, and spawning of herring. These are zooplankton abundance, temperature, salinity, predators (for all life stages) and competitors (for all life stages).

There is some doubt that larval abundance in autumn-early winter can be a good criterion of year class strength, since recruitment does not occur for at least 1 year (juvenile fishery) or 3 years at a minimum for the adult fishery, and much can happen to any stage of a year class in the intervening period. Spring larval surveys may provide a slightly better measure of abundance, after the critical first winter of life has passed. However, escapement from sampling nets increases with increasing size of larvae, and behavior of post-larvae at metamorphosis is poorly understood, so the spring larval surveys may not provide a good criterion of abundance either. If larval surveys are to be conducted they should be intensive and close-interval, following a standard sampling plan, and sorting must be on a real-time basis. Fixed location sampling of larvae in selected estuaries, carried out on a limited scale by Graham since 1962, should be carefully evaluated, and if considered of utility, should be continued and expanded to include locations in eastern and western Maine.

It seems, though, that monitoring for recruitment and early determination of year class strength should not emphasize larvae, but should emphasize 1, 2 and 3-year-old fish, possibly sampled in autumn-early winter in coastal waters with off-bottom gear, and in selected offshore areas also. Larval sampling may be more important as a tool to help understand the stock recruitment process than as a method of predicting year class strength.

7.3 RESEARCH TO MEET SHORT-TERM MANAGEMENT NEEDS

Obvious immediate questions relevant to management are: "What is the present stock size? How is it distributed? What recruitment can we expect this year?" The questions are simple; the work required to provide adequate answers is not. Much of the background data for adequate answers will come from monitoring, but informed comprehensive analyses of the data are at the core of any program to meet short-term requirements for management.

Estimates of stock size depend on historical information from the fishery and from surveys of adult stocks, augmented by information about egg and larval abundance at spawning sites. Information about distribution of the stock again comes from the fishery and from surveys for adults, augmented by tagging results. Information about recruitment is derived from various kinds of pre-recruit surveys, the success of the juvenile fishery, and the relative representation of year classes in the juvenile fishery.

Most of the ingredients for short-term responses to management needs are in place at present, but the responsibility for integration of all monitoring, research and assessment activities is diffuse, and requires better coordination.

7.4 RESEARCH TO MEET LONGER-TERM GOALS

Longer-term goals -- understanding of herring stocks and their responses to fishing and environmental changes, as well as development of better assessment and predictive models -- are usually acknowledged as important, but are also usually lost in pressures to provide immediate answers to immediate problems. Research often becomes totally involved in documenting <u>what</u> is taking place in fish stocks, leaving no time or funding for investigations of <u>why</u> the observed phenomena occur. Use of "best available scientific information" for management decisions is probably a necessary management practice, as long as there are no delusions of misconceptions about the quality of such information and the levels of reliability of existing data bases.

Most of the research leading to understanding the biology of herring has been reduced in recent years because of priorities on people and time set by immediate management needs. Biologists continue to collect samples useful to examination of such biological characteristics as changes in growth rates, disease prevalence, meristics, fecundity, distribution, and mortality rates, but rarely do they have time to even prepare these samples for study, let alone analyze results or contemplate their significance. Beginning about 1970, with the impetus of ICNAF concern about declining stocks, a great data base has been acquired (otoliths, scales, gonad weights, meristic characters) but has been analyzed only superficially since that time, and still consists principally of original data sheets or computer cards and tapes. Catalogs of these largely unpublished data sets should be prepared (for both juveniles and adults), evaluated, and analyzed.

Another research area that has suffered most from pressures of the moment is that which can be described as herring population dynamics. Ideally this should be a mixture of application of existing theory with a more contemplative review and analysis of concepts, as well as development of better models for assessment and prediction. The more theoretical developmental aspects of population dynamics research have been slighted or ignored, or have been relegated to minimally-funded and sporadic university contracts. What remains is little time or energy for anything but application of existing data to existing fishery models, recognizing their often conceptual unsuitability to a pelagic species such as herring, using assumptions which may or may not be valid, and producing estimates with questionable reliability. Admittedly the nature and extent of the data base is of great significance to the reliability of any quantitative manipulation, but improvement of the data base without concomitant increase in time available to analyse, contemplate, ponder, and experiment with the data would be unfortunate.

Another research area, related to the preceding, that has suffered from pressures for immediate data analyses to meet short-term management needs, is that of ecosystems research -- the broader examination of the environmental matrix within which herring are embedded, and the role that herring play within this matrix. Important issues to be addressed include interspecies interactions and the effects of varying herring stock size (resulting from exploitation) on other ecosystem elements. Such research obviously constitutes a small aspect of development of the kind of data base necessary for total ecosystem management.

Beyond these generalizations, it would seem useful to structure proposals for longer-term research in terms of responses to critical and persistent problems discussed in the previous chapter. They are:

(1) Accuracy of stock assessments and validity of the conceptual basis for assessments;

(2) Stock-recruitment relationships;

(3) Discreteness of stocks;

(4) Determinants of year class strength;

(5) Spawning sources of juveniles caught in coastal waters;

(6) Criteria for predicting recruitment;

(7) Use and adequacy of models;

(8) Pooled area assessments;

(9) Ecosystems interactions.

7.4.1 Accuracy of Stock Assessments and Validity of the Conceptual Basis for Assessments

It would seem entirely logical at the outset to ask "What data are needed for adequate assessments of current stock status?" Obviously we need data on catches and the age composition of catches. We also need information on fishing effort, recruitment, growth, and natural mortality. We also need fishery-independent measures of abundance, from surveys. But it is the degree of precision of the data that is more difficult to define. In addition to the question about what data are needed for adequate assessments, we must also ask the question "What precision of estimates is required, and how can this degree of precision be attained?" For example, would doubling the number of surveys (once a decision has been made about the most desirable surveys to be conducted) increase the precision of estimates by a corresponding or even a substantial amount? As another example, the accuracy of catch statistics should be improved -- but will the cost of increased statistical effort (more complete coverage of ports and vessels, log books, and auditing log books) be commensurate with increased precision of estimates?

Herring assessments since 1973 have been made on the basis of qualitative judgments based on surveys and statistics from the juvenile fishery. Estimates of stock size have been based principally on best available data from the fisheries; with increasing restriction on catches since 1974 such estimates are more difficult to achieve, and other bases for estimation of stock size are needed. We now need to build in specific management decisions more directly, and this is difficult, since the history of herring fisheries has been one of exploitation, ultimate dependence on a single year class, and collapse.

Cohort analysis, dependent on adequate aging of fish, has been the basis for studying historical trends in stock size. We now have a time series from the mid-1960's to 1973. Results of expansion of the catch equation for more recent years (since 1973) are particularly sensitive to unverified assumptions about the current fishing mortality rate. Therefore, the assessment of current stock size is based on the assumed strength of year classes at age 3, as indicated by the catch rate of each year class in the juvenile fishery relative to the catch rate of earlier year classes of known size (calculated by cohort analysis). This gives an estimate of current stock size which can be projected into the future, given some assumptions about the size of recruiting year classes. Judgments can then be made about optimum and minimal stock size.

Cohort (virtual population) analysis is a history, and to predict, we need current information on recruitment and fishing mortality rates. Assessments at present are based almost entirely on recruitment estimates at age 3. If the juvenile fishery is to be managed, as well as the adult fishery, then we need accurate estimates of abundance of one-year-olds.

Management of herring stocks on a long-term equilibrium basis can be wasteful relative to approaches possible with completely accurate and highly precise assessments, since estimates will tend to be conservative, and full advantage of strong year classes cannot be taken if the objective is to maintain a satisfactory stock size over the long term.

A conservative strategy may not be wasteful if the objective of management is to maintain production with a low risk of failure, when faced with relatively unprecise assessments. Year classes should be exploited to the extent indicated by management objectives, but to do this we must understand the strength of a year class at an early age. This is the critical problem of herring stock assessment.

At present we are using juvenile catch statistics to qualitatively judge year class strength, but the fishery may in any given year miss some concentrations, because of variation in availability. Additionally, saturation of processing facilities and potential increases in effort can be problems. Also, it is difficult to judge changes in exploitation rate. There have been major shifts in the pattern of the adult fishery, from emphasis on fall spawning aggregations to a spring fishery; the spring fishery of course eliminates a portion of the year class that would otherwise contribute to fall spawning aggregations. Assessments relevant to particular spawning stocks must therefore be influenced by migrations and intermixing -- and by the fishery on intermixed stocks at times other than spawning;

There are other problems with present assessment methods:

(a) The juvenile catch has been a good indicator of year class strength, but now with more mobile gear (purse seining and pair trawling), this measure may have to be tempered by inclusion of effort statistics.

(b) Some juveniles may be "double-counted", in that if juveniles move along the coast, a year class may look strong at age 2 in one location and the same year class may move and look strong at age 3 in another location -- and the observations added, to make it seem that the year class is better than it really is.

Present guiding principles in stock assessment are:

(1) The amount of future assessment activity depends on the degree of precision of information desired by management agencies.

(2) In the absence of real data on stock separation we must consider major spawning areas and thus possible stocks separately so that no single stock will be overfished. However, we must manage all stocks with the same management goals and strategies.

(3) We now have enough experience with the passage of year classes through the fishery to begin making good evaluations of assessments.

(4) There is now enough evidence to state that Georges Bank stock size is well below minimum stock size (recognizing that the figure set for minimum stock size was a management figure -- a decision of ICNAF -- based on what was known of existing stock size).

(5) Virtual population analysis in itself is not a tool for assessing current stock size.

Increased precision of assessments can be attained by several methods:

(1) Assessments should be extended to include 3-year-olds on the Maine coast, and probably to the entire juvenile fishery there.

(2) Assessments are now required that are consistent with management subdivisions, zones, and seasonal periods proposed in the new Fishery Management Plan.

(3) The use of statistics from the juvenile fishery in calibrating assessments may be improved by including a factor for availability, and also an economic factor (packing capacity, inventory, market condition).

7.4.2 Stock-Recruitment Relationships

A matter of continuing and vital interest in fishery science is the relationship between size of the spawning population in any given year and size of the year class produced by that spawning population. Several studies have indicated that the relationship is weak or nonexistent -- or even inverse. Examination of 16 year classes (1931-1947) of Pacific herring (Tester, 1948; Ricker, 1954) for a relationship between intensity of spawning and resulting year class strength disclosed a slight negative correlation. The largest year classes were produced by smaller than average spawnings; and the smallest year classes were produced by larger than average spawnings during the period of study.

Studies of the possible relationship of spawning stock size and subsequent recruitment of progeny in the western North Atlantic have been inconclusive, with the suggestion that factors other than adult stock size may be important in determining size of year classes resulting from spawning in any given year. The uncertainty in heavily exploited populations like herring is that below an undetermined minimum stock size, success of reproduction and size of year classes may be related to stock size, and a direct relationship may emerge. This matter should be explored further with stocks of concern to this document, since the available data base is now probably better than that available to previous investigators of other herring stocks elsewhere in the world.

Concerning herring fecundity and spawning, it seems clear that egg bed surveys have been incomplete, especially for areas other than Georges Bank, and that even the information on fecundity is weak. Maps have been developed showing locations of spawning on the Maine coast and for the entire Gulf of Maine, but the surveys on which the maps were developed were sporadic, and often geographically restricted.

Further study of fecundity and gonad/body weights at age should be made to achieve estimates of stock size even though such studies are difficult and results are variable. Age at maturity seems to have changed in recent years, and it seems that larval abundance correlates better with stock size than with recruitment. From a practical standpoint it is feasible to estimate egg production given an estimate of stock size and maturity-fecundity data; but it is not practical to estimate egg production by sampling egg beds. In any case it would still seem necessary to identify larval mortality factors if there is any hope of unraveling stock-recruitment relationships.

7.4.3 Discreteness of Stocks

Three approaches to better understanding of the degree of spawning stock isolation should be part of a future herring research program. They are, in order of priority, tagging, biochemical genetics and parasite tags. Critical paths for these approaches are summarized in Figure 45.

Tagging

Equally as significant as correct estimates of recruitment is the understanding of stock distribution and intermixing -- at spawning time and throughout the year and at all ages, since fisheries now exist on a year-round basis. The most effective approach by far seems to be a long-term intensive tagging program, emphasizing the marking of spawning aggregations, but including other seasons and ages. We have learned much from tagging, and continued tagging work will be valuable. It seems that there is more movement and intermixing of Gulf of Maine and Nova Scotia fish than we had thought, and this has changed management strategy. Tagging, if intensive enough, can of course provide information about fishing mortality for each stock.

Possible approaches would be:

(a) Tag ripe fish on all principal spawning sites in autumn. This should be a multiple area reasonably synoptic tagging using foreign vessels (seiners) as well as United States vessels. Other possibilities for tagging platforms would be menhaden purse seiners, or NOAA or contract vessels rigged for purse seining.

(b) Tag adults from October to April, from Georges Bank south to Virginia, to determine the extent to which herring from the Gulf of Maine and Georges Bank mix in Subarea 6 and Div. 5ZW outside the spawning period.

(c) Tag 3-year-olds or large 2-year-olds at the end of the sardine fishery of Maine in autumn.

(d) Tag 2-year-olds on Georges Bank and in the Block Island area in winter (especially in years when they occur in abundance).

Tagging, even if done intensively, still has significant deficiencies -- most notably the problem of obtaining adequate tag returns. For example, as long as there is no commercial fishing on Georges Bank it will be very difficult to obtain returns from this area. Therefore, even if there was significant dispersion from the Gulf of Maine to Georges Bank, it is unlikely this would be revealed by a tagging program at present.

Biochemical Genetics

Biochemical approaches to understanding of stocks and their intermixing should be continued since they are at present our only avenues to genetic descriptions of the species and its subgroups. Morphological and morphometric criteria are extremely vulnerable to environmental modification; biochemical criteria are less vulnerable, although as Koehn (1971) has pointed out, selective forces can change within one generation the expected equilibrium gene frequencies, including those detectable by biochemical methods.

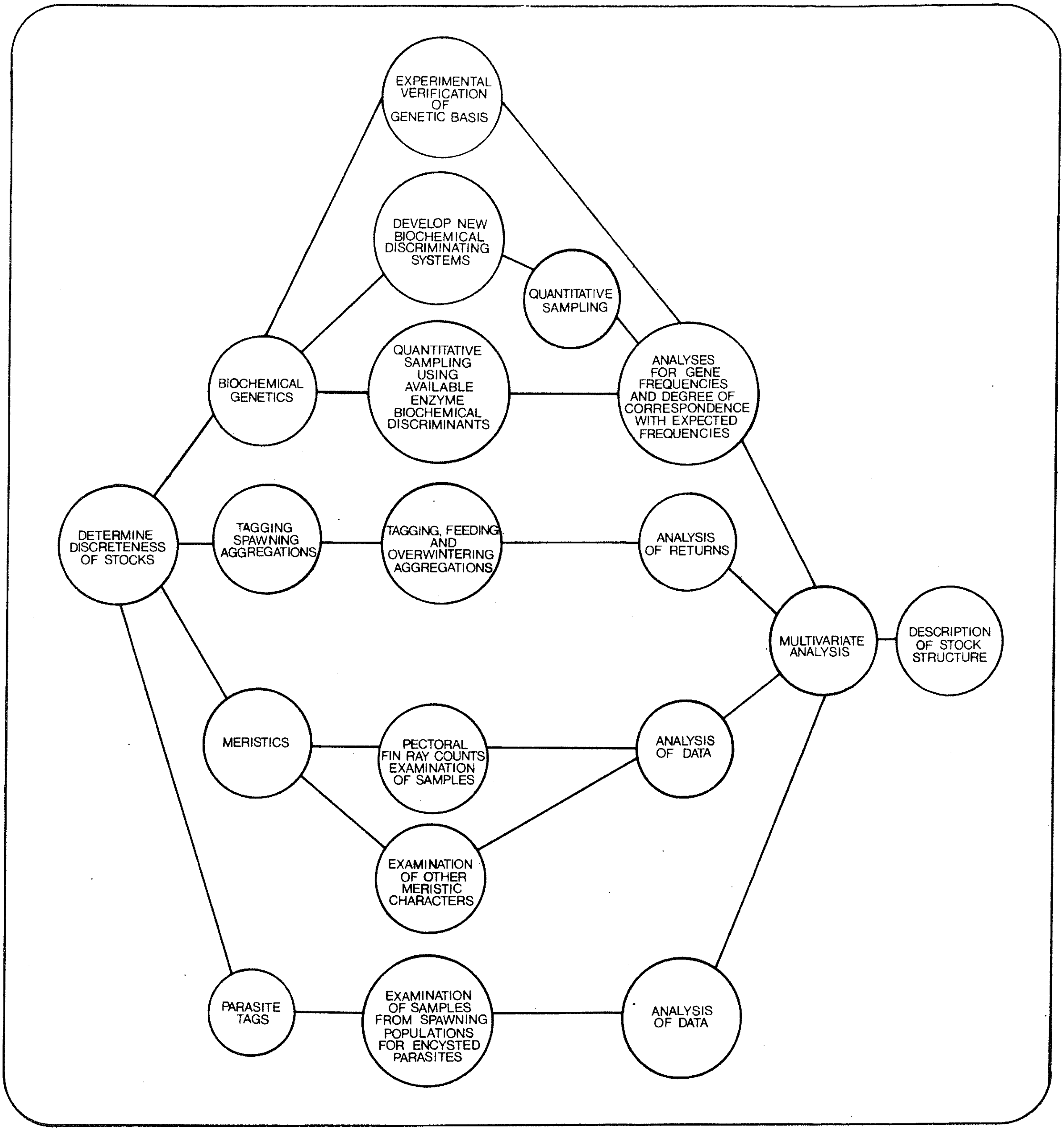


Figure 45. Critical paths to understanding the discreteness of herring stocks.

When combined with the more pragmatic method of tagging, biochemical genetics can provide the basis for genuine understanding of the discreteness of herring subgroups, and of the extent of their intermixing at other than spawning times. Genetic models are available and can be utilized to serve both these ends, once a satisfactory data base of genotype frequencies is available from biochemical studies.

Good progress has been made in the identification of enzyme systems with reasonably simple genetic relationships. Some quantitative work has been done with these systems, but results have not been fully analyzed or interpreted. This should be done, and several of the most promising systems should be used in examining new samples from spawning populations <u>at the time of spawning</u>.

Based on results obtained, existing genetic models should be utilized, and new ones developed that will assist in understanding the extent of intermixing of stocks and the source(s) of juveniles taken in coastal waters. Sampling should be repeated annually and age composition determined, to see if any variability in gene frequencies occurs -- and if so, how much.

An attractive aspect of the approach is that genetic models of population intermixing are available, and determination could be made, with experimental populations of other species, of the maximum intermixing that would allow genetic variations to persist.

Parasite Tags

The use of parasite tags has provided valuable information about stocks and movements of a number of fish species, including cod, haddock, flounders, and redfish. The technique does not provide genetic information about stocks, but if enough environmental information is available, it can provide clues about movements (or lack of movements) of the hosts. Usually encysted larval parasites, or those permanently attached to the fish, are best. The parasites should be conspicuous, and persist for an extended period (1 year minimum).

Some of the parasites of Northwest Atlantic herring have provided information about movements of juveniles in coastal waters (Sindermann, 1956) and also about intermixing of adult stocks (Sindermann, 1957). Much more information is available but unpublished (Boyar, unpublished manuscript) about the distribution of an especially promising larval nematode (Anisakinae) in adult herring stocks over a 6-year period.

This work should be extended by examination of samples from all spawning aggregations, for occurrence and abundance of all of the parasites that meet the tag criteria mentioned. Age composition must be determined. Multivariate analysis should provide worthwhile information on maximum possible intermixing. This should be followed by examination of samples from adult catches at other times of the year. The sampling would continue for several years, to determine extent of seasonal and annual variability.

In addition to the three approaches discussed, we should not abandon morphometrics and meristics as a possible source of information about the fate of progeny of separate spawnings -- in terms of where nursery areas are, and where recruits to spawning stocks come from. We have data on meristics from the 1960 to 1967 year classes. These should be looked at more carefully than they have been, and possibly some new collections made.

7.4.4 Determinants of Year Class Strength

Different factors (density dependent or density independent) may be more significant than others in affecting year class survival in any given year. Use of simulation models has led to the conclusion that variations are now best treated as random, but more attempts at correlations need to be made. A series of hypotheses should be developed and prioritized, taking into account the availability of data and cost of obtaining data. Early emphasis should be placed on relevant environmental parameters that are available readily and inexpensively -- such as data on wave heights sensed by satellites, or winter storm impact, or satellite-sensed chlorophyll levels. Also, cold water intrusions over banks and spawning areas vary from year to year, and may be important in spawning and survival. Currents (particularly through important deep channels such as South Channel) are also variable from year to year, and may be important to larval distribution and survival.

We need to test long time series of environmental data, where available, against year class strength of herring. Relevant time series, for factors such as surface and bottom temperature, currents, and storm effects, have been and are being assembled and interpreted by the Atlantic Environmental Group (NMFS).

The abundance of year classes of other species (sand lance, rock gunnel, menhaden) should be examined for possible relation to herring year class survival. Direct or inverse relationships with competitors or predators should be explored.

In the area of species interactions (predation and competition), we should explore Hempel's North Sea pelagic-demersal change as a possible example of predation effects on eggs and larvae. According to Hempel's concept, when pelagics (herring and mackerel) are abundant, they prey on eggs and larvae of demersal species, and may reduce the demersal biomass, and when pelagics are scarce, more larvae of demersal fish survive. This shift from pelagic to demersal fish abundance seems to have occurred in the North Sea in recent years, but as yet there is no substantive evidence for such a change in the western North Atlantic (Grosslein et al., 1978), where stocks of both pelagics and demersals are reduced at present. It may be that data are inadequate to detect a shift, or that the time span to permit such a shift has been too short, so continued attention to this matter is of great importance. It may also be that the biological systems in the North Sea and Georges Bank are fundamentally different. Fish productivity in the North Sea is probably limited by food availability, while there appears to be no evidence of this situation in the Georges Bank area.

The recent explosive increase in abundance of sand lance larvae found in MARMAP plankton collections of the Northeast Fisheries Center may be either a transient phenomenon, or an indicator of substantive change. Its possible association with herring abundance is still somewhat questionable, since sand lance abundance did not begin to increase until adult herring stocks were very low, but they increased at a time when year classes seemed to be improving, based on juvenile herring catches.

Several aspects of herring larval life seem worthy of additional study, in terms of influence on year class strength:

(1) Inshore larval aggregations and the effect of such aggregations on survival seem significant, even in advance of the schooling phenomenon which appears soon after metamorphosis in the spring. The inshore and estuarine movements of larval aggregations seem directed and purposeful, rather than random, and the mechanisms favoring integrity of such aggregations should receive additional study.

(2) The feeding of larvae is clearly a significant factor in survival. Some data exist (Chenoweth, 1970) relating mortality of larvae to condition, as indicated by length-weight analyses. Also, there is some data suggesting that high food densities must be present before larval feeding is initiated. Lasker's (1975) observation on the importance of particle distribution in feeding of anchovy larvae should be examined for herring larvae.

(3) Patchiness of food can have a profound effect on survival of larvae, and physical and biological factors of the environment which result in formation of food patches also determine the survival of herring larvae.

(4) The relation of temperature to larval survival has received much attention, but relationships are still ambiguous. Below optimum bottom temperatures at time of spawning (such as those that prevailed on Georges Bank in 1977) may have some influence on hatching and survival, as may the rate of increase in temperatures during the past decades. (There is, however, little general correlation of autumn larval abundance and year class strength).

(5) Predators of larvae can be locally abundant, and can be drawn from many of the animal phyla. Cycles of annual abundance of principal predators could affect pressure on larval herring populations.

(6) Transport and retention of larvae are still subjects of debate in areas such as Georges Bank and the Gulf of Maine, and can have major influences on survival. Vertical distribution is important here.

Critical paths to determination of factors influencing year class strength are summarized in Figure 46.

7.4.5 Spawning Sources of Juveniles

The spawning source of juveniles taken in the Maine and New Brunswick coastal fisheries is still uncertain, despite extensive comparisons of morphometrics, meristics, larval drift, and serological-biochemical characteristics. There is some feeling that juveniles from the western and central sectors of the Maine coast are probably derived from the western Gulf of Maine spawning population, but there is some evidence that the New Brunswick and eastern Maine juveniles are not derived from the Nova Scotia spawning population.

Because of the inconclusiveness of previous studies, which depended on environmentally-modifiable characters, it would seem that the approach of choice at present would be through biochemical genetics, once the three principal spawning populations (and maybe lesser ones) are fully characterized, and sufficient genetic markers are available to make comparisons. Such an approach would require intensive sampling, biochemical testing, and statistical analyses over several years, but if

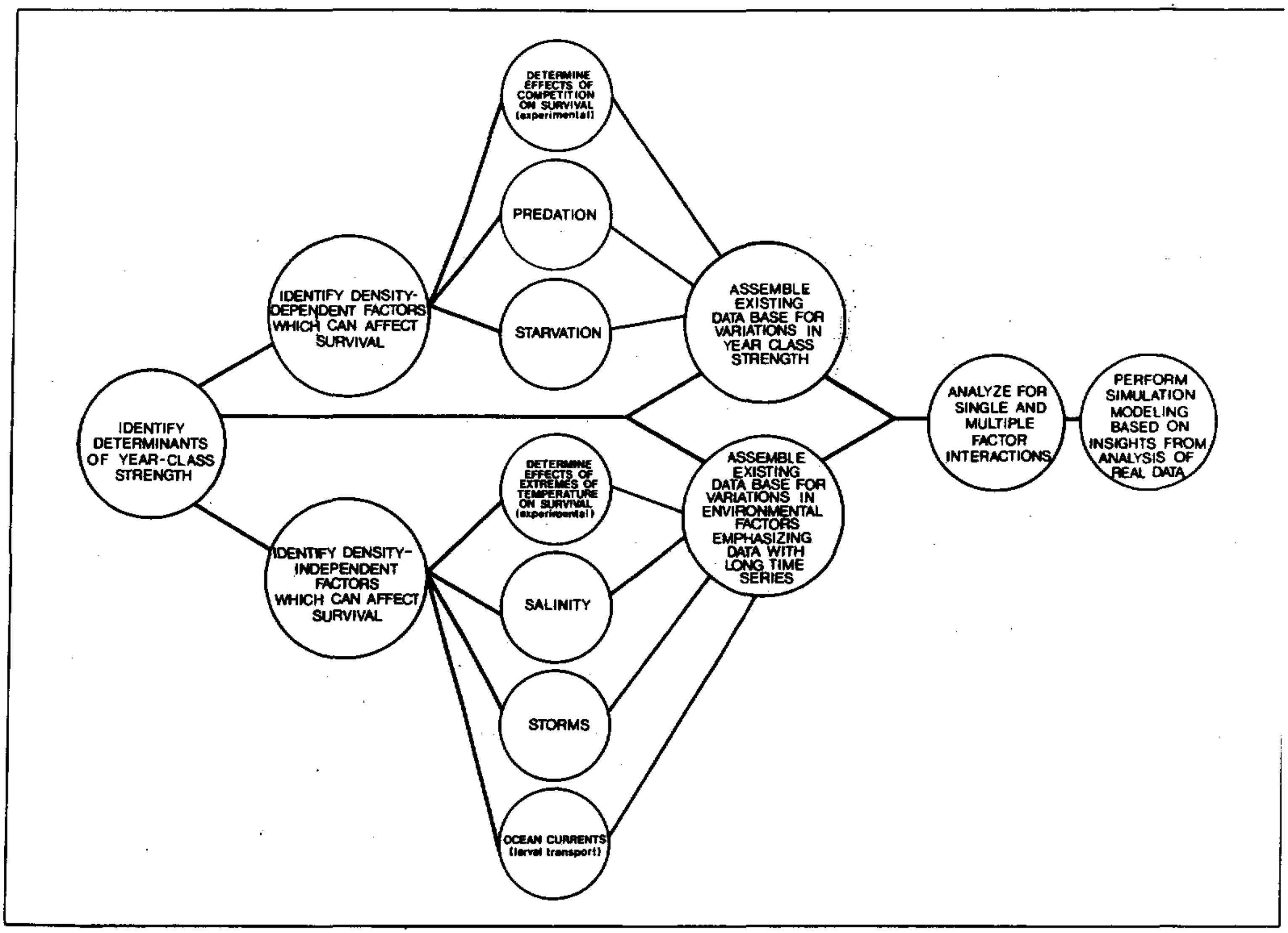


Figure 46. Critical paths to determination of year class strength.

adequately pursued it could provide definitive answers to questions about which spawning population contributed and (if there is intermixing) what the relative contributions of several spawning populations might be.

7.4.6 Criteria for Predicting Recruitment

Estimates of recruitment should begin, ideally, with egg bed surveys and extend through autumn larval surveys, spring larval surveys, juvenile surveys, analysis of juvenile catch statistics, and analysis of age 3 fish in juvenile and adult fisheries. A program utilizing all of these steps is too expensive. Egg bed and larval surveys do not always give an adequate forecast of abundance. There are two possible approaches to provision of the necessary early fishery-independent measure of recruitment (beyond the present late-winter early-spring offshore trawling survey):

(a) Juvenile surveys (age 1 fish) in the spring of the year seem to offer the best hope for a fisheries-independent estimate of year class strength. It may be that selected inshore areas could be sampled, and not the entire offshore area. Cape Cod and Cape Cod Bay have been suggested as key monitoring sites (Anthony, 1977). An early spring survey could have dual purposes of sampling late larvae as well as juveniles, possibly with large neuston nets or fine mesh Isaacs-Kid trawls.

(b) A second and equally good possibility for estimates of recruitment to the adult fishery would be a late-autumn early-winter coastal pelagic survey (for age 2 fish), conducted after the juvenile fishery has ended, emphasizing the areas a few miles offshore, and preceding the winter migration.

Either or both of these surveys should be accompanied by hydroacoustic surveys, if we are to get a good picture of pre-recruit abundance.

Regardless of the method selected, there is a universally recognized need for valid pre-recruit estimates of abundance for all stocks, if adequate assessments are to be made.

We obviously need better estimates of recruitment, as early in the life of each year class as possible, to improve assessments. If abundance of a year class is determined early (possibly by spring, when fish are 6 months old) then we can look at fish in their first year of life, and possibly get a measure of catch per unit effort from a fishery-independent survey in spring or in late summer and autumn. These surveys might take the form of a synoptic look at abundance using chartered purse seiners, or using airplane spotters for night surveys of brit abundance, or both. Dr. Cole of the University of Massachusetts has pointed out (personal communication) that Dr. Carritt of the Geology Department of that University has been using a multi-spectral camera with low-level remote-sensing fixed wing aircraft, which might have application to such a survey.

We should then look at the catch per unit effort for the weir and stop seine component of the juvenile fishery. The change in effort in this fishery makes a reassessment necessary. Additionally, other criteria (such as presence or absence of 2-year-olds in spring trawl catches on Georges Bank or inshore surveys in the spring) should be added to the data base, as should information from the Canadian juvenile fishery.

The final step would be a survey of 3-year-olds, probably in autumn. With these criteria, an estimate of recruitment at age 3 could be assembled. The steps in this process are summarized in Figure 47.

A reasonable question that has been asked is "Are we putting too much effort (relatively) into assessment and assessment-related activities, when the key problem is a more specific one of recruitment of each year class and prediction of its size?" An affirmative answer to this of course leads to subsidiary questions such as "What are the best kinds of surveys that would be representative of a large area?" and "What age can be the best early indicator of year class abundance, and where should

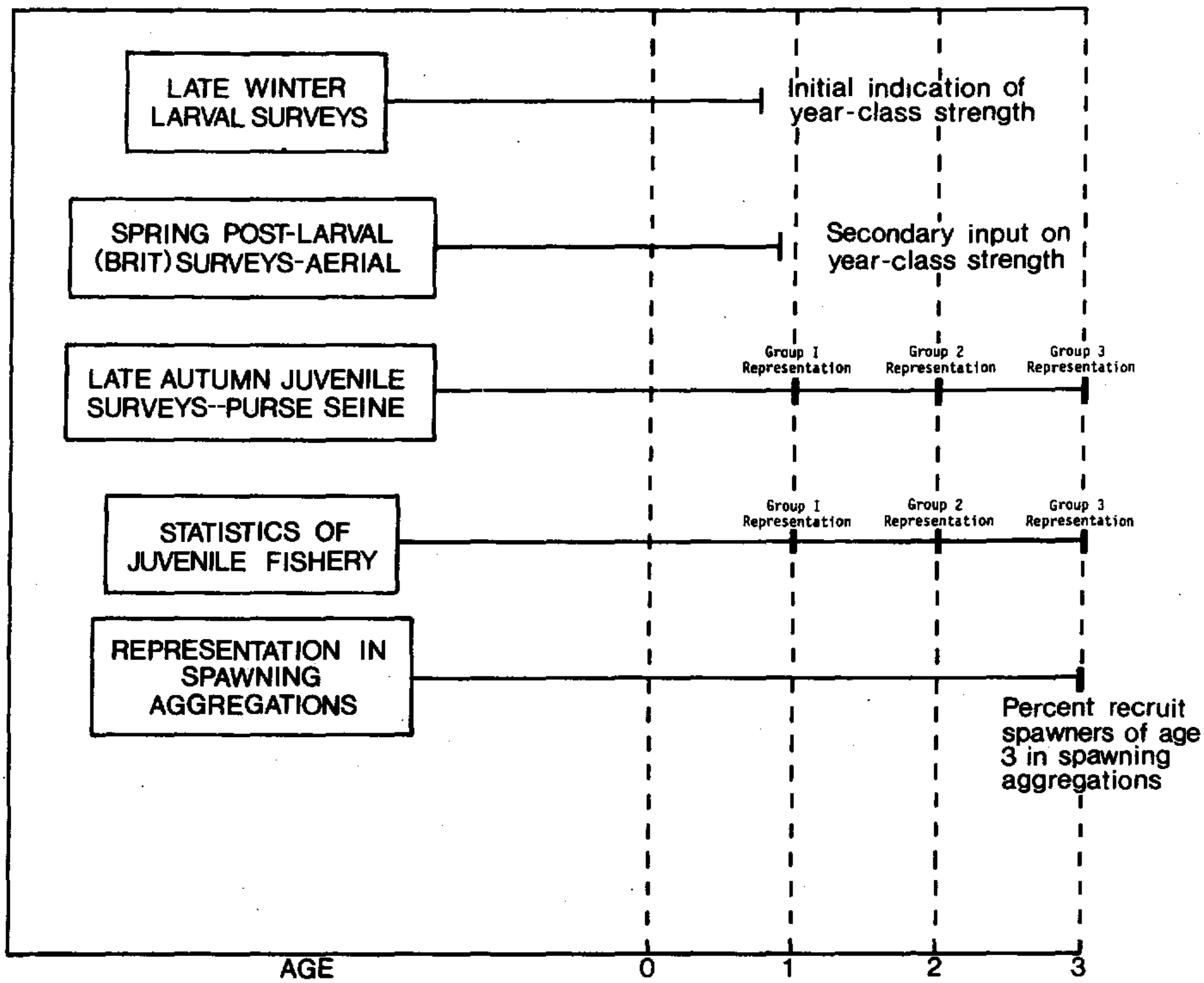


Figure 47. Steps in the development of pre-recruit estimates of abundance.

surveys for fish of this age be conducted?" The proposed program should be responsive to these questions. Alternatively, we might ask "Are there more robust management policies, which better utilize the available data, and minimize the potential danger associated with data and biological unknowns?" Regulation by catch quota is probably the most scientifically demanding form of management. Perhaps there are other less demanding methods of management which would still accomplish management objectives.

7.4.7 Use and Adequacy of Models

As was pointed out in the preceding chapter, models can serve a variety of purposes, but their proper use and their limitations must be fully understood. Generally, there are two levels of modeling: (1) the more utilitarian year to year fishery models, which depend for their accuracy on a constantly improving data base and best possible prerecruit information; and (2) the longer-term models to provide insights about implications of particular management strategies, and to address basic questions such as stock-recruitment and success of year classes. These long-term models depend on data and expertise available; they can point out inconsistencies in data; they can merge data sets; and they can provide longer-term information about the future of the fishery. The long-term models are extremely important, not for making short-term decisions but for providing insights to improve the decisions made from the immediate assessment status of the stock. In other words without these longer-term models and conclusions; the assessment of the stock becomes a description of its abundance; without the assessment component.

Models can be used to determine effects of different alternative management plans, once the objectives of such plans (maximize harvest, maximize economic benefits, maintain stocks, rebuild stocks) are clearly stated and understood by managers. There probably should be greater attention to and more use of "management" models in determining management strategies for stock maintenance or rebuilding, but a better data base is needed, since the precision of the model depends on the accuracy of data inputs. The NERFMC management model for herring (NERFMC, 1978) is an example of the potential application of such models, in which allocations are made by season and area, with provision for modification and "fine tuning" based on results of experience and acquisition of new data.

The use of simulation models can be important in developing hypotheses about variations in year class strength and in testing such hypotheses. Thus far the conclusion seems to be that the causes of such variations are unknown and thus must be treated

7.4.8 Pooled Area Assessments

Pooled area assessments are an obvious necessity for the future. Necessary data are available, extending back to 1964, providing a significant time series. With recent data from tagging, which suggest more migration than we had assumed, pooled area assessments become of great importance.

We need to add to this a possible "second tier" type assessment, since at present each stock is assessed conservatively, and if conservatisms are added, the total assessment may be well below existing stock size. A limited approach was involved in the second tier quota concept developed recently by ICNAF.

Use of pooled area assessments in no way precludes the necessity of continuing assessments of each spawning stock.

7.4.9 Ecosystems Interactions

Total ecosystem management as a desirable future alternative to single-species or multi-species management has been discussed often (Edwards, 1976; Gulland, 1977, 1978). Such management requires a much better understanding of species interactions than we now have, and also requires better understanding of non-living as well as living components of production systems. However, the available data base to support an attempt at total ecosystem management of fish stocks is probably better for Georges Bank than for any other comparable marine area. It would seem reasonable to make a large-scale experiment in total ecosystem management on Georges Bank, beginning with several years of simulation work before any significant management steps are taken.

This large-scale experiment in total biomass management requires, in addition to full understanding of trophic interactions, a much better grasp of the effects of man-made perturbations, principally through selective removal of particular species, and through removals by non-directed fisheries. Thought must also be given to the methodology of total effort management as a corollary.

Contamination of the coastal environment by industrial and other pollutants is an increasing problem in many parts of the world. Evidence now exists (Longwell, 1977) that fish larval development may be affected by high levels of contaminants in surface waters. Herring and many other larvae typically inhabit the upper water layers where concentrations of pollutants can be high. Since many herring larvae occupy coastal and even estuarine waters for up to six months, they may be at risk to this potential mortality factor during this period.

Monitoring and research programs concerned with survival and abundance must take possible pollution effects into account (Figures 48 and 49). Even though there is little specific information on contaminant-induced mortality of herring larvae from field studies, there is a significant amount of experimental

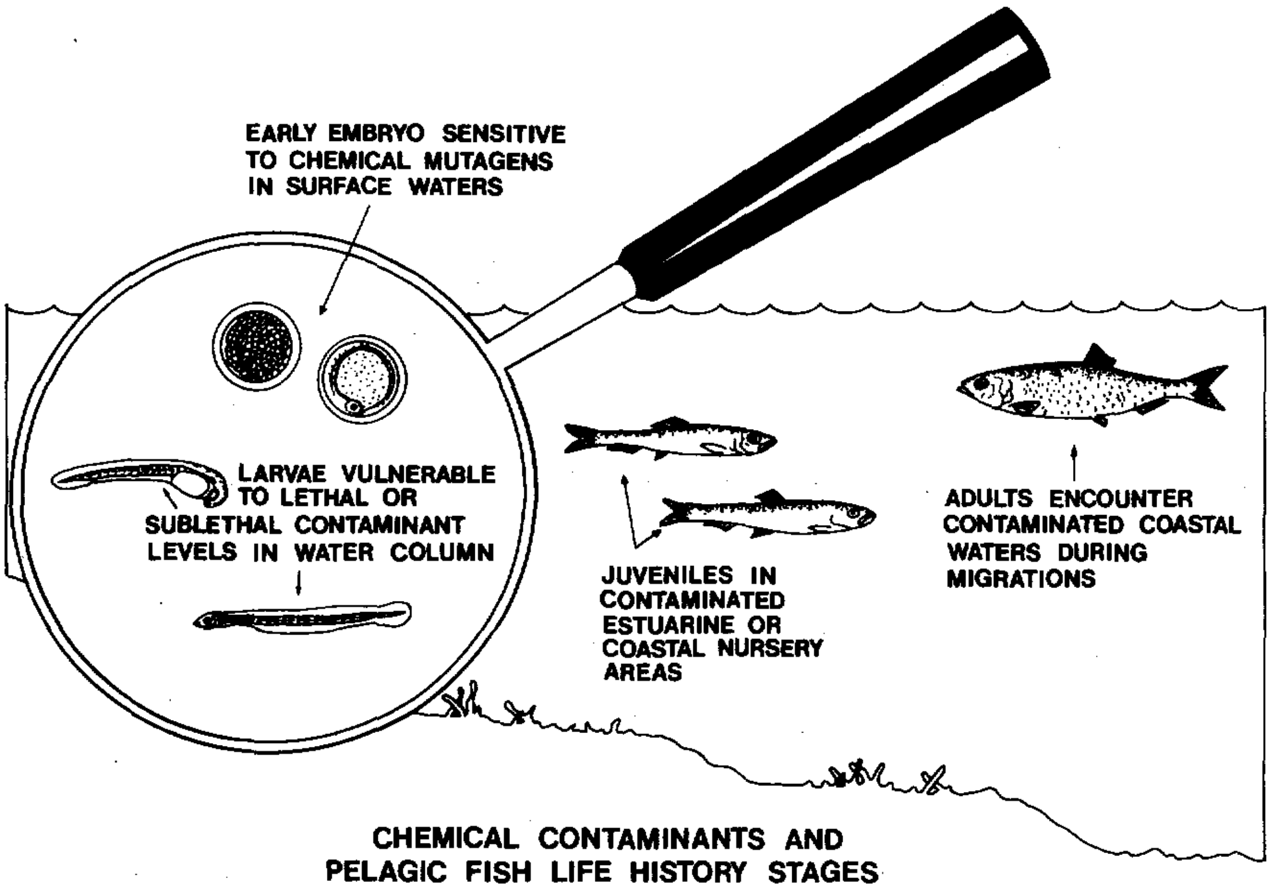


Figure 48. Points in the life cycle of herring where pollutants may have effects.

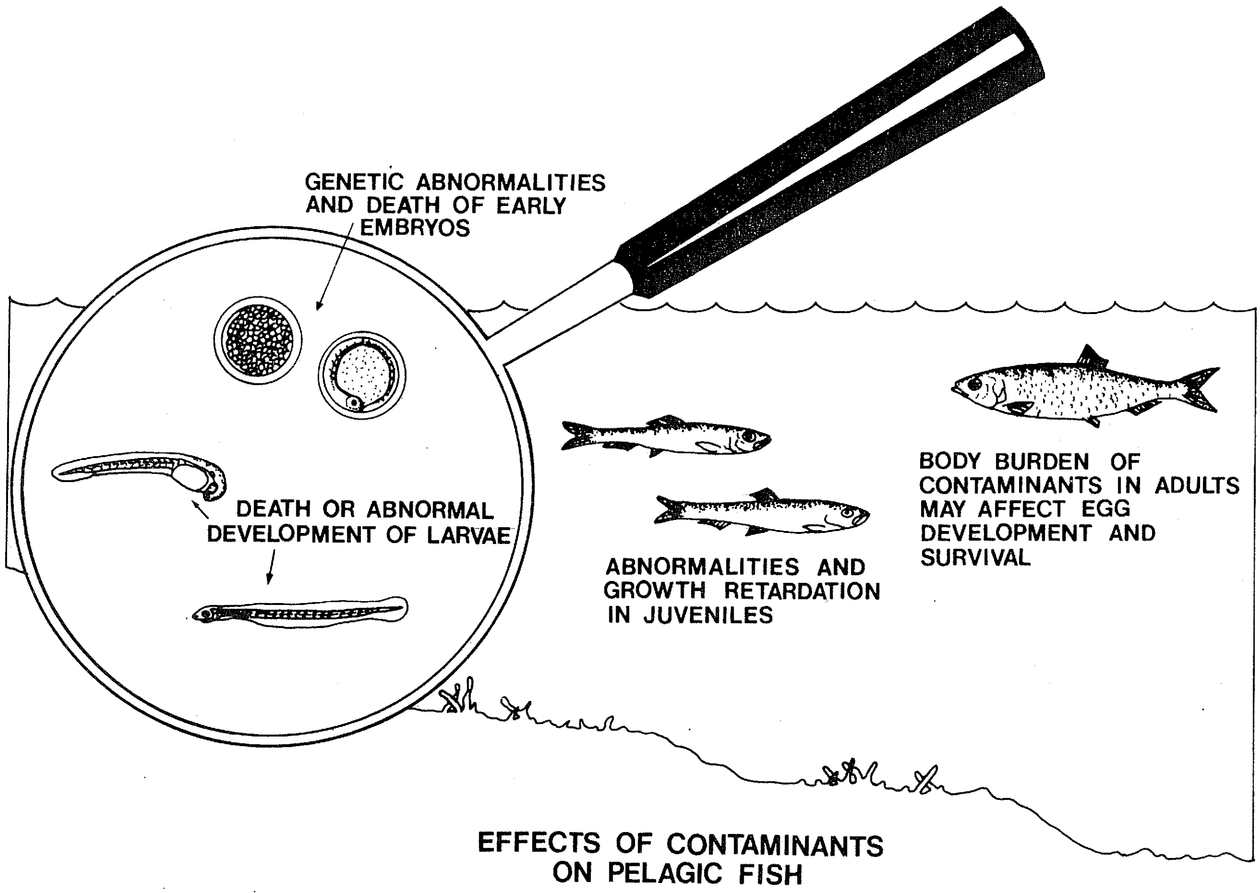


Figure 49. Some effects of contaminants on herring life history stages.

evidence for pollutant effects. Probably the best is that developed by Rosenthal and his associates (Rosenthal and Stelzer, 1970; Stelzer, Rosenthal and Stebers, 1971; Rosenthal and Alderdice, 1976). High percentages of morphological anomalies and lower survival rates characterized herring larvae exposed to a number of contaminants, including cadmium, dinitrophenol, and ferric hydroxide. In other studies with herring larvae, petroleum and its distillates, as well as oil dispersants, have been shown to be toxic (Struhsaker et al., 1974; Lindén, 1976).

Clearly, coastal/estuarine pollution of herring nursery areas should be a matter of concern in the design of research to understand factors affecting abundance of herring.

7.5 ANALYSIS OF RESEARCH OPTIONS AND PRIORITIES

Of the many enticing components that would be part of an ideal herring research program, there are only a few that emerge as of top priority -- faced as we must be with practical limitations of funding of single species research programs, as compared with broader and more desirable total ecosystems studies that would include all species. Three components -- monitoring, population dynamics, and stock identification -- seem most important at the moment, since if these are adequately pursued, they should provide definitive (or at least better) information about solutions to the critical and persistent problems identified in the preceding chapter.

These three high priority components of a core program have the added value of providing information relevant to short-term management needs and longer-term goals of basic understanding.

(1) Monitoring. Surveys and collection of fishery statistics constitute the essence of a program to monitor abundance and recruitment. Key aspects are (in descending order of priority):

Catch statistics from adult and juvenile fisheries;

Fishery-independent trawling surveys of spawning populations;

Fishery-independent juvenile surveys; and

Autumn larval surveys to assess spawning stock size (the projected MARMAP coverage (particularly of the Gulf of Maine) probably is inadequate for estimates of spawning stock size because the frequency of coverage is too low).

(Seasonal environmental data collection should be an integral part of all survey cruises).

(2) Population Dynamics. Application of existing fishery production models must for the near-term be part of the continuing effort of assessment biologists, but their role should be immediately enlarged to focus on development of models directly relevant to fluctuating pelagic populations, and to interspecies interactions.

To model predator-prey interactions, we need to know more than we do about food consumption of fish, and therefore additional studies of the food web, including all life stages, will be required. Real insights about population dynamics require difficult biological studies (feeding, growth, mortality, disease, etc.). Such process-oriented studies should have continuing priority.

Also, since annual recruitment is a critical factor in assessment of fully-exploited stocks, and since an understanding of processes producing good or poor year classes can lead to more accurate prediction, some continuing emphasis on simulation modeling should be part of a core program.

(3) Stock Identification. Since an understanding of the stock structure of an exploited species is so fundamental to management, it is obvious that resolution of questions about discreteness of spawning stocks and the nature and extent of intermixing during non-spawning periods must be part of any core program of herring research. Tagging studies, with initial emphasis on spawning populations at the time of spawning, offer the best and most immediate approach, with use of parasite tags as a concomitant but subsidiary approach. These studies will not provide the kind of genetic information that will probably be required to determine the origin of juveniles in coastal waters -- for this, biochemical genetic studies, again beginning with spawning populations, will be required.

Reduction of a herring research program to these three basic elements -- monitoring, population dynamics, and stock identification -- will undoubtedly be repugnant to those who see a need for broad studies of ecosystems dynamics as a basis for total ecosystems management, and to those who would like total research commitment to satisfaction of short-term management needs. There should, however, be elements in the proposed core program that will be mildly satisfactory to both extremes.

It is obvious that this so-called core program does little to provide understanding of <u>why</u> herring stocks fluctuate, it merely documents <u>what</u> takes place. Beyond documentation of what is happening and attempts to analyze effects of fishing on stocks (and assuming a greater research commitment), the most critical problem concerns survival and recruitment of year classes. The problem is a difficult one; it has defied resolution thus far. Solution requires knowledge of how year classes fluctuate, and how environmental factors which may influence egg and larval survival vary from year to year. Correlations must be sought, preferably using computer simulation techniques.

7.6 RESEARCH COORDINATION

The research efforts outlined in this chapter are those which can be carried out by the National Marine Fisheries Service, Northeast Fisheries Center, augmented by available cooperative field surveys on foreign research ships and by state and university contracts (possibly in biochemical genetics and simulation modeling).

Interaction and coordination with other research groups are also necessary:

(1) There is a need for periodic reviews of the status of knowledge of herring and herring stocks. These reviews should include participation by federal, state, university, and Regional Council experts. The discussions should include consideration of stock assessments and other topics directly related to herring management, and should update the data base relevant to herring management plans. The discussions should also include cooperative research oriented toward broader understanding of the biology, ecology, and population dynamics of western North Atlantic herring.

(2) It is apparent that herring do not respect international boundaries, and the recent information on movements and intermixing of stocks further indicates the extent of this disrespect. Continuing dialogue and cooperative studies between the United States and Canada are and will be important, particularly in the following areas:

   (a) Pooled area assessments (a critical matter, because of intermixing);

   (b) Joint juvenile surveys for recruitment estimates;

   (c) Joint larval surveys;

(d) Joint tagging, especially of spawning fish;

(e) Improvement and timely exchange of catch statistics;

(f) Common agreement on the conceptual basis for assessment.

Areas of mutual concern such as these indicate the desirability of periodic joint United States-Canadian research workshops, possibly annually.

CHAPTER 8

8. THE FUTURE OF THE NORTHWEST ATLANTIC HERRING FISHERY

CONTENTS

8.1 INTRODUCTION

The herring fisheries of the Northwest Atlantic are at present at a significant point in the generalized historical development of fisheries -- the point where severely restrictive quotas are applied, based on available scientific information, in the expectation that stocks will rebuild (Figure 50). Management of herring stocks in the western North Atlantic, in a real sense, is a recent phenomenon, dating only since about 1972. This chapter reviews (briefly) the brief history of such management, against the background of the recent history of other exploited herring stocks, and then attempts to look to the future of the herring fishery and management regimes.

8.2 RECENT HISTORY OF EXPLOITED HERRING STOCKS

Intensive exploitation of Northwest Atlantic herring stocks began in 1961 with the appearance of the Soviet distant water fleet on Georges Bank, and increased through much of the decade 1960-1970. On a broader scale, the contribution of the herrings to world fish production increased dramatically during the 1960's -- so that the world catch of herring and related species in 1967 was almost 20 million MT, or over 40% of the total catch of all marine species (FAO Yearbook of Fishery Statistics). On a worldwide basis herring are important to humans as food, and as sources of fish meal and oil. Additionally, they play a major role in marine food chains.

Herring landings in the eastern Atlantic during the 1960's were about 3.5 million MT, with Norway and Iceland taking about 70% of the total, and USSR half the remainder. The expansionist era of

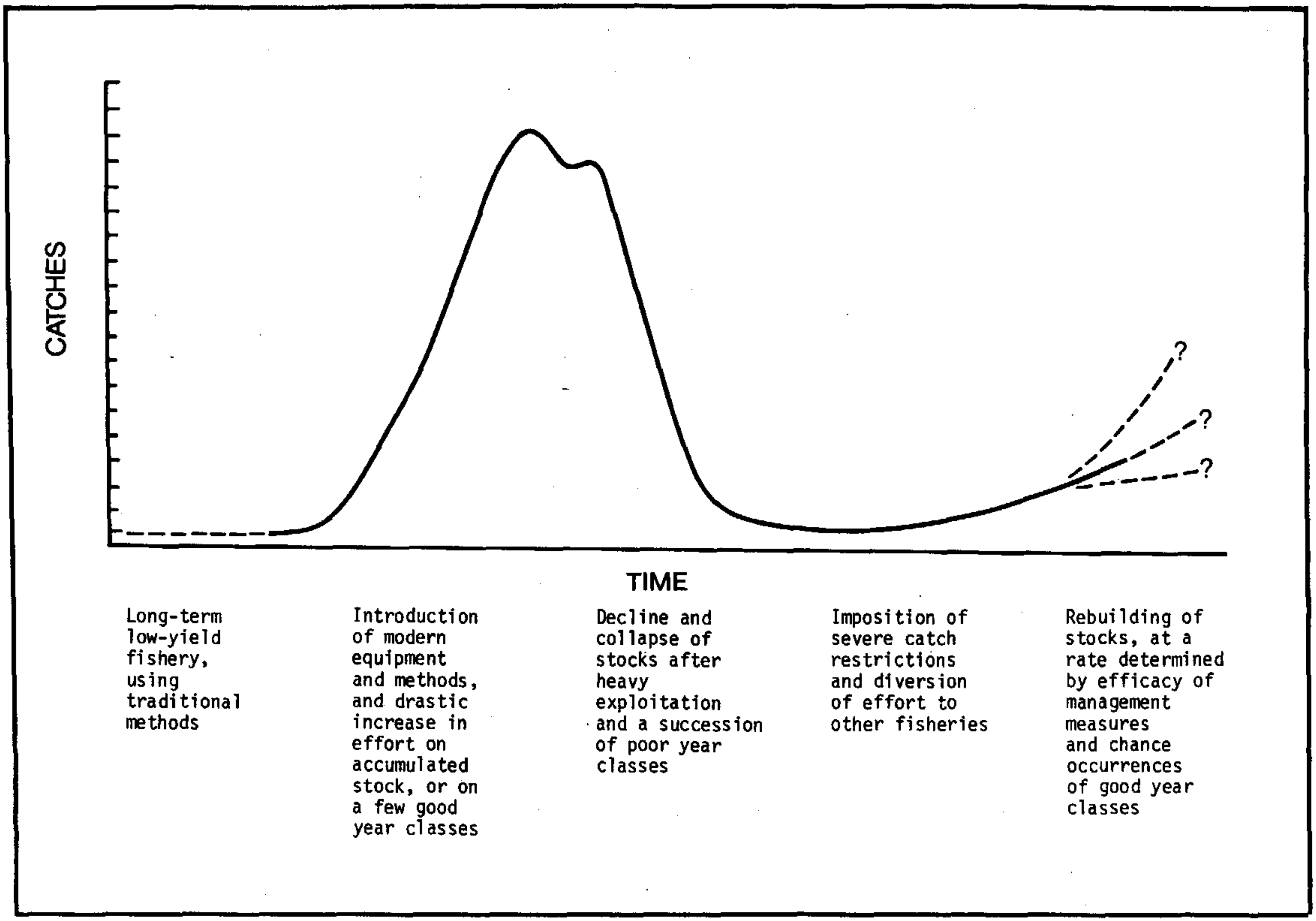


Figure 50. Generalized sequence of stages in exploitation of fish stocks.

the 1960's was reversed drastically in the 1970's, when there was a nearly world-wide failure of recruitment to herring stocks. This was particularly true of the Northeast Atlantic stocks, which had been exploited intensively beginning after World War II, as well as of the Northwest Atlantic (with the single exception of the 1970 year class in the Northwest Atlantic).

Trends in Georges Bank and Gulf of Maine stock abundance, recruitment, and catches were summarized recently (NERFMC, 1978) as follows:

"The stock of herring on Georges Bank increased to a tremendous size during the early 1960's as a result of two very good year classes, and only light fishing. By the mid-1960's, recruitment dropped off while fishing effort increased and the stock declined to a low level by 1972. Since then the stock has been supported by the recruitment, in 1973, of a single strong year class (1970 year class) which by 1977 had been pretty much fished out on Georges Bank.

The stock in the western Gulf of Maine was also high (when the adult fishery began) in 1967, but again a series of poor year classes and intensive fishing decreased the stock to a low level. The stock partially recovered in 1974 and 1975 with the recruitment of the strong 1970 year class (which characteristically recruits later than on Georges Bank). This year class was still strongly represented in the 1977 adult fishery".

Trends in stock size, catch and effort for the Georges Bank fishery (5Z & SA6) and for the western Gulf of Maine fishery (5Y) as summarized by NERFMC (1978) were presented in Figures 37 and 38, and the trends in recruitment at age 3 are shown in Figure 51.

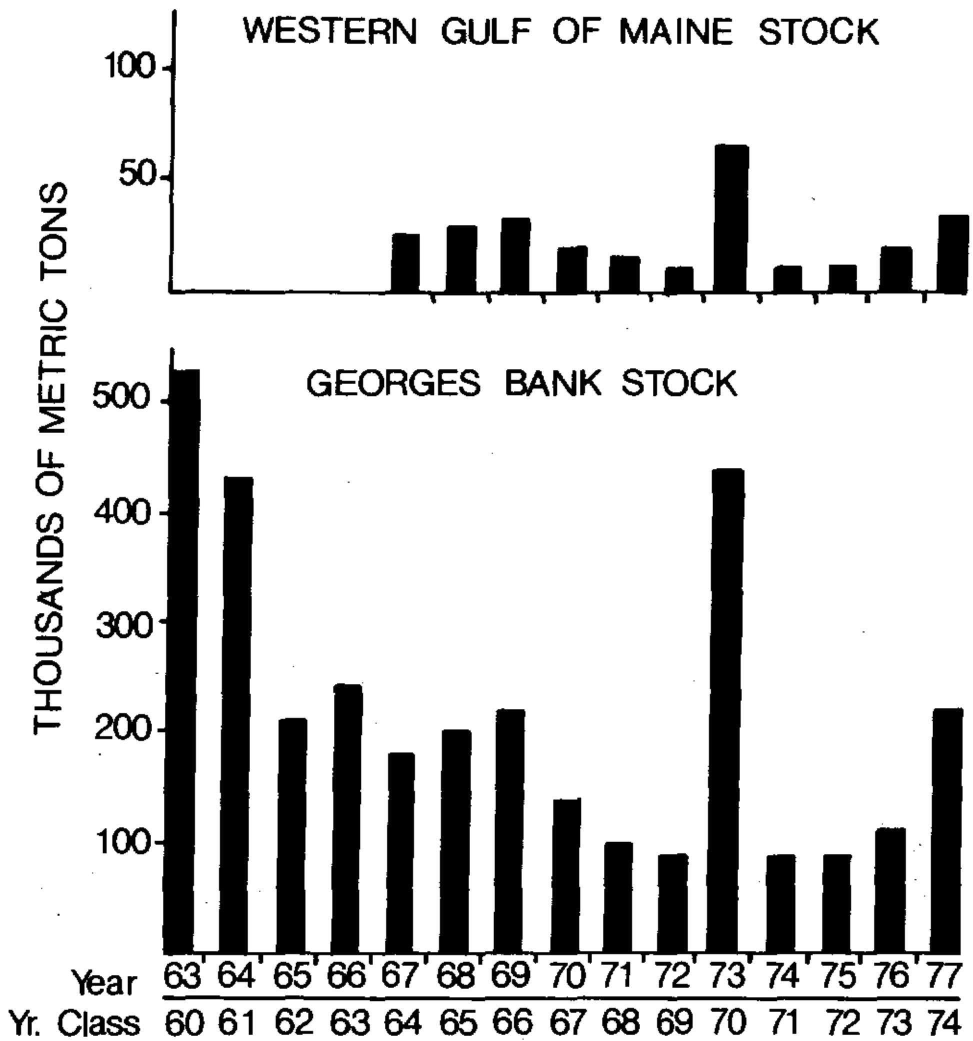


Figure 51. Trends in recruitment at age 3 for western Gulf of Maine stock, 1967-1977, and Georges Bank stock, 1963-1977 (from NERFMC, 1978). The accuracy of estimates for most recent year classes is of course less than that for earlier years.

It is interesting (and somewhat alarming) that trends during the 1970's for other exploited Atlantic herring stocks followed the same dismal path as those of the western North Atlantic. The North Sea herring stocks are at an extremely low level, with stringent catch regulations now in effect (Figure 52). The history of this stock was reviewed recently by Dornheim (1978). In the mid-1960's intensive fishing resulted in severe reductions in stock size, as indicated by decreased catch per unit effort and reduction in larval abundance. A number of ineffective regulations were imposed beginning in the late 1960's, including closure of spawning areas, other areal or seasonal closures, and catch quotas. In 1971 the Northeast Atlantic Fisheries Commission (NEAFC) decided on total closure in May and from August 20 to September 30 -- a measure which remained in force until 1974, when a total quota with national allocations was imposed. The quota was exceeded. In 1976 the quota was 160,000 MT while the catch was 183,000 MT -- and this catch was less than half the 1975 catch. The 1976 catch for the North Sea was the lowest on record, with the exception of the war years. In 1977 the directed fishery for herring was prohibited for the entire North Sea, by vote of the European Community (except for a small June fishery by The Netherlands). The estimated spawning stock size at the beginning of 1977 was extremely low (85-155,000 MT, or about 30% of the estimated stock size in 1950) and the 1974, 1975, and 1976 year classes seem poor. The Herring Assessment

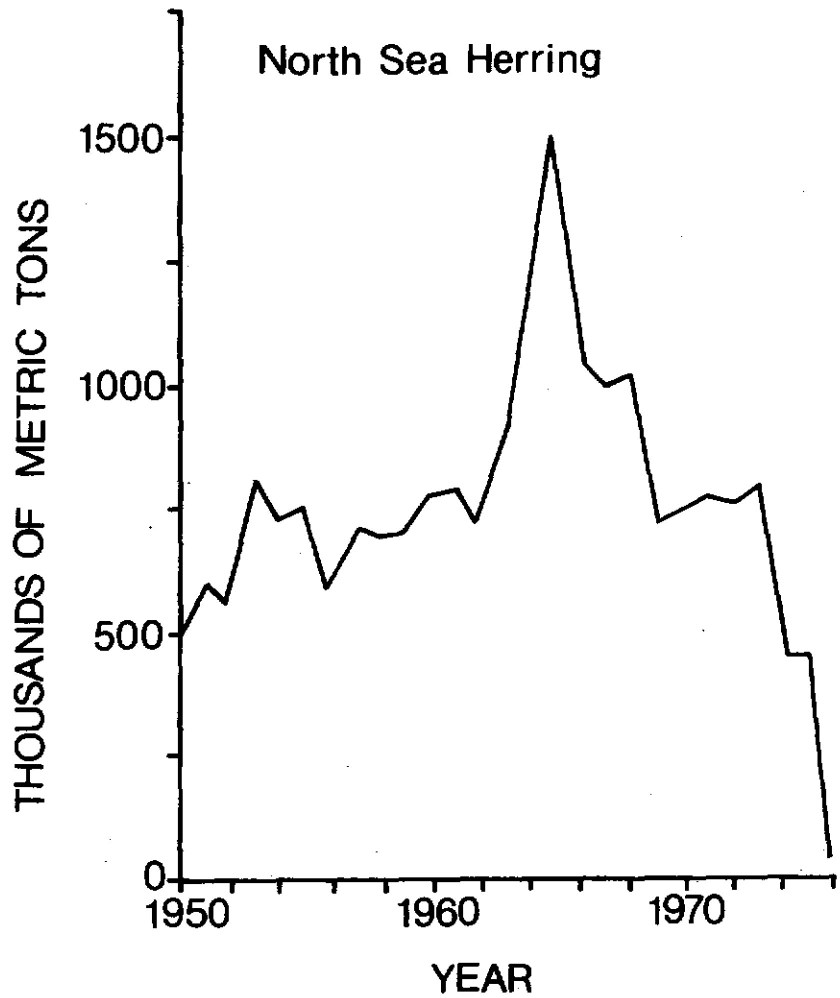


Figure 52. North Sea herring catches 1950-1976 (modified from NERFMC 1978).

Working Group recommended continuation of the total ban on all types of directed herring fisheries in the North Sea, but even so, recovery of the stock will depend on success of recruitment over the next several years.

The world famous Norwegian Atlanto-Scandian herring stock has collapsed, due to poor recruitment and heavy exploitation (Figures 53 and 54). The recent history of this stock, as summarized by Dornheim (1978) is depressingly similar to that of Georges Bank. Increasing catches up to 1966 were dependent on the very strong 1959 year class, but an almost complete failure of recruitment combined with continued intensive fishing pressure reduced catches drastically. By 1970 spawning stock size was at a very low point, and few larvae were found in spawning areas. Spawning stocks recovered slightly after 1972, and were estimated at 200,000 MT at the beginning of 1977 (which is still very low). However, the 1975 and 1976 year classes are considered poor, and any increase in stock size will depend on absence of a directed fishery.

The Scottish Hebrides herring stock has also declined (Figure 55), and severe catch limitations have been imposed, following several years of intensive fishing in the early 1970's. After a peak of almost 250,000 MT in 1973, catches declined to only 107,000 MT in 1976. This catch was only 78% of the quota of 136,000 MT imposed by NEAFC -- due partly to severe restrictions on the coastal fishery imposed by the Scottish government. Continuation of severe catch restrictions (48,000 MT in 1977) combined with recruitment of moderately-sized 1973 and 1974 year classes should aid stock rebuilding.

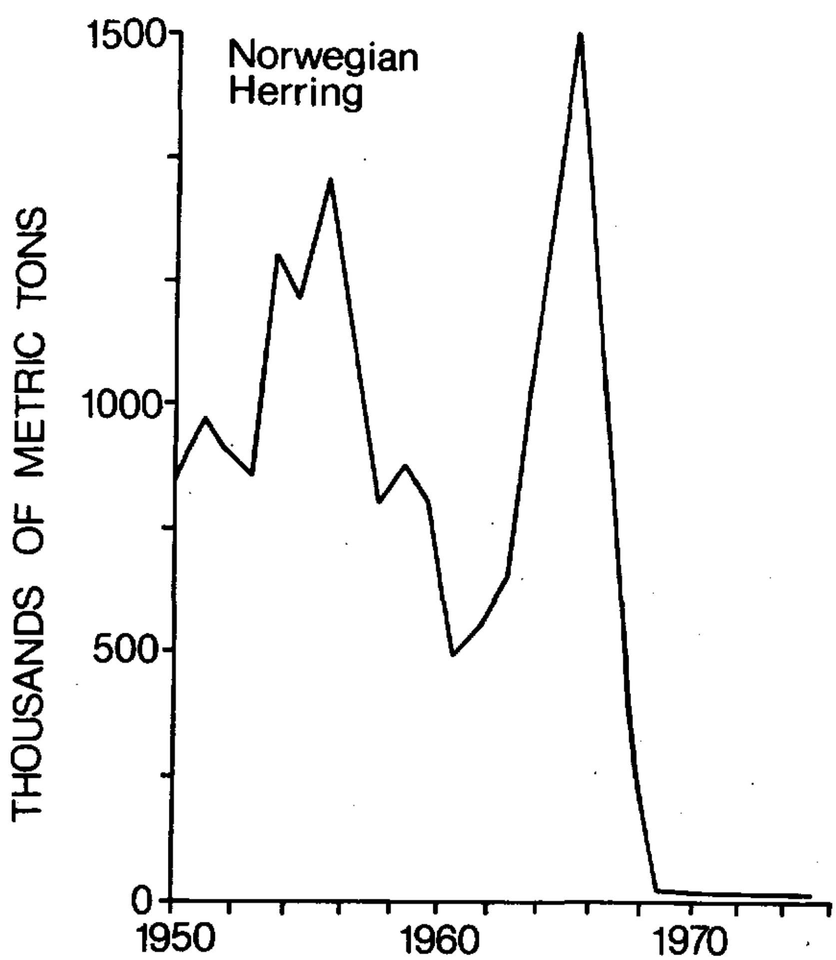


Figure 53. Norwegian sea herring catches, 1950-1975 (modified from NERFMC 1978).

Figure 54. Herring catch off Norway.

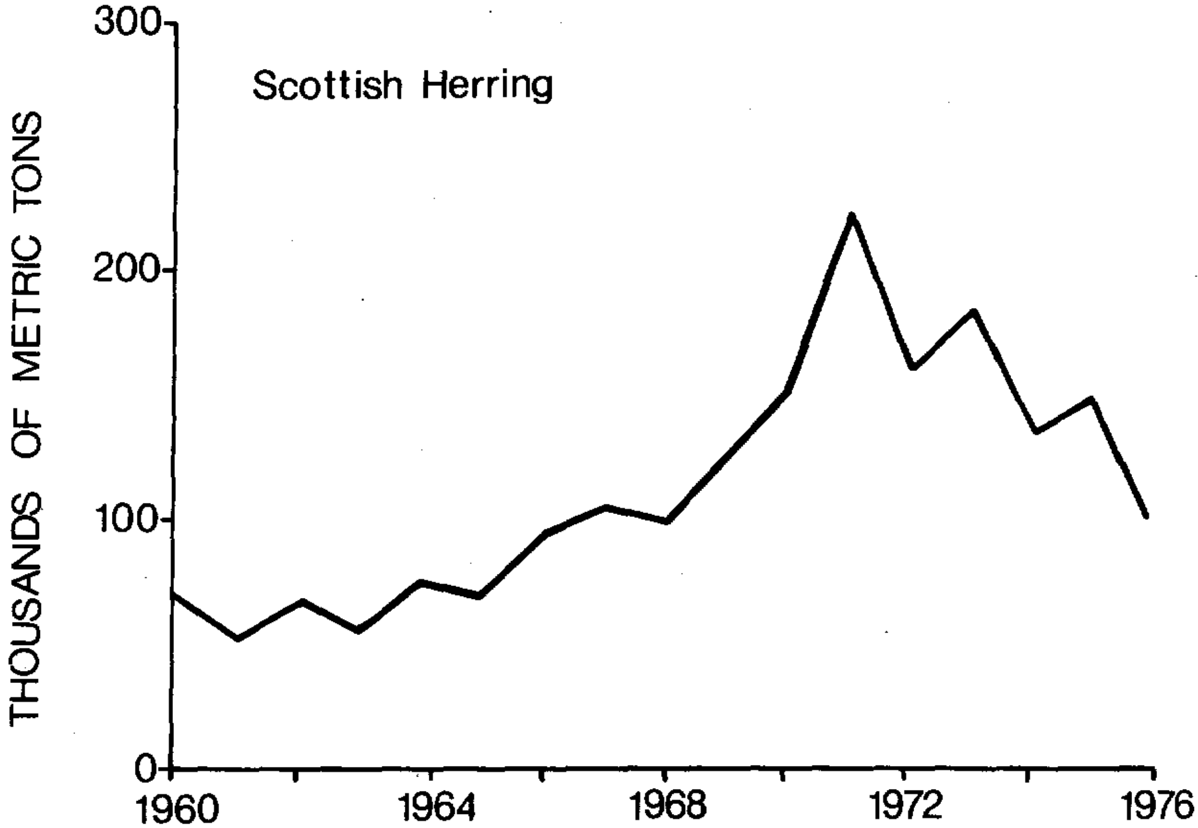


Figure 55. Scottish Hebrides herring catches 1960-1976 (modified from NERFMC, 1978).

The Celtic herring stock is at a low level (Figure 56) because of poor recruitment and heavy fishing in the early 1970's (Dornheim, 1978). Catch for the 1976-1977 season was only 7,000 MT -- the lowest since 1956. Quotas set by NEAFC were not reached in 1974-1975 or in 1975-1976, despite the fact that fishing effort was not reduced. The estimated stock size at the beginning of 1977 was only 8,300 MT -- about one-fifth of the estimated minimum stock size which would insure survival of the stock. The Herring Assessment Working Group recommended a total ban on a directed fishery for the 1977-1978 season.

The only relief from this gloom is found in recent partial recovery of some Pacific herring stocks, whose cycle of poor recruitment and heavy exploitation, followed by stringent catch regulations, is about a decade in advance of the Atlantic cycle. The Hokkaido herring stock which had collapsed by 1960 after years of heavy exploitation, is beginning to recover, and the British Columbia herring stocks, which declined drastically in the mid-1960's are increasing under severe catch restrictions first imposed in 1968.

From the history of exploited herring stocks there are several generalizations that can be made:

(1) Early symptoms of overfishing are decreases in average size and age and in catch per unit of effort.

(2) The decline of herring fisheries can be just as dramatic as their growth.

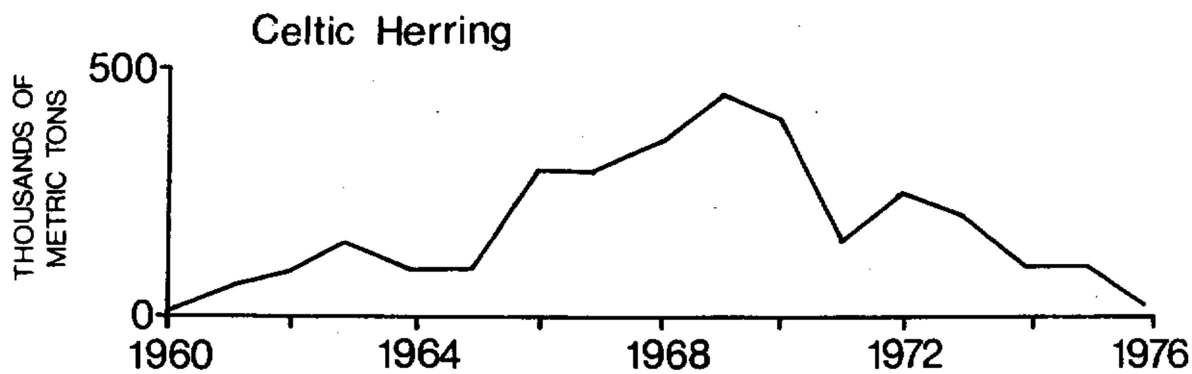


Figure 56. Celtic sea herring catches, 1960-1976 (modified from NERFMC 1978).

(3) Drastic fluctuations occur in survival of year classes, and with continued exploitation there is increasing dependence on single successful year classes.

(4) Continued heavy exploitation using modern equipment, coincident with a series of poor year classes, results in collapse of the stock, with imposition of severely restrictive catch regulations.

(5) Even after severe restrictions on catch, recovery of the stock usually depends on recruitment of one or more strong year classes.

We seem incapable of achieving balance in exploitation of herring or any other fish stock. It seems clear that before 1960 most of the Northwest Atlantic herring stocks were underexploited. Georges Bank and Banquereau were untouched; fishing mortality for Gulf of St. Lawrence and Newfoundland stocks was estimated to be less than 10% annually -- so the only intensive fishery was the juvenile fishery for sardines in Maine and New Brunswick. Although evidence is poor, it is possible that fishing mortality in certain years may have reached 50% (Tibbo, 1970b). Then, in less than two decades, we have seen exploitation, then overexploitation, and now (Georges Bank, 1977) indication of the collapse of at least one spawning stock. Throughout much of this period, and certainly during the most recent decade, there has been continuing attention to the stocks by an international regulatory body (ICNAF) but failure to control fishing effort soon enough to prevent obvious overexploitation.

8.3 GEORGES BANK: A CASE HISTORY OF RESPONSE OF A HERRING STOCK TO EXPLOITATION

Within a time span of less than two decades -- from 1961 to 1978 -- the herring stock of Georges Bank has moved from the status of a virgin unfished population to one of apparent collapse. After a slow start in the early 1960's, production reached 373,000 MT in 1968, and then dropped precipitously to about 1,000 MT in 1977. International management arrived too late (1972) and was too weak to prevent a decline which was apparent as early as 1970, and management under extended jurisdiction (beginning in 1977) has thus far emphasized stock maintenance instead of stock rebuilding. Also, some of the decline in the Georges Bank herring stock was probably inevitable. The stock size in the 1960's (and the catch which it supported) was at an unusually high level as a result of the recruitment of several good year classes. It is unlikely that this large stock size would have been maintained even without fishing.

Because the exploitation of the Georges Bank herring stock is so typical of the way in which fisheries have depleted populations in the absence of effective regulation, it seems worthwhile to summarize events since 1961 -- as a case history, and as a prelude to future management of that stock.

8.3.1 The Fishery

After several years of exploratory fishing, the USSR committed a portion of its distant water fleet to Georges Bank herring in 1961, taking in that year 68,000 MT of adults with bottom trawls and gill nets. Except for minor catches by other countries, the USSR dominated the fishery until 1967, when Poland, FRG and GDR began taking significant tonnages. Peak production occurred in 1968, when 373,000 MT were taken (143,000 MT by USSR, 75,000 MT by Poland, 71,000 MT by FRG, 67,000 MT by GDR, 13,000 MT by Canada, and the small remainder by other countries, including USA). Various fishing methods were used, beginning with gill nets (1961-1963), and bottom trawls (1961-1976), then moving to purse seines (1968-1976), and mid-water trawls (1971-1976).

8.3.2 Year Class Strength and Stock Abundance

Initial foreign exploitation of Georges Bank herring encountered a virgin population which included the strong 1956 year class. Expansion of the fishery in the mid-1960's coincided with recruitment of the strong 1960 and 1961 year classes. The 1963 year class was also reasonably good, and these three year classes supported the fishery through much of the period 1965 to 1970. The moderately abundant 1966 year class and the poor 1967 and 1968 year classes supported the fishery from 1970 to 1972, while the very strong 1970 year class provided 73% of the catch from 1973 to 1976 (Anthony and Waring, 1978). The 1971-1973 year classes were poor, and account in large part (when combined with continued intense exploitation) for the drastic decline in abundance. The strength of the 1974 year class is still somewhat uncertain, but from early indications, the 1975 year class seems moderately strong, the 1976 year class seems very strong, and the 1977 year class seems good (based on abundance of one-year-old fish on the Maine coast). These later year classes of course have not yet been recruited into the adult fishery, so it is premature to attempt to estimate their relative strengths.

Herring stock abundance on Georges Bank during this period has been reviewed recently by Anthony and Waring (1978). Key points in their review are:

(1) During the period 1961-1965, with three strong year classes (1956, 1960, 1961), the Georges Bank estimated spawning stock increased rapidly from 272,000 MT in 1963 to 1,140,000 MT in 1967.

(2) Lower recruitment in the late 1960's would have resulted in a decline in abundance even in the absence of an intensive fishery.

(3) Because of the heavy exploitation and poor recruitment, stock abundance declined drastically to only 144,000 MT in 1973 (87% reduction from 1967 to 1973).

(4) Recruitment of the strong 1970 year class temporarily increased stock abundance (by 75% in 1973 and by 138% in 1974) despite continued high catches (202,000 MT in 1973 and 150,000 MT in 1974).

(5) After 1974 the stock abundance is uncertain. It appears that the size of the 1971-1974 year classes may have been overestimated. Projected stock increases in 1976 and 1977 did not occur; the decline in catch in 1976 and the virtual absence of a catch in 1977 makes any estimates of abundance very questionable (Anthony and Waring, 1978).

8.3.3 Reasons for Decline of Georges Bank Herring Stock

When faced with a change in abundance of the magnitude described for Georges Bank from 1961 to 1977, there is a need to explore all possible explanations, in addition to the obvious one -- overexploitation. Such an impartial and thorough exploration was published recently (Anthony and Waring, (1978), in which a number of possible reasons for stock decline -- poor assessments, poor management, excess fishing mortality, effects of juvenile fisheries, effects of migration, concentration of fishing effort on spawning areas, and fishing directly on spawning beds -- were reviewed in detail. A summary of their findings is as follows:

Assessments through 1972 appear to have been reasonably accurate, but beginning in 1974, recruitment apparently declined to an all-time low, and assessments failed to detect this. Part of the problem was use of the conventional level of 550 million fish for a poor year class, when the actual number might have been much lower. Also, disagreements among scientists about TAC's may have resulted in management decisions to accept higher TAC options.

Poor Management. TAC's are influenced more by considerations of social disruption or short-term economic gains than by conservation of stocks, so managers consistently select high options when choices are offered by scientists, or in some instances managers have accepted TAC's which are one to three times the recommended amount. This has been the history of Georges Bank herring management under ICNAF.

Excess fishing mortality. The 1972 ICNAF Herring Working Group recommended that $F_{0.1}$ is equal to about 0.33-0.38 -- a proper F level for Georges Bank, given average recruitment (if recruitment is below average, then F should be less than 0.33). Anthony and Waring (1978) pointed out that from 1968-1975 the lowest average F for herring age 4 and older was 0.53, and reached 1.35 in 1972.

Effects of juvenile fishery. Juvenile fisheries decrease yields significantly, and a recent ICNAF Herring Working Group Report (1975) indicated that the yield per recruit would almost double if no juveniles were taken. However, the relationship between coastal juvenile stocks and Georges Bank adults is still uncertain, and the time sequence of declines in the Maine juvenile and Georges Bank adult fisheries leads to the conclusion that the juvenile fishery did not contribute significantly to the decline of the Georges Bank stocks, as discussed in an earlier section.

Effects of migration. Recent tagging information indicates overwintering movement of Nova Scotia fish southward, where they may be taken in catches considered to be derived from Georges Bank stock. This could have resulted in overestimation of the Georges Bank stock abundance, with consequent setting of TAC's that were excessive if the fishery became more concentrated on spawning aggregations or if the migration of northern fish lessened.

Concentration of fishing effort on spawning areas. Based on shifts in areas fished, egg bed locations, and areas of larval abundance, Anthony and Waring (1978) have assembled a highly plausible explanation for the decline in Georges Bank herring based on a sequential destruction of subunits of the spawning stock moving westward from the Northeast Peak in the 1960's to the southwestern portion of the Bank in the mid-1970's. According to this hypothesis, Nantucket Shoals is the only remaining spawning area; all the others have been fished out.

Fishing directly on spawning beds. Herring schools can be scattered and the spawning process interfered with by intensive fishing activities such as took place on Georges Bank spawning grounds in the late 1960's and early 1970's. Anthony and Waring (1978) have hypothesized that recruitment declines on Georges Bank may thus be due to the act of fishing as well as to decline in abundance of spawning stocks. (A similar hypothesis was proposed by J. Graham in a letter dated June 13, 1977 to the executive director of NERFMC).

After completing the thorough analysis summarized above, Anthony and Waring offered no conclusion about the relative contributions of the factors they had considered to the decline of Georges Bank herring stocks. Their narrative, though, leaves little doubt (in my mind at least) that they consider excess fishing mortality, poor management, concentration of fishing effort on spawning areas, fishing directly on spawning beds, and actions taken as a consequence of inadequate assessments -- in descending order of significance -- as important contributors to the decline of Georges Bank herring.

The future of the Georges Bank stock is interesting to contemplate. The TAC for 1978 is low; the 1975 year class (which is considered good) will be partially recruited in 1978; the 1976 year class (which is considered very strong) will be recruited in 1979; and a reasonably effective management regime is in place and operational. The opportunity seems to be at hand to demonstrate whether or not this pelagic offshore stock can be managed to produce the magic optimum yield -- whether management regulations to rebuild stocks have real meaning for pelagic populations -- and whether, with our present limited understanding, we can really dampen the oscillations of a fluctuating pelagic species.

8.4 MANAGEMENT REGIMES

The herring fishery in international waters of the western North Atlantic was regulated during the period 1972 to 1977 by the International Commission for the Northwest Atlantic Fisheries or (in the case of Statistical Area 6) by bilateral agreements. The Fishery Conservation and Management Act of 1976 established (effective March 1, 1977) a 200 mile fishing zone within which the United States would regulate fisheries under the concept of optimum yield. Under provisions of the Act, a Preliminary Fishery Management Plan for herring was prepared by the Department of Commerce and published on February 22, 1977, and a Draft Fishery Management Plan for herring was published in April 1978 by the New England Regional Fishery Management Council.

Significant aspects of these management regimes will be summarized in following sections.

8.4.1 The Role of ICNAF in Assessment and Management of Stocks

ICNAF was established in 1949, and during its history has dealt with many fish stocks of the western North Atlantic, beginning with cod, haddock, and redfish. National quota regulations began in 1972, and herring was the first species for which national allocations were developed and implemented. An adequate data base for herring was developed in the 1960's. Even though a decline in herring stocks of Georges Bank and the Gulf of Maine was apparent by 1970, largely because of intense foreign fishing which began in the mid-1960's, regulation of the herring fishery under ICNAF did not begin until 1972 when catch quotas of 30,000 and 150,000 tons were set for the Gulf of Maine (Div. 5Y) and Georges Bank (Div. 5Z and SA6) stocks, respectively. Realistic imposition of quotas was delayed even further -- until 1976 -- when a crisis was clearly developing in the Georges Bank fishery.

During the period of ICNAF regulation (1972-1977), total allowable catches (tons) for these stocks were as follows:

Year	Gulf of Maine (5Y)	Georges Bank (5Z+6)
1972	30,000	150,000
1973	25,000	150,000
1974	25,000	150,000
1975	16,000	150,000
1976	7,000	60,000
1977	7,000	33,000

Until 1971, the Northwest Atlantic Treaty Convention did not provide for national allocation of catch quotas. Faced with the likelihood that fishing nations would rush for the allowable catch without national allocations, Article VIII of the 1949 Convention was changed on December 15, 1971, to read:

"The Commission may, on the recommendation of one or more Panels, and on the basis of scientific investigations and economic and technical considerations, transmit to the Depository Government appropriate proposals for joint action by the Contracting Governments, designed to achieve the optimum utilization of the stocks of those species of fish which support international fisheries in the Convention Area". Within one month's time of this change in the Convention, total allowable catches and national allocations were set for Atlantic herring in the Gulf of Maine and Georges Bank area. For the first time in the history of international fisheries regulations, total allowable catch was allocated among member countries considering historical performance, interests of new entrants, and special needs of coastal states.

Subsequent herring management actions taken by ICNAF during the period 1972 to 1976 concerning Georges Bank herring have been summarized by Anthony and Waring (1978) as follows:

1972. Size limit. Herring less than 9 inches (22.7 cm) total length cannot be caught, except for a small area off southwest Nova Scotia.

Stock size. An attempt was made to determine the level of catch in 1973 that would maintain the stock size at the level existing at the beginning of 1973.

1973. TAC constraints. The TAC may not exceed the level of catch which will result in the restoration of the adult stock (age 4 and older) to at least 225,000 tons by the end of 1974, and the Commission may not decide on an amount larger than the 1973 quota (150,000 tons) unless the adult stock size at the end of 1973 has reached a level (500,000 tons) which will provide the MSY by the end of 1974. (This was continued to January, 1976).

1974. Conventional level for poor recruitment. (For use in stock assessments). If a year class is known to be poor at time of recruitment, it is assumed equal to the size of the 1969 year class at age 3 or 550 million fish (later changed to 610 million). This is the poorest year class observed in this fishery.

Conventional level for unknown recruitment. When information is lacking on the strength of a year class such as when predicting several years in advance, a conventional level of 800 million fish is assumed at age 3 (which is slightly conservative over a long period).

1976. Prohibition of directed fishery. No directed fishing for herring from January 1 to June 30, 1976 except by purse seines and vessels less than 33.5 meters in length.

Area and time restrictions. Fishing only allowed in a "window" area from August 15 to September 30, 1977.

Stock maintenance. At the January 1976 Special Meeting, the commission agreed to "a level of catch for the herring stock in Div. 5Z and SA6 for subsequent years which will maintain the adult stock at a level of at least 225,000 T, and that the TAC will be set at 60,000 tons/yr or less, until such time as the adult stock reaches a level of 500,000 T.

Thereafter the commission will set the TAC so as to maintain the adult stock at a level of at least 500,000 T".

But preliminary data from March 1976 surveys indicated that a catch in 1977 of 60,000 tons would cause further reduction in stock size, so the stock assessment subcommittee recommended that the TAC for 1977 be set at 50,000 tons.

In December, 1976, after earlier serving notice of intent to withdraw from ICNAF, the United States reaffirmed its commitment to rebuilding of herring stocks. It had proposed (June, 1976) a TAC of 33,000 tons for Subarea 5 and Statistical area 6 for 1977, with no directed fishery for distant water fishing countries. However, in December, 1976, the United States reconsidered its position and stated that it would permit Canada, France, FRG, GDR, and Poland to have directed fisheries.

The regulations promulgated by the Secretary of Commerce (Preliminary Fishery Management Plan for Atlantic Herring) on February 22, 1977, permitted foreign harvest of 21,000 tons of herring from the Georges Bank (5Z+SA6) stock and 1,000 tons of herring (by Canada) from the Gulf of Maine (5Y) stock and established a window area on Georges Bank in which directed fisheries could be prosecuted during the spawning season. Subsequent incidental catches by foreign nationals that have taken their directed quota would be limited to 5% of the total catch by weight of other species on board the vessel in question.

A summarization of the responses of stocks to fishing during the period of ICNAF regulation was made by Clark and Anderson (1977):

"During the period of regulation under ICNAF, the Gulf of Maine and Georges Bank herring stocks have been reduced to levels (146,000 tons for Georges Bank and 31,000 tons for the

Gulf of Maine) at which low recruitment is believed to be more probable and recruitment more disastrous to the fishery and stock. The abundance increased to 359,000 tons (Georges Bank) and 91,000 tons (Gulf of Maine) by 1974, and decreased again to 204,000 tons (Georges Bank) and 58,000 tons (Gulf of Maine) by 1976. During 1976 the abundance continued to decrease to 45,000 tons in the Gulf of Maine but increased to 229,000 tons on Georges Bank".

"Due to low levels of abundance the ICNAF Assessment Subcommittee recommended a catch quota of zero for the Gulf of Maine (5Y) stock and 50,000 tons or less for the Georges Bank stock (5Z+SA6) for 1977. The very strong economic consequences to the USA of a zero quota for the Gulf of Maine subsequently resulted in establishment by the Commission of a quota of 7,000 tons (for the Gulf of Maine (5Y) stock), which would result in an estimated decrease of about 49% in adult stock biomass (age 4 and older) from 1977 to 1978, while the quota for the Georges Bank (5Z+SA6) stock was set at 33,000 tons which would result in an increase of about 13% in the adult stock biomass (age 4 and older) from 1977 to 1978".

However, the actual 1976 catch from the Gulf of Maine stock was 18,000 MT -- far above the total allowable catch of 7,000 MT; while the 1976 actual catch from the Georges Bank stock was 43,000 MT -- well below the total allowable catch of 60,000 MT.

8.4.2 Assessment and Management Under the Fishery Conservation and Management Act of 1976

The "Draft Fishery Management Plan for the Atlantic Herring Fishery of the Northwestern Atlantic", published by the New England Regional Fishery Management Council in April 1978, is a comprehensive document outlining stock rebuilding strategies, beginning with the smallest stock -- western Gulf of Maine -- which is at a "critically low level". The intent is to slow down and stabilize the harvest of herring from this stock and begin rebuilding by 1980, by setting season and area quotas beginning in autumn 1978. The rebuilding plan is based on seasonal migrations and intermixing of three stocks (Georges Bank, western Gulf of Maine, and Nova Scotia); it is designed to allow maximum domestic harvest of adult Georges Bank herring, while minimizing fishing impacts on depleted Gulf of Maine stocks. Proposed total allowable catch is 24,000 MT for Georges Bank-Gulf of Maine. Proposed quotas for the Gulf of Maine area: autumn 1978 -- 4,000 MT; winter-spring 1979 -- autumn 1978 -- 13,500 MT, and winter-spring 1979 -- 2,500 MT. Optimum stock size for the western Gulf of Maine is estimated at 100,000 MT, from which 17,000 MT could be harvested annually once the stock is restored to optimum size -- a process estimated to require four to five years beginning with the 1979-1980 fishing year, if quotas are implemented.

However, the plan also provides for a delay of one year in the commitment to begin rebuilding western Gulf of Maine stocks if it becomes apparent that the Georges Bank-southern New England stock size cannot support a viable commercial fishery. The Council has also stated that United States fishermen are capable of harvesting the entire allowable catch, so no surplus for foreign fishermen exists or is likely to exist until the stocks have been rebuilt to optimum levels.

Under the terms of the Fisheries Management and Conservation Act of 1976, management measures in any Fishery Management Plan are designed to achieve, on a continuing basis, the optimum yield (OY) from the fishery, defined as "the maximum sustainable yield from the fishery, modified by relevant social, economic or ecological considerations, with the goal of providing the greatest overall benefits to the nation, with particular reference to food production and recreational opportunities". The OY for the western Gulf of Maine stock has been set at 8,000 MT, and for Georges Bank-southern New England, 16,000 MT.

The Draft Fishery Management Plan is designed to reflect more efficient utilization of the Gulf of Maine stock by setting a ratio of 70:30 for winter-spring and summer-fall periods. This should avoid undue hardship on the Gulf of Maine fall purse seine fishery by encouragement of the fall Georges Bank-southern New England purse seine fishery.

The New England Fishery Management Council based its management plan on the assumption that the Georges Bank stock will be retained under United States management jurisdiction -- an issue presently being contested by Canada.

The Council has also recommended that:

(1) the provisions of the FMP through appropriate institutional arrangements be made applicable to all herring fisheries from the shorelines of the New England and Mid-Atlantic States out to the limit of the U. S. fishery Conservation Zone with the exception of the fisheries for one and two-year-old herring in the territorial waters of the State of Maine; and that

(2) the management provisions be specified based on the presumption that the State of Maine in the management of the fisheries for one and two-year-old herring carefully considers the bioeconomic interaction between the juvenile and adult components of the Gulf of Maine herring stock and through appropriate measures seeks to contribute towards the achievements of the management objectives established by the Council.

The traditional fishery within Maine territorial waters takes about 6,000-8,000 MT of adults incidental to the juvenile fishery, and the question has been raised as to whether this is an incidental catch or a directed fishery for adults. If it is a directed fishery, then presumably it should be subject to quotas imposed.

Maine has prepared its Herring Management Plan (as of October 1978) which will propose a 3,500 MT TAC for fish greater than 10 inches in Maine territorial waters, with monthly quotas.

These fish will be predominantly four years and older. The New England Regional Fishery Management Council's recommendation of an adult catch of 6,000-8,000 tons would apply to fish 9 inches and longer, or predominantly three-year-old fish and older. In some years, the catch of three-year-old fish in Maine waters has been very substantial, therefore, the proposed regulation by the State of Maine would not necessarily restrict the adult catch (as defined by the New England Regional Management Council) to 6,000-8,000 tons. Spawning closures are one of the most significant parts of Maine's plan, and, like the Council, the plan requests coordination in management.

8.4.3 Guidelines for Future Management of Herring Stocks

The primary goal of research is to provide the best possible information relevant to long-term management of the herring resource. Such management must be carried out within a framework -- and with an understanding -- of interactions between herring and the ecosystems of which the species is a part. The primary goal of ecologically-sensitive resource management should be maintenance of resource populations and ecosystems in desirable states, while still providing adequate economic and social benefits.

Guiding principles for management must therefore include the following:

(1) Monitoring, analyses, and assessments must be a concomitant of exploitation of the herring resource.

(2) Management measures for herring must take into account possible impacts on other living resources, and must be based on adequate understanding of the biological characteristics of the herring resource and its environment.

(3) Management decisions must take into account a conservative safety factor -- recognizing the imperfections in the data bases for such decisions.

(4) The ecosystem must be maintained at a point where the dangers of long-term adverse effects and irreversible changes are minimized, while still allowing maximum economic benefits to humans (an extremely difficult task).

(5) Herring resource management policy must result in an equitable distribution of benefits between present and future users of the resource.

These principles are specific applications and expansions of a thoughtful general restatement of living resource conservation goals recently enunciated by Holt and Talbot (1978).

Other summarizations of management principles were published by Gulland (1971), Alverson (1972) and Larkin (1972). Fishery management is based on a series of related hypotheses, as summarized by Alverson (1972):

(1) yield from a given cohort can be maximized by proper utilization strategy;

(2) surplus yield is maximized at a population level roughly one-half that of a virgin stock; and

(3) a predictable stock-recruitment relationship exists, and if understood, it can be used in conjunction with yield per recruit theory to establish an optimum harvest strategy.

Serious problems for fishery managers, as discussed by Gulland (1971), Alverson (1972) and others are:

(1) biological information is only one and not always the most important of a number of factors involved in decisions about stock management;

(2) the profit from a fishery often does not justify the cost required for truly scientific management;

(3) objectives of management are often poorly defined and can change frequently and drastically; reasons for regulations (optimize production, maximize economic yield, etc.) must be clearly stated;

(4) scientists and managers are often unwilling to clearly define and differentiate their respective roles -- which are respectively providing information and making timely and correct decisions;

(5) application of a rigorous scientific method is often insisted on in making management decisions, even when complete scientific understanding is not always necessary for effective management; and

(6) difficult if not impossible institutional arrangements exist for implementing regulations that would lead to effective management.

The basic theme for a recent paper by Larkin (1972) is that present patterns of renewable resource use are basically unscientific, and are handicapped severely by unwillingness of fishery managers to admit fundamental ignorance and to experiment. Experimentation entails a high degree of risk; it requires a clearly stated hypothesis, and a willingness to admit error and to revise the hypothesis if accumulated evidence clearly indicates a need. The alternative is continued rationalization for failures, and consequent absence of advances in understanding.

With herring stocks of Georges Bank and the Gulf of Maine at a low level, the management options of choice clearly must be prevention of further decline and rebuilding of the stocks. Anthony (1977) has described what must be done:

"Rebuilding the stocks can only be accomplished by harvesting at levels less than the yearly increases due to growth and recruitment. At present stock sizes the annual surplus depends almost entirely on the size of the recruiting year classes, but precise estimates of annual recruitment in advance of fishing are not possible at present". (Annual surplus production by the adult herring population (age 4 and older) will always depend almost entirely on size of recruiting year classes. This occurs because the growth rate of adult herring is too slow to offset the loss due to natural mortality).

Inclusion of the juvenile fishery in management plans was also identified as a need for the future by Anthony (1977):

"Much of the management practices for herring have dealt with tonnages and not with numbers of individual fish. This can result in misconception about fishing mortality, since a ton of two-year-old fish and a ton of five-year-old fish are quite different things. A ton of herring that are two years old contains about 30,000 fish, while a ton of herring that are five years old contains only about 3,000 fish".

"Looking at total annual catches from 1961 to 1973 from southern Nova Scotia, Georges Bank, and the Gulf of Maine combined -- and separating the catches by age, it is apparent that two-year-old fish are numerically much more abundant in such catches -- constituting 42% of all fish taken, even though in tonnage they rank much lower (Anthony, 1978) (Table 11)".

"Future management should be in terms of numbers of fish, as well as tonnage, and the effect of juvenile mortality on adult stock size should be of major concern".

Table 11. Tonnages and numbers of fish by age (from Anthony, 1977b).

Age	Period 1956-1973				Period 1961-1973			
	Total Catch		Average Catch		Total Catch		Average Catch	
	millions fish	1000 tm	millions fish	1000 tm	millions fish	1000 tm	millions fish	1000 tm
1	5934.42	58.5	329.69	3.4	3704.62	33.9	284.97	2.3
2	30754.98	920.8	1708.61	54.2	18963.78	605.2	1458.75	50.4
3	7298.28	957.7	405.46	56.3	5698.28	798.3	438.33	66.5
4	2528.64	643.4	158.04	45.9	2527.54	643.2	194.43	49.5
5	2713.35	851.2	180.89	65.5	2713.35	851.2	180.89	65.5
6	2309.02	724.7	164.93	55.7	2309.02	724.7	164.93	55.7
7	1780.09	612.7	136.93	47.1	1780.09	612.7	136.93	47.1
8	884.65	312.1	68.05	26.8	884.65	312.1	68.05	26.8
9	288.96	129.1	24.08	12.9	288.96	129.1	24.08	12.9
10	133.98	46.3	19.14	5.8	133.98	46.3	19.14	5.8
11	10.80	7.0	1.54	1.0	10.80	7.0	1.54	1.0

Some timely and relevant advice about fish stock management and the proper role of scientific advice to managers was supplied recently by Gulland (1977). His key statement is this:

"In practice, management policies will have to be determined in each case in the light of current objectives of society, and of the scientific understanding of the stocks, bearing in mind that they will never be completely accurate".

The scientific advisory function, as summarized by Gulland, is simple:

(1) Provide a review of the state of the fish stocks, particularly the effect of exploitation on them; and

(2) Advise on the immediate and long-term effects of the objective(s) of different management measures.

He points out that "It is not, in principle, the responsibility of scientists to recommend one or another measure, but in practice scientific advice can have the force of specific recommendations" and that "The theoretical distinction between scientist and administrator should be maintained in practice, since both functions are difficult, and scientific advice should not be shaped by administrative convenience".

Stock assessments based on best available scientific data are obviously the purview of scientists, within the following guidelines:

(1) Assessment groups must be allowed adequate time to look at and think about data, analyse it properly, and prepare documents for scientific as well as management use.

(2) Assessments should be prepared and submitted on a regular annual schedule -- and once submitted, this should be the official statement for the year -- without short-term updates dictated by management groups. The only modification would be if an abrupt change in stocks or environment is detected, at which time a red-flag type of report would be issued. The position should be maintained by scientists that "this is what we know and these are your options, and beyond this we will not go".

(3) Scientists should present results of analyses in scientific and popular reports simultaneously to management councils and the public -- as a specific end point of scientific involvement.

(4) Recommendations of scientists about TAC's to management groups must be based on clear statements by managers of the specific objectives of management.

(5) Scientists should not be put into positions of defending optimum yields, which are management decisions.

(6) Research must be responsive to management needs, but selection of research approaches should be the prerogative of the scientist and not the manager.

Some general recommendations about future management of the herring fishery would include the following:

(1) Minimum stock size must be established and maintained, and efforts made to achieve an optimum stock size. (Minimum stock size is a highly variable concept, as was pointed out by Graham (personal communication). It could be: (a) a size at which recruitment becomes highly unstable; (b) a size at which migratory behavior changes and distributions are altered; (c) a size at which the fishery becomes uneconomic; or (d) a size at which the species is endangered).

(2) Management of the herring fishery must be based on best possible estimates of recruitment by individual year classes.

(3) It would seem that management must be almost on a year-to-year sliding scale, based on the best information that is available about recruitment and existing stock size.

(4) Even though genetically identifiable subpopulations of herring do not seem to exist, and assuming a unit stock for Georges Bank, Gulf of Maine and southwestern Nova Scotia, management should still be based on the concept of geographic subunits, which may vary in abundance and in proportion of the whole

from year to year. However, these must be integrated into an overriding pooled area assessment, which examines the status of the species south of Chedabucto Bay, and which estimates allowable catches for the area as a whole. Allocations should include a "second tier" component, with provisions for shifts in fisheries if the catch in one area is too low.

(5) Management plans and decisions about regulations must include a full appreciation of the concept of "risk". Since stock assessments contain elements of imprecision, there is a higher degree of risk if optimum yields are set at higher levels. A conservative optimum yield provides lower risk of further declines in stocks and greater opportunity for rebuilding.

(6) Management of the herring fishery should keep in mind the concept of maximum yield per recruit, which involves trade-offs between the juvenile and adult fisheries.

(7) Fishery management thinking is usually oriented toward high sustainable yields, but occasionally the value of stability in a fishery could be questioned -- from the point of view that a pelagic fishery dependent on annual recruitment might be highly unstable but still could be managed for maximum production.

It seems implicit in fishery management thinking that what is done in setting catch quotas will result in rebuilding of stocks -- when this may be almost completely a function of recruitment, and hence can be determined by natural factors. Peaks and troughs can be dampened by restrictions on catches, but fish populations are unstable, so fish may be wasted during peak years with this approach.

(8) The juvenile herring fishery must be managed effectively in territorial waters of all states, as well as outside such waters. Better definition and standardization of what constitutes state territorial waters is needed.

(9) Any management plan should include a degree of flexibility, to allow for changes in seasonal migration paths or stock size, or to accommodate to changing management objectives.

(10) The New England Fishery Management Council should have advice from a separate and independent "assessments oversight committee" with membership including representatives of all states as well as the federal government, to review all assessment documents. This

committe would be similar in function to the ICNAF STACRES (Standing Committee on Research and Statistics) Committee, and would do its analyses separately from those done by Council staff members.

Alternatively, the assessments oversight committee could include representation from the scientific staff of the Fishery Management Council as well as state and federal scientists, to insure full communication between scientific and management elements, and to provide a forum for resolution of different interpretations of data.

(11) A critical question that fishery management groups must address is "What is the level of accuracy and precision of information that is really needed for management?" The degree of fine tuning of regulatory measures must be coordinated with the reliability of the data base, otherwise managers become involved in splitting hairs over such questions as whether they should manage for 5% or 10% recovery, when the assumptions do not warrant that degree of precision. This can be described as "over-management" (Hennemuth, personal communication) which results from misconceptions about the complex quantitative steps in making assessments -- which may lead to false attitudes about precision of assessments.

(12) Most management policies tend to be restrictive, such as TAC's and closures. The possibility of positive management policies should not be ignored. There should be directed programs as parts of management plans that make specific efforts to protect and improve the habitats of herring, particularly in shallow waters.

(13) Finally, there should always be room for consideration of new stock assessment and management principles, once their validity has been determined. Among many possibilities here is that there may be something unique about herring and other pelagic stocks that causes them to collapse under exploitation -- some principle that we have not comprehended. The pragmatists would feel that this is a simple matter of consistently exceeding surplus production, regardless of size of recruitment, and possibly this is so, but options for alternative thinking must persist.

CHAPTER 9

SUMMARY

This document has attempted to provide a perspective on events that have occurred within the past two decades in the western North Atlantic herring stocks of concern to the United States. Production from the fishery underwent enormous expansion during the 1960's, then began a precipitous decline in the mid-1970's, due apparently to reduction in stock size caused by a combination of intensive fishing (beyond surplus production) and a succession of poor year classes. The Georges Bank stock is of particular concern, since it seems at the point of collapse. The accident of two good year classes (1960 and 1961) entering and passing through the fishery (until 1969) at a time of increasing fishing pressure by foreign vessels, and then inability or unwillingness to reduce exploitation levels when stock abundance depended on successive poor year classes, has led to the present extremely low level of the Georges Bank herring population. The western Gulf of Maine spawning stock has also been drastically reduced by intensive fishing beginning in the mid-1960's, while the southern Nova Scotia stock has shown more recent evidence of decline, beginning in the mid-1970's.

Throughout much of this period, management of stocks was non-existent or minimal until 1972, in terms of reducing intensive fishing pressure, and is only now beginning to show signs of being really effective, under extended fisheries jurisdiction by the United States and Canada. Recent severe restrictions on allowable catches should arrest further decline, but management to allow stock rebuilding in the Gulf of Maine is still several years away, and any significant rebuilding of that stock will probably depend on the recruitment of one or more strong year classes. The proposed 1978 quota for Georges Bank should allow immediate rebuilding of the stock, even with poor recruitment.

A continuing and urgent need is for better information about stock size and recruitment. With intense exploitation, the fishery has become largely dependent upon recruitment of each year class. Stock assessments have been made since the late 1960's, but recent restrictions on catches reduce the utility of the principal assessment tool (virtual population analysis). Estimates of annual recruitment have been based on several criteria, beginning with larval surveys, but none has proved entirely satisfactory.

Critical and persistent problem areas include the need for (1) a better understanding of stock size and the discreteness of stocks, at spawning as well as at other times, (2) resolution of the question of spawning sources of juveniles fished in coastal waters, (3) better understanding of recruitment, and the criteria that provide best estimates of recruitment, (4) a better understanding of the relationship of size of spawning stocks, success of spawning, and size of the resulting year class, and (5) a better understanding of natural mortality, and how it varies annually and geographically. Information about mortality in early life history stages is especially important.

The relationship of spawning stock size to size of subsequent year classes is not understood for herring. Environmental factors are clearly involved. Temperature can influence time of spawning; larval food abundance may be variable seasonally and yearly; predation on eggs, larvae and juveniles may vary in intensity annually and geographically; and disease-caused mortalities may severely affect stock size.

Environmental factors -- especially those operative during the early part of the first year of life -- clearly have an overriding influence on year class survival. Those factors which seem most important to success of reproduction and survival of larvae have recently been summarized (NERFMC, 1978) as:

1. Bottom conditions (including man-made disturbances) at sites of spawning and egg deposition (Figure 57);
2. Oceanic conditions (currents, winds, ocean climate) which can influence spawning migrations and normal dispersal of larvae to nursery areas;
3. Water temperature, which can affect timely arrival of adults at spawning sites and synchronization of food production with larval development;
4. Food availability (kind, size, abundance), which can be all-important to larval survival;
5. Predator activity (timing, intensity) which can affect egg and larval survival drastically.

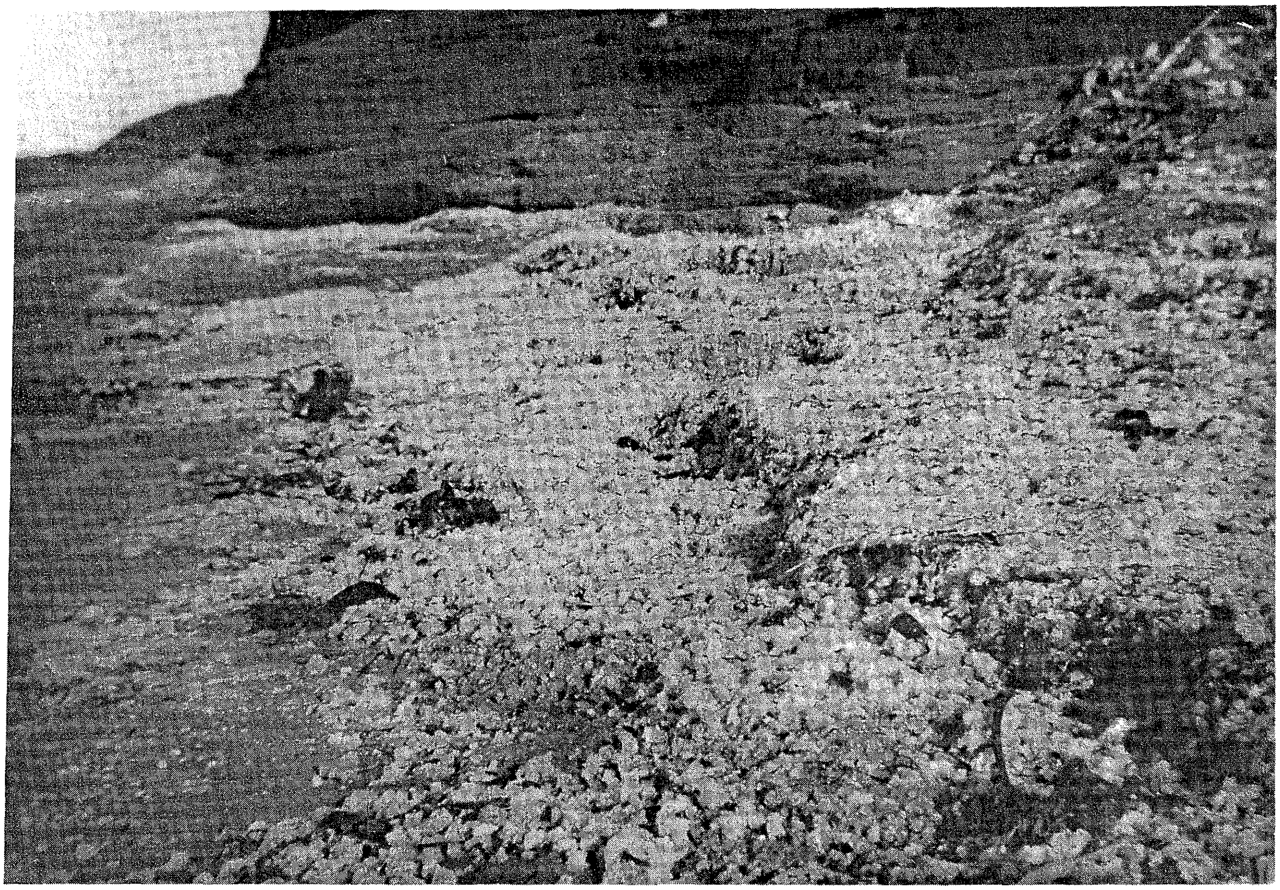


Figure 57. Eggs of spring spawning Gulf of St. Lawrence herring washed ashore during a late-spring storm.

Effects of environmental factors on success of reproduction and larval survival are of course only one component of a larger view of interactions of herring at all life history stages with other species and with their physical-chemical environment. Participation in this larger arena of ecosystem dynamics requires a strong and long-term data base -- some of which is available for the area of concern to this document. Continued monitoring, along with analyses and simulations, can be identified as needs for the future.

A proposed program for monitoring and research has been outlined, with greatest emphasis and priority placed on improved monitoring of abundance and recruitment, so that better estimates of recruitment can be made; augmentation of population dynamics studies, including the development of fishery production models suited to fluctuating pelagic species; and increased attention to stock identification and migrations of stocks, principally through an expanded long-term tagging effort.

The immediate research activities, responsive to needs of fishery management agencies, are not uniquely separable from longer-term research necessary to fully understand the dynamics of herring production -- but there must be some rational balance, so that today's management requirements are met, without total disappearance of more fundamental studies.

There is a clearly identifiable need for continuing dialogue with management agencies (State and Regional Council) and with Canadian counterparts (because of stock intermixture). The objectives of stock management -- whether stock maintenance or rebuilding -- must be clearly stated by managers and understood by scientists; the scientists' role is then to present options and recommendations about allowable catches, which may be considered by managers (along with other factors) in developing and modifying regulations.

At present -- with herring stocks of the western North Atlantic at a low ebb, but with a potentially effective regulatory mechanism (extended fisheries jurisdiction) finally in place -- there is opportunity for scientific management of herring stocks of concern to the United States. Available information necessary for management should be augmented by a long-term selective monitoring system based on accurate early estimation of size of each recruiting year class; an expanded tagging program to better define movements and intermixing; and a more fundamental approach to herring population dynamics than has been feasible in the past. Promising initial steps toward total ecosystems management of Georges Bank fish production should be expanded into a major future research effort, since it is only from such studies that true understanding of stock fluctuations and effects of man's perturbations can be derived.

10. REFERENCES

AASEN, O.

1954. Estimation of stock strength of the Norwegian winter herring. J. Cons. Perm. Int. Expl. Mer 24: 95-110.

AHLSTROM, E. H.

1954. Distribution and abundance of egg and larval populations of the Pacific sardine. U.S. Dept. Int., Fish Wildl. Serv., Fish Bull. 56: 83-140.

1957. A review of recent studies of subpopulations of Pacific fishes. pp. 44-73. In Marr, J. C. (ed.), Contributions to the study of subpopulations of fishes. Spec. Sci. Rept. U.S. Fish Wildl. Serv., Fish. No. 208, 129 p.

ALDERDICE, D. F., AND F. P. J. VELSEN.

1971. Some effects of salinity and temperature on early development of Pacific herring (*Clupea pallasi*). J. Fish. Res. Board Can. 28: 1545-1562.

ALLEN, J., T. BARLOW, J. WARD, JR., AND L. DONALDSON.

1837. Reports of the Commissioners appointed by the House of Assembly to procure information respecting the state of the herring fishery at Grand Manan. J. House of Assembly New Brunswick 1836-37, App. No. 2: pp. 13-17.

ALLEN, R. L., AND P. BASASIBWAKI.

1974. Properties of age structure models for fish populations. J. Fish. Res. Board Can. 31: 1119-1125.

ALMEIDA, F. P.

1976. Middle Atlantic mixed fishery. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 52-53.

1976. USSR - Pelagic trawl fisheries. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 64-65.

ALMEIDA, F. P., AND T. S. BURNS.

1978. Preliminary results of the International Herring Tagging Program conducted on the northeast coast of the United States in 1977. NMFS, Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 78/07, 10 pp.

ALTUKHOV, Y. P., K. A. TRUVELLER, V. S. ZENKIN, AND N. S. GLADKOVA.

1968. A-system of blood groups in herring (Clupea harengus L.). Genetica 2: 155-167.

ALVERSON, D. L.

1972. Science and fishery management. In Rothschild, B. J. (ed.), World fisheries policy multidisciplinary views, pp. 211-218. U. Wash. Press, Seattle, 272 pp.

ANCELLIN, J.

1953. Hareng du sud de la Mer du Nord et de la Manche Orientale, Campagne de 1952-53. Ann. Biol., Copenh. 9: 202-205.

ANCELLIN, J.

1963. Herring tagging in the North Sea and Eastern English Channel. ICNAF Spec. Pub. No. 4, pp. 323-326.

ANDERSEN, K. P., H. LASSEN, AND E. URSIN.

1973. A multispecies extension to the Beverton and Holt assessment model with an account of primary production. ICES Doc. CM1973/H:20.

ANDERSON, E. D.

1973. Assessment of Atlantic mackerel in ICNAF Subarea 5 and Statistical Area 6. ICNAF Res. Doc. 73/14, Ser. No. 2916, 38 pp.

1975a. Recovery time of fish stocks in ICNAF Subarea 5 and Statistical Area 6 to the MSY biomass level. NMFS, Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 75-8, 3 pp.

1975b. The effects of a combined assessment for mackerel in ICNAF Subareas 3, 4 and 5, and Statistical Area 6. ICNAF Res. Doc. 75/14, Ser. No. 3458, 14 pp.

1976a. Description of major stocks in ICNAF SA5 and 6. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 13-40.

1976b. Estimates of maximum sustainable yield of fish stocks in ICNAF Subarea 5 and Statistical Area 6. NMFS, Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 76-05, 2 pp.

1976c. Measures of abundance of Atlantic mackerel off the northeastern coast of the United States. ICNAF Res. Doc. 76/6/12, Ser. No. 3781, 18 pp.

ANDERSON, E. D., AND H. DORNHEIM.

1974. A preliminary report on the joint FRG-US juvenile herring survey by R/V Walther Herwig in ICNAF Div. 4X and 5Z in March-April 1974 with a comparison with the 1973 FRG juvenile herring survey. ICNAF Res. Doc. 74/115, 10 pp.

ANONYMOUS.

1959. International Passamaquoddy Fisheries Board, Report to the Int. Joint Comm. Ottawa and Washington, D. C.

1960. Passamaquoddy Fisheries investigations, 1956-59. Report to the International Joint Commission by International Passamaquoddy Fisheries Board. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 360, 40 pp.

1972. Report of Herring Working Group, 1972. ICNAF Redbook 1972, Pt. I, Appendix II, p. 56.

1973. Tidal current tables 1974 Atlantic Coast of North America. U.S. Dept. Commerce, NOAA, National Ocean Survey, 200 pp.

1975. Report of the Herring Working Group - April, 1975. ICNAF Summ. Doc. 75/19, 11 pp.

ANTHONY, V. C.

1971. The density dependence of growth of the Atlantic herring in Maine. Rapp. P.-v. ICES 160: 197-205.

1972. Population dynamics of the Atlantic herring in the Gulf of Maine. Ph.D. Thesis, University of Washington, 266 pp.

ANTHONY, V. C.

1976a. Estimation of numbers of herring to be tagged in addressing the herring stock intermixture problem. ICNAF Res. Doc. 76/6/66, Ser. No. 3854, 5 pp.

1976b. The effect on stock size from various assumptions of year class strength for the Div. 5Z and Statistical Area 6 herring stock. ICNAF Res. Doc. 76/6/122, Ser. No. 3979, 7 pp.

1977a. June 1977 assessments of herring from the Gulf of Maine and Georges Bank areas. NMFS, Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 77-16, 16 pp.

1977b. Public record of hearings on Atlantic herring. U.S. Dept. Commerce, Nat. Mar. Fish. Ser., NOAA, April 19, 1977.

1978. Personal Communication. Maine Department of Marine Resources, Boothbay Harbor, ME.

ANTHONY, V. C., AND H. C. BOYAR.

1968. Comparison of meristic characters of adult Atlantic herring from the Gulf of Maine and adjacent waters. ICNAF Res. Bull. 5, pp. 91-98.

ANTHONY, V. C., AND B. E. BROWN.

1972. Herring assessment for the Gulf of Maine (ICNAF Div. 5Y) stock. ICNAF Res. Doc. 72/13, 25 pp.

ANTHONY, V. C., AND S. H. CLARK.

1976. Resources needed for management of the fishery resources off the northern coast of the U.S.A. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 72-76.

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. ICNAF Res. Doc. 75/110, Ser. No. 3603, 45 pp.

ANTHONY, V. C., H. DORNHEIM, AND G. JOAKIMSSON.
1976. Results of the 1975 and 1976 Federal Republic of Germany young herring surveys in ICNAF Subareas 4 and 5. ICNAF Res. Doc. 76/6/118, Ser. No. 3945, 21 pp.

ANTHONY, V. C., AND G. WARING.
1978. Assessment and management of the Georges Bank herring fishery. ICES Sympos. on Biol. Basis of Pelagic Fish Stock Mgmt., Doc. No. 4, 74 pp.

ARTHUR, D. K.
1956. The particulate food and the food resources of the larvae of three pelagic fishes, especially the Pacific sardine (Sardinops caerulea). Ph.D. Thesis, Univ. Calif., Scripps Inst. Oceanogr., 231 pp.

AU, D. W. K.
1973. Total sustainable finfish yield from Subareas 5 and 6 based on yield per recruit and primary production consideration. ICNAF Res. Doc. 73/10, Ser. No. 2912, 6 pp.

AU, D. W. K., T. L. MORRIS, AND J. JOHRMANN.
1973. Preliminary report of ICNAF larval herring (Clupea harengus) survey in the Gulf of Maine and Georges Bank during December 1972. ICNAF Res. Doc. 73/11, Ser. No. 2913.

AU, D. W. K., AND T. L. MORRIS.

1974. Report of larval herring surveys in the Gulf of Maine and on Georges Bank during December 1973 and February 1974 conducted by R/V Albatross IV. ICNAF Res. Doc. 74/72, Ser. No. 3305, 31 p.

BALKOVOY, V. A.

1973. Preliminary results of investigations on distribution and abundance of herring larvae on Georges Bank in September-October 1972. ICNAF Res. Doc. 73/97, Ser. No. 3056, 7 pp.

BALKOVOY, V. A., I. K. SIGAJEV, AND A. P. NAKONECHNAJA.

1975. The results of the survey on abundance and distribution of herring larvae on Georges Bank, 18-30 October 1974. ICNAF Res. Doc. 75/66, Ser. No. 3550, 21 pp.

BALKOVOY, V. A., V. A. SUSHIN, I. K. SIGAJEV.

1974. Preliminary results of herring larval survey on Georges Bank, 15 October-1 November 1973. ICNAF Res. Doc. 74/13, Ser. No. 3160, 38 pp.

BANNISTER, R. C. A., O. HARDING, AND S. J. LOCKWOOD.

1974. Larval mortality and subsequent year-class strength in the plaice (Pleuronectes platessa L.), pp. 21-37. In Blaxter, J. H. S. (ed.), The early life history of fish. Springer-Verlag, New York.

BATTLE, H. I., A. C. HUNTSMAN, A. M. JEFFERS, G. W. JEFFERS, W. H. JOHNSON, AND N. H. MCNAIRN.

1936. Fatness, digestion and food of Passamaquoddy young herring. J. Biol. Board Can. 2: 401-429.

BEAMISH, F. W. H.

1964. Respiration of fishes with special emphasis on standard oxygen consumption. II. Influence of weight and temperature on respiration of several species. Can. J. Zool. 42: 177-188.

BEARDSLEY, R. C., AND B. BUTMAN.

1974. Circulation on the New England Continental Shelf: Response to strong winter storms. Geophys. Res. Letters 1(4): 181-184.

BECKER, H. B., AND A. CORTEN.

1974. The precision of abundance estimates from young herring surveys in the North Sea. ICES Doc. CM1974/H:19, 9 pp.

BECKETT, J. S.

1971. Interim report of herring tagging in the Gulf of St. Lawrence, 1970. ICNAF Res. Doc. 71/95, Ser. No. 2565, 4 pp.

BECKETT, J. S., W. T. STOBO, AND C. A. DICKSON.

1974. Southwesterly migration of Atlantic mackerel, *Scomber scombrus*, tagged off Nova Scotia. ICNAF Res. Doc. 74/94, Ser. No. 3330.

BENKO, I. K.

1964. Taxonomic position of herring from the Georges and Banquereau Banks. Probl. Ichthyol. 4(1). Moscow.

BERTHELSEN, E., AND K. P. MADSEN.

1953. Young herring from the Bløden Ground area. Ann. Biol., Copenh. 9: 179-180.

BEVERTON, R. J. H.

1962. Long-term dynamics of certain North Sea fish populations. *In* E. D. LeCren and M. W. Holdgate (eds.), The exploitation of natural animal populations, pp. 242-259. Blackwell, Oxford.

BEVERTON, R. J. H.

1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing. Rapp. P.-v. ICES 154: 44-67.

BEVERTON, R. J. H., AND S. J. HOLT.

1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Foundat. Sympos. on the lifespan of animals, pp. 142-177.

BHATTACHARYYA, R. N.

1957. The food and feeding habits of larval and post-larval herring in the northern North Sea. Scottish Home Dept. Marine Research 3, 14 pp.

BIGELOW, H. B.

1926. Plankton of the offshore waters of the Gulf of Maine. U.S. Bur. Fish. Bull. 40(2): 1-509.

1927. Physical oceanography of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 40(2): 511-1027.

1927. Dynamic oceanography of the Gulf of Maine. Bull. Natur. Resourc. Counc., Wash., D. C., No. 61, pp. 206-211.

BIGELOW, H. B., AND W. C. SCHROEDER.

1953. Fishes of the Gulf of Maine. U.S. Fish. Wildl. Serv., Fish. Bull. 53(74): 1-577.

BIGELOW, H. B., AND W. W. WELSH.

1925. Fishes of the Gulf of Maine. U.S. Bur. Fish. Bull. 40(1): 1-567.

BIRJUKOV, N. P., AND L. S. SHAPIRO.

1971. The relationship between year class strength of Vistula Bay herring, the state of the spawning schools and the quality of sexual products. Rapp. P.-v. ICES 160: 18-23.

BIRTWISTLE, W., AND H. M. LEWIS.

1923. Scale investigations of shoaling herring from the Irish Sea. Lancashire Sea Fisheries Comm. Rept. (Eng.) 31, pp. 64-86.

BISHAI, H. M.

1960. The effect of water currents on the survival and distribution of fish larvae. J. Cons. Perm. Int. Explor. Mer 25: 134-146.

BISHOP, Y. M. M.

1959. Errors in estimates of mortality obtained from vertebral counts. J. Fish. Res. Board Can. 23: 145-190.

BISHOP, Y., AND L. MARGOLIS.

1955. A statistical examination of Anisakis larvae (Nematoda) in herring (Clupea pallasi) of the British Columbia coast. J. Fish. Res. Board Can. 12: 571-592.

BJERKNES, J.

1963. Climatic change as an ocean-atmosphere problem. WMO-UNESCO Rome Sympos. Changes in climate. UNESCO, Paris, pp. 297-321.

BLAXTER, I. G.

1971. Development rates and mortalities in Clyde herring. Rapp. P.-v. ICES 160: 27-29.

BLAXTER, J. H. S.

1956. Herring Rearing - II. The effect of temperature and other factors on development. Scottish Home Dept. Marine Research 5, 19 pp.

1958. The racial problem in herring from the viewpoint of recent physiological and evolutionary theory. Rapp. P.-v. ICES 143: 10-19.

1960. The effect of extremes of temperature on herring larvae. J. Mar. Biol. Ass. U.K. 39: 605-608.

1962. Herring Rearing - IV. Rearing beyond the yolk-sac stage. Scottish Home Dept. Marine Research 10,18 pp.

1965. The feeding of herring larvae and their ecology in relation to feeding. Calif. Coop. Fish. Inv. Repts. 10: 79-88.

1973. Monitoring the vertical movements and light responses of herring and plaice larvae. J. Mar. Biol. Ass. U.K. 53: 635-647.

BLAXTER, J. H. S., AND W. DICKSON.

1959. Observations on the swimming speeds of fish. Rapp. P.-v. ICES 24: 472-479.

BLAXTER, J. H. S., AND K. F. ERMLICH.

1974. Changes in behaviour during starvation of herring and plaice larvae. In J. H. S. Blaxter (ed.), The early life history of fish, pp. 575-588. Springer-Verlag, New York.

BLAXTER, J. H. S., AND G. HEMPEL.

1961. Biologische Beobachtungen bei der Aufzucht von Heringsbrut. Helgol. Wiss. Meeresunters. 7(5): 260-283.

BLAXTER, J. H. S., AND G. HEMPEL.

1963. The influence of egg size on herring larvae (Clupea harengus harengus L.). Rapp. P.-v. ICES 28: 211-240.

BLAXTER, J. H. S., AND F. G. T. HOLLIDAY.

1958. Herring (Clupea harengus L.) in aquaria. II. Feeding. Scottish Home Dept. Marine Research 6, 22 pp.

BLAXTER, J. H. S., AND F. G. T. HOLLIDAY.

1963. The behavior and physiology of herring and other clupeids. Adv. Mar. Biol. 1: 261-393.

BLAXTER, J. H. S., and M. P. Jones.

1967. The development of the retina and retina-motor responses in herring. J. Mar. Biol. U.K. 47: 677-697.

BOHL, H.

1962. Selectivity of herring in bottom trawls. ICES Doc. CM1962/74.

1965. Escape of herring, haddock and whiting through the codend meshes of a herring bottom trawls. ICES Coop. Res. Rept. Ser. B, pp. 101-116.

BORUTSKII, E. V.

1960. The fishery forage base. Akademiya Nauk, USSR. Trudy Instituta Morfologii Zhirotnykh im. A. N. Severtsova, 13: 5-61. (Transl. by Israel Program for Scientific Translations, No. 842).

BOWERS, A. B.

1969. Spawning beds of Manx autumn herrings. J. Fish. Biol. 1: 355-359.

BOWERS, A. B., AND F. G. T. HOLLIDAY.

1961. Histological changes in the gonad associated with the reproductive cycle of the herring (Clupea harengus L.). Scottish Home Dept. Marine Research 5, 16 pp.

BOWMAN, R. E., AND R. W. LANGTON.

1978. Fish predation on oil-contaminated prey from the region of the ARGO MERCHANT oil spill. In University of Rhode Island, Center for Ocean Management Studies, In the wake of the ARGO MERCHANT.

BOWMAN, R. E., R. O. MAURER, AND J. A. MURPHY.

1976. Stomach contents of twenty-nine fish species from five regions in the northeast Atlantic -- data report. NMFS, Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 76-10, 37 pp.

BOYAR, H. C.

1961. Swimming speed of immature Atlantic herring with reference to the Passamaquoddy tidal project. Trans. Am. Fish. Soc. 90: 21-26.

1965. Age, length, and state of maturity of adult herring in Subarea 5. ICNAF Res. Doc. 65/40, Ser. No. 1504, 5 pp.

1966. Distribution and abundance of larval herring on Georges Bank. ICNAF Res. Doc. 66/62, 4 pp.

1967. Age, length and maturity of adult herring in Subareas 4 and 5, 1966. ICNAF Res. Doc. 67/24, Ser. No. 1802, 5 pp.

1968. Age, length and gonadal stages of herring from Georges Bank and the Gulf of Maine. ICNAF Res. Bull. No. 5: 49-61.

1970a. Distribution and abundance of larval herring (Clupea harengus harengus L.) on Georges Bank and adjacent waters in 1962 to 1969. ICNAF Res. Doc. 70/71, 5 pp.

BOYAR, H. C.

1970b. Offshore and inshore herring are of separate populations. Portland Press Herald, Industrial and Financial Edition 83(2): 35.

BOYAR, H. C., AND R. A. CLIFFORD.

1971. Mean length of herring of various age-groups and year-classes obtained during the onset and peak of the spawning season from ICNAF Subareas 4 and 5, 1966-1970. ICNAF Ann. Meet. 1971, Res. Doc. 71/122, Ser. No. 2620, 5 p.

BOYAR, H. C., R. A. COOPER, AND R. A. CLIFFORD.

1973. A study of the spawning and early life history of herring (Clupea harengus harengus L.) on Jeffrey's Ledge in 1972. ICNAF Res. Doc. 73/96, Ser. No. 3054, 27 pp.

BOYAR, H. C., R. R. MARAK, F. E. PERKINS, AND R. A. CLIFFORD.

1973. Seasonal distribution and growth of larval herring (Clupea harengus harengus L.) in the Georges Bank-Gulf of Maine area from 1962 to 1978. Rapp. P.-v. ICES 35: 36-51.

BOYAR, H. C., AND F. E. PERKINS.

1971a. Age, length and maturity of adult herring in ICNAF Subareas 4 and 5, 1970. ICNAF Ann. Meet. June 1971, Res. Doc. 71/101, Ser. No. 2578, 5 p.

1971b. The occurrence of a larval nematode (Anisakis sp.) in adult herring from ICNAF Subareas 4 and 5, 1962-1969. ICNAF Res. Doc. 21/99, Ser. No. 2576, 2 pp.

BOYAR, H. C., F. E. PERKINS, AND R. A. CLIFFORD.

1972. Age, length and maturity of adult herring in ICNAF Divisions 5Z, 5Y, 4X and Subarea 6, 1971. ICNAF Res. Doc. 72/51, Ser. No. 2759, 8 p.

BOX, G. E. P., AND W. G. HUNTER.

1962. A useful method for model building. Technometrics 4: 301-318.

BRAWN, V. M.

1960a. Seasonal and diurnal vertical distribution of herring (Clupea harengus L.) in Passamaquoddy Bay, N.B. J. Fish Res. Board Can. 17: 699-711.

1960b. Underwater television observations of the swimming speed and behaviour of captive herring. J. Fish. Res. Board Can. 17: 689-698.

1960c. Temperature tolerance of unacclimated herring (Clupea harengus L.). J. Fish. Res. Board Can. 17: 721-723.

1960d. Survival of herring (Clupea harengus L.) in water of low salinity. J. Fish. Res. Board Can. 17: 725-726.

1960e. Seasonal and diurnal vertical distribution of herring (Clupea harengus L.) in Passamaquoddy Bay, N. B. J. Fish. Res. Board Can. 17: 699-711.

1962. Physical properties and hydrostatic function of the swimbladder of herring (Clupea harengus L.). J. Fish. Res. Board Can. 19: 635-656.

BRIDGER, J. P.

1956. On day and night variations in catches of fish larvae. Rapp. P.-v. ICES 22: 42-57.

1960. On the relationship between stock, larvae and recruits in the Downs herring. ICES Doc. CM1960/Herring Comm. Paper 159.

1961. On fecundity and larval abundance of Downs herring. Fish Invest. Lond., Ser. II, 23(3): 30 pp.

BRIUZGIN, V. L.

1963. Methods of studying the growth of fish from their scales, bones and otoliths. Vop. Ikthiol. 3(2): 347-365. (Fish. Res. Board Can. Transl. No. 553).

BROWN, B. E.

1971. An analysis of data on population abundance of herring in ICNAF Subareas 5Z and 6. ICNAF Ann. Meet. 1971, Res. Doc. 71/124, Ser. No. 2622, 6 p.

1976a. A prospectus on the basis for fishery management on the northwest Atlantic continental shelf off the coast of the United States of America. ICNAF Res. Doc. 76/6/102, Ser. No. 3925, 10 pp.

1976b. Appendix to A prospectus on the basis for fishery management on the northwest Atlantic continental shelf off the coast of the United States of America. ICNAF Res. Doc. 76/6/102, Ser. No. 3925, 78 pp.

BROWN, B. E., J. A. BRENNAN, E. G. HEYERDAHL, M. D. GROSSLEIN, AND R. C. HENNEMUTH.

1973. An evaluation of the effects of fishing on the total finfish biomass in ICNAF Subarea 5 and Statistical Area 6. ICNAF Res. Doc. 73/8, Ser. No. 2910, 26 pp.

BROWN, B. E., J. A. BRENNAN, E. G. HEYERDAHL, M. D. GROSSLEIN, AND R. C. HENNEMUTH.

1976. The effects of fishing on the marine finfish biomass in the Northwest Atlantic from the eastern edge of the Gulf of Maine to Cape Hatteras. ICNAF Res. Bull. 76/12, pp. 49-68.

BRUCE, J. R.

1924. Changes in the chemical composition of the tissues of the herring in relation to area and maturity. Biochem. J. 18: 469-485.

BRYANTSEV, V. A.

1966. The influence of water masses of the New England and Nova Scotia shelf on the formation of commercial concentrations of herring. ICNAF Spec. Pub. No. 6, pp. 597-602.

BÜCKMANN, A.

1950. Die Untersuchungen der Biologischen Anstalt über die Ökologie der Heringsbrut in the südlichen Nordsee. II. Helgol. Wiss. Meeresunters. 3: 171-205.

BUMPUS, D. F.

1957. Surface water temperatures along the Atlantic and Gulf coasts of the United States. Spec. Sci. Rept.-Fish., U. S. Fish Wildl. Serv., No. 214, 153 pp.

1960. Sources of water contributed to the Bay of Fundy by surface circulation. J. Fish. Res. Board Can. 17: 181-197.

1973. A description of the circulation on the continental shelf of the east coast of the United States. Progress in Oceanography 6: 111-157.

1975. Review of the physical oceanography of Georges Bank. ICNAF Res. Doc. 75/107, Ser. No. 3600, 31 pp.

BUMPUS, D. F., AND L. M. LAUZIER.

1965. Surface circulation on the continental shelf off eastern North America between Newfoundland and Florida. Am. Geograph. Soc., Ser. Atlas Mar. Environ., Folio 7, 8 plates, 4 pp.

BUMPUS, D. F., R. E. LYNDE, AND D. M. SLAW.

1973. Physical Oceanography. In Coastal and offshore environmental inventory: Cape Hatteras to Nantucket Shoals. Marine Publ. Series No. 2, U. of Rhode Island.

BURD, A. C.

1962. Growth and recruitment in the herring of the southern North Sea. Fish. Invest. Lond., Ser. 2(5): 42 pp.

1969. Trials with principal component analysis for herring racial studies. ICES Doc. CM1969/H:30, 4 pp, 7 pp. of tables.

BURD, A. C., AND D. H. CUSHING.

1962. I. Growth and recruitment in the herring of the southern North Sea. II. Recruitment to the North Sea herring stocks. Fish. Invest. Lond., Ser. 2, 23(5): 71 pp.

BURD, A. C., AND W. G. PURNELL.

1973. The relationship between larval abundance and stock in North Sea herring. Rapp. P.-v. ICES 164: 30-36.

BURNS, T. S.

1977. Preliminary results of the International Herring Tagging Program conducted on Georges Bank and Jeffrey's Ledge. ICNAF Working Paper 77/4/10, 5 pp.

CADDY, J. F., J. J. GRAHAM, T. D. ILES, A. M. PANKRATOV, AND I. K. SIGAJEV.

1971. A preliminary report on the combined USSR, USA, and Canadian surface ship and submersible study of herring spawning grounds, Georges Bank, 1970. ICNAF Res. Doc. 71/85, Ser. No. 2554, 20 pp.

CADDY, J. F., AND T. D. ILES.

1973. Underwater observations on herring spawning grounds on Georges Bank. ICNAF Res. Bull. 10, pp. 131-139.

CHAPMAN, D. G.

1961. Statistical problems in dynamics of exploited fish populations. Biology and Problems of Health 4: 153-168.

CHAPMAN, D. G., AND D. S. ROBSON.

1960. The analysis of a catch curve. Biometrics 16: 354-368.

CHASE, J.

1955. Winds and temperatures in relation to the brood-strength of Georges Bank haddock. J. Cons. Perm. Int. Explor. Mer 21: 17-24.

CHENOWETH, S. B.

1970. Seasonal variations in condition of larval herring in Boothbay area of the Maine coast. J. Fish. Res. Board Can. 27: 1875-1879.

1973. Fish larvae of the estuaries and coast of central Maine. U.S. Dept. Commerce, Fish. Bull. 71(1): 105-113.

CHEVIER, J. R., AND R. W. TRITES.

1960. Drift bottle experiments in the Quoddy Region, Bay of Fundy. J. Fish. Res. Board Can. 17: 743-762.

CHRZAN, F., AND B. DRAGNIK.

1968. Observations on herring caught on Georges Bank. ICNAF Redbook 1968 (Part III): 53-61.

CLARK, S. H., AND B. E. BROWN.

1977. Changes in biomass of finfishes and squids from the Gulf of Maine to Cape Hatteras, 1963-1974, as determined from research vessel survey data. Fish. Bull., U.S. 75: 1-21.

CLARK, S. H., AND B. E. BROWN.

1978. Trends in biomass of finfish and squids in ICNAF Subarea 5 and Statistical Area 6, 1964-1977, as determined from research vessel survey data. NMFS, Northeast Fisheries Center, Woods Hole Laboratory (Ms. to be published in Investigacion Pesquera).

COLTON, J. B., JR.

1959. A field observation of mortality of marine fish larvae due to warming. Limnol. Oceanogr. 4: 219-222.

1963. History of oceanography in the offshore waters of the Gulf of Maine. Spec. Sci. Rept.-Fish., U.S. Fish Wildl. Serv. No. 496, 18 pp.

1968a. A comparison of current and long-term temperatures of continental shelf waters, Nova Scotia to Long Island. ICNAF Res. Bull. 5, pp. 110-129.

1968b. Recent trends in subsurface temperatures in the Gulf of Maine and continuous waters. J. Fish. Res. Board Can. 25: 2427-2437.

COLTON, J. B., JR., AND R. R. BYRON.

1977. Gulf of Maine-Georges Bank ichthyoplankton collected on ICNAF larval surveys September 1971-February 1975. NOAA Tech. Rept., NMFS SSRF-717, 35 pp.

COLTON, J. B., JR., AND J. R. GREEN.

1975. Progress report on analysis of sampler and behavior-related variation in the catch of larval herring on ICNAF larval herring surveys. ICNAF Res. Doc. 75/108, Ser. No. 3601, 20 pp.

COLTON, J. B., JR., K. A. HONEY, AND R. F. TEMPLE.

1961. The effectiveness of sampling methods used to study the distribution of larval herring in the Gulf of Maine. J. Cons. Perm. Int. Explor. Mer 26: 180-190.

COLTON, J. B., JR., R. R. MARAK, S. R. NICKERSON, AND R. R. STODDARD.

1968. Physical, chemical, and biological observations on the continental shelf, Nova Scotia to Long Island, 1964-1966. U.S.F.W.S. Data Report 23, 190 pp.

COLTON, J. B., JR., AND R. R. STODDARD.

1972. Average monthly sea-water temperatures Nova Scotia to Long Island 1940-1959. Am. Geograph. Soc., Ser. Atlas Marine Environment, Folio 21.

COLTON, J. B., JR., AND R. F. TEMPLE.

1961. The enigma of Georges Bank spawning. Limnol. Oceanogr. 6: 280-291.

COOPER, R. A., J. R. UZMANN, R. A. CLIFFORD, AND K. J. PECCI.

1975. Direct observations of herring (Clupea harengus harengus L.) egg beds on Jeffrey's Ledge, Gulf of Maine in 1974. ICNAF Res. Doc. 75/93, Ser. No. 3573, 6 pp.

CORLETT, J.

1965. Winds, currents, plankton and year class strength of cod in the western Barents Sea. ICNAF Spec. Pub. 6: 373-385.

CORNICK, J. W., R. M. MACKELVIE, AND J. E. STEWART.

1972. A note on bacteriological examination of moribund herring from Placentia Bay. In Effects of elemental phosphorus on marine life. Fish. Res. Board Can., Atl. Reg. Circ. No. 2: 53.

CRISP, D. J.

1975. Secondary productivity in the sea. In D. E. Reichle, J. F. Franklin, and D. W. Goodall (eds.), Productivity of world ecosystems, pp. 71-90. Natl. Acad. Sci., Wash., D. C.

CUSHING, D. H.

1959. On the effect of fishing on the herring of the southern North Sea. J. Cons. Perm. Int. Explor. Mer 24: 283-307.

1962. Recruitment to the North Sea herring stocks. Fish. Invest. Lond., Ser. 23(5): 43-71.

1967. The grouping of herring populations. J. Mar. Biol. Ass. U.K. 47: 193-208.

1971. The dependence of recruitment on parent stock in different groups of fish. J. Cons. Perm. Int. Explor. Mer 33: 340-362.

1973. Food and the stabilization mechanism in fishes. Mar. Biol. Assoc. India. Special publication dedicated to Dr. N. K. Panekkar, May 1973, pp. 29-39.

1974a. The natural regulation of fish populations. pp. 399-413. In Harden-Jones, F. R. Sea fisheries research. John Wiley and Sons, New York.

1974b. The possible density-dependence of larval mortality and adult mortality in fishes. In J. H. S. Blaxter (ed.), The early life history of fish, pp. 103-111. Springer-Verlag, New York.

1975. Marine ecology and fisheries. Syndics of the Cambridge Univ. Press, Cambridge. 168 pp.

CUSHING, D. H.

1977. The problems of stock and recruitment. *In* J. A. Gulland (ed.), Lond., Fish population dynamics, pp. 116-133. John Wiley.

CUSHING, D. H., AND J. P. BRIDGER.

1966. The stock of herring in the North Sea and changes due to fishing. Fishery Invest. Lond., Ser. 2, 25(1): 123 pp.

CUSHING, D. H., AND A. C. BURD.

1957. On the herring of the southern North Sea. Fishery Invest. Lond., Ser. 2, 20(11): 31 pp.

CUSHING, D. H., AND J. G. K. HARRIS.

1973. Stock and recruitment and the problem of density dependence. Rapp. P.-v. ICES 164: 142-155.

DAHLGREN, E. H.

1936. Further developments in the tagging of the Pacific herring. Cons. Perm. Int. Explor. Mer 11: 229-247.

DAMKAER, D. M., AND D. W. K. AU.

1974. A preliminary investigation of the food of larval herring from Georges Bank. ICNAF Res. Doc. 74/68, Ser. No. 3293, 5 p.

DAS, N.

1968. Spawning, distribution, survival, and growth of larval herring (*Clupea harengus* L.) in relation to hydrographic conditions in the Bay of Fundy. Tech. Rept. Fish. Res. Board Can. 88, 129 pp.

DAS, N.

1972. Growth of larval herring (*Clupea harengus*) in the Bay of Fundy and Gulf of Maine area. J. Fish. Res. Board Can. 29: 573-575.

DAVIS, C. W.

1975. Preliminary results of juvenile fish survey on Georges Bank and Nantucket Shoals by Albatross IV, 13-22 May 1975. ICNAF Res. Doc. 75/118, 6 pp.

1976. Spring and autumn bottom-water temperatures in the Gulf of Maine and Georges Bank, 1968-1975. ICNAF Res. Doc. 76/6/112, 14 pp.

DAVIS, C. W., AND J. J. GRAHAM.

1970. Brit herring along Maine's coast. Commercial Fisheries Review 32(5): 32-35.

DAVIS, C. W., AND T. L. NORRIS.

1976. Preliminary report on the distribution, catches of age 1 herring in the Gulf of Maine, Georges Bank and Nantucket Shoals during the spring of 1976. ICNAF Res. Doc. 76/6/114, Ser. 3937, 8 p.

DAVIS, C. W., G. WARING, M. GROSSLEIN, T. BURNS, AND V. ANTHONY.

1975. Size distribution and recruitment estimates for sea herring of the Georges Bank-Gulf of Maine region, based on research vessel surveys. ICNAF Fish. Res. Doc. 75/110, 45 pp.

DAY, C. G.

1957. Drift bottle studies over the Gulf of Maine and Georges Bank. Woods Hole Oceanogr. Inst., Ref. No. 57-1, 17 pp.

1958a. Surface circulation in the Gulf of Maine as deduced from drift bottles. Fishery Bull,, Fish Wildl. Serv. U.S. 141: 443-472.

1958b. Surface circulation in the Gulf of Maine. Spec. Sci. Rept.-Fish. U.S. Fish Wildl. Serv. No. 496, 18 pp.

DAY, L. R.

1957a. Populations of herring in the northern Gulf of St. Lawrence. J. Fish. Res. Board Can. 11: 103-119.

1957b. Populations of herring in the southern Gulf of St. Lawrence. Bull. Fish. Res. Board Can. 111: 121-137.

1957c. Vertebral numbers and first-year growth of herring (Clupea harengus L.) in relation to water temperature. Bull. Fish. Res. Board Can. 111: 165-176.

DECAMPS, P.

1971. Study of the biological characteristics of spring and autumn herring taken off Cape Breton Island and Burgeo Bank. ICNAF Res. Doc. 71/40, Ser. No. 2525, 6 pp.

1972. Observations on herring taken in ICNAF Subareas 4 and 5. ICNAF Res. Doc. 72/55, 10 pp.

DECAMPS, P., AND D. BRIAND.

1973. Some biological data on the herring (Clupea harengus harengus L.) in the Gulf of St. Lawrence, Southwestern Newfoundland and Banquereau areas in 1972. ICNAF Redbook 1973 (Part III), pp. 109-118.

DECAMPS, P., AND D. BRIAND.

1974. Results of studies on herring of the Gulf of St. Lawrence, and Banquereau and Georges Bank. ICNAF Res. Doc. 74/58, 12 pp.

DELIGNY, W.

1969. Serological and biochemical studies on fish populations. Oceanogr. Mar. Biol. Ann. Rev. 7: 411-513.

DELL, M. B.

1968. A new fish tag and rapid cartridge-fed applicator. Trans. Am. Fish. Soc. 97: 57-59.

DICAPUA, R. A.

1966. On the application of immunological techniques in geographic group studies of Atlantic herring. I. Immunoelectrophoresis. J. Exp. Zool. 162: 1-13.

1969. On the application of immunological techniques in geographic group studies of Atlantic sea herring, C. harengus. II. Herring serum analysis by gel diffusion. J. Exp. Zool., Vol. 172, No. 1

DICKIE, L. M.

1971. Food chains and fish production in the Northwest Atlantic. ICNAF Environmental Symposium No. 10, pp. 201-219.

1972. Food chains and fish production. ICNAF Spec. Pub. No. 8, pp. 201-219.

DOLLFUS, R. P.

1956. Liste des parasites animaux du hareng de l'Atlantique Nord et de la Baltique. J. Cons. Perm. Int. Explor. Mer 22: 58-65.

DONALDSON, L., J. WARD, T. BARLOW, J. BROWN, T. WYER, AND J. ALLEN.

1837. Report of the Bay of Fundy deep-sea fisheries, prepared by the Commissioners appointed to inquire into the state of the herring fishery at Grand Manan. J. House of Assembly New Brunswick 1836-1837, App. No. 2, pp. 18-36.

DORNHEIM, H.

1975. Kein starker Jungheringsjahrgang auf der Georges Bank in Sicht Infn. Fischw. 22(3/4): 81-82.

1975. Mean weight at age of the 1970 year-class herring in ICNAF Div. 5Z. ICNAF Res. Doc. 75/114, Ser. No. 3607, 3 pp.

1978. Status of the herring stocks fished by the Federal Republic of Germany fleet. Mar. Fish. Rev. 40(4): 21-24.

DORNHEIM, H., T. D. ILES, AND M. D. GROSSLEIN.

1973. A preliminary report on the German young herring survey carried out by R/V Walther Herwig in ICNAF Subarea 5 and Statistical Area 6 in February-March 1973, with adenda 1 and 2. ICNAF Res. Doc. 73/84, Ser. No. 3036, addendum 1, 22 pp, addendum 2, 10 pp.

DOUBLEDAY, W. G.

1975. Environmental fluctuations and fisheries management. ICNAF Res. Doc. 75/9/134, Ser. No. 3687, 15 pp.

1975. Preliminary report on a sampling study of Subdivision 4Vn commercial herring landings for 1974. ICNAF Res. Doc. 75/36, Ser. No. 3515, 16 pp.

1976. Environmental fluctuations and fisheries management. ICNAF Selected Papers, No. I, pp. 141-150.

DOUCET, W. F.

1960. Economic study of the herring fishery of Charlotte County, New Brunswick, 1956-67. J. Fish. Res. Board Can. 17: 815-870.

DRAGANIK, B.

1966. Age, rate of growth and sexual maturity of herring captured on Georges Bank, 29 August-1 October 1965. ICNAF Ann. Meet. 1966, Res. Doc. 66/48, Ser. No. 1650.

DRAGANIK, B.

1973. Estimates of fishing mortality and stock size for Georges Bank herring. ICNAF Redbook 1973 (Part III), pp. 105-108.

DRAGANIK, B., AND B. RAST.

1970. The fecundity of Georges Bank herring. ICNAF Redbook 1970 (Part III), pp. 117-122.

DRAGANIK, B., AND C. ZUSKOWSKI.

1967. Further studies on herring caught on Georges Bank in November and December 1966. ICNAF Redbook 1967 (Part III), pp. 39-46.

DRAGESUND, O.

1968. On herring larvae of Norwegian spring spawners: effect of time and location of spawning on year-class strength in the period 1959-1965. Coun. Meet. ICES 1968(6), pp. 1-41.

DRAGESUND, O., AND O. NAKKEN.

1971. Mortality of herring during the early larval stage in 1967. Rapp. Proc.-v. ICES 160: 142-146.

DRAPEAU, G.

1973. Sedimentology of herring spawning grounds on Georges Bank. ICNAF Res. Bull. No. 10, pp. 151-162.

DUTT, S.

1958. Number of pectoral fin rays in the spring and autumn spawning herring in Kiel Bay. Rapp. P.-v. ICES 143: 109-113.

EARLL, R. E.

1887. The herring fishery and the sardine industry. In G. B. Goode, The fisheries and fishery industries of the United States, Sec. 5(1): 417-542.

1889. Notes on certain fishery industries of Eastport, Maine in 1886. Bull. U.S. Fish Commission 7: 267-274.

EARLL, R. E., AND H. M. SMITH.

1889. The American sardine industry in 1886. Bull. U.S. Fish Commission 7: 161-192.

EDWARDS, R. L.

1976. Middle Atlantic fisheries: Recent changes in population and outlook. Amer. Soc. Limnol. Oceanogr., Spec. Symp. 2, pp. 302-311.

EDWARDS, R. L., AND R. E. BOWMAN.

1978. An estimate of the food consumed by continental shelf fishes in the region between New Jersey and Nova Scotia. Northeast Fisheries Center, Woods Hole Laboratory, Woods Hole, Mass., U.S.A. (Unpublished MS). (Invited paper, presented at the symposium on predator-prey species in fish communities and their role in fisheries management, July 23-27, 1978, Atlanta, Georgia).

EINARSSON, H.

1951. Racial analysis of Icelandic herrings by means of otoliths. Rapp. P.-v. ICES 128(1), App., pp. 55-74.

EPPLEY, R. W.

1972. Temperature and phytoplankton growth in the sea. Fish. Bull., U.S. 70: 1063-1085.

FAO/ACMRR.

1974. The scientific advisory function in international fishery management and development bodies. Suppl. 1 to the report of the Seventh Session of the advisory Committee on Marine Resources Research, Rome, 17-24 Oct. 1973. FAO Fish. Rep. 142, Suppl. 1, 14 pp.

FISH, C. J., AND M. W. JOHNSON.

1937. The biology of the zooplankton population in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. J. Fish. Res. Board Can. 3: 189-322.

FISHER, R. A.

1963. Statistical methods for research workers. Thirteenth edition-revised. Hafner Pub. Co. Inc., New York. 356 pp.

FORD, E.

1933. An account of the herring investigation conducted at Plymouth during the years from 1924-1933. J. Mar. Biol. Ass. U.K. 19: 305-383.

FORD, E., AND H. O. BULL.

1926. Abnormal vertebrae in herring. J. Mar. Biol. Ass. U.K. 14: 509-517.

FOREST, A., AND D. BRIAND.

1975. Supplementary data on meristic characteristics of herring (Clupea harengus harengus L.) stocks in the southern part of the Gulf of St. Lawrence, the southern coast of Newfoundland and Banquereau Bank. ICNAF Res. Doc. 75/30, Ser. No. 3496, 13 pp.

FORRESTER, W. D.

1960. Current measurements in Passamaquoddy Bay and the Bay of Fundy 1957 and 1958. J. Fish. Res. Board Can. 17: 727-729.

FOX, W. W., JR.

1970. An exponential surplus-yield model for optimizing exploited fish populations. Trans. Amer. Fish. Soc. 99: 80-88.

FUGLISTER, F. C.

1947. Average monthly sea surface temperatures of the western North Atlantic ocean. Pap. phys. Oceanogr. 10(2): 25 pp.

FURTAK, A.

1973. Environmental conditions in the region of Georges Bank, Gulf of Maine, Nantucket Shoals, and the western part of the Nova Scotia Shelf, 2-28 October 1972. ICNAF Res. Doc. 73/21, 5 pp.

GALES, L. E.

1968. A preliminary report on a computer program to simulate the dynamics of a group of interrelated animal populations (GRSIM). Fish Analysis Center, Univ. of Washington, 16 pp. (mimeo).

GALKINA, L. A.

1971. Survival of spawn of the Pacific herring (*Clupea harengus pallasi*) related to the abundance of the spawning stock. Rapp. P.-v. ICES 160: 30-41.

GARROD, D. J.

1973. The variation of replacement and survival in some fish stocks. Rapp. P.-v. ICES 164: 43-56.

GAUTHIER, M.

1967. Infection of the herring by *Ichthyosporidium hoferi*. Nat. Can. 94(1): 159-160.

GIEDZ, M.

1978. Stages of maturity in gonads in herring from Georges Bank. ICNAF Res. Doc. 78/6/20, Ser. No. 5174.

GOODE, G. B.

1884. The herring tribe. The herring - Clupea harengus. In G. B. Goode and associates. The fisheries and fishery industries of the United States. Section I. Natural history of useful aquatic animals, pp. 549-568. Gov. Print. Off., Wash., D. C.

GRAHAM, J. J.

1970a. Temperature, salinity, and transparency observations, coastal Gulf of Maine, 1962-65. U.S. Fish Wildl. Serv., Data Rept. 42, 43 pp.

1970b. Coastal surveys of the Western Gulf of Maine. ICNAF Res. Bull. No. 7, pp. 19-31.

1972. Retention of larval herring within the Sheepscot estuary of Maine. U.S. Natl. Mar. Fish. Serv., Fish. Bull. 70: 299-305.

GRAHAM, J. J., AND H. C. BOYAR.

1965. Ecology of herring larvae in the coastal waters of Maine. ICNAF Spec. Pub. No. 6, pp. 625-634.

GRAHAM, J. J., AND S. B. CHENOWETH.

1971. Distribution and abundance of larval herring, Clupea harengus harengus Linnaeus, over egg beds on Georges Bank. ICNAF Res. Doc. 71/102, Ser. No. 2579, 6 p.

1973. Distribution and abundance of larval herring, Clupea harengus harengus Linnaeus, over egg beds on Georges Bank. ICNAF Res. Bull. No. 10, pp. 141-150.

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., U.S. 70: 307-321.

GRAHAM, J. J., AND C. W. DAVIS.

1971. Estimates of mortality and year-class strength of larval herring in western Maine, 1964-67. Rapp. P.-v. ICES 160: 147-152.

GRAHAM, J. J., C. W. DAVIS, AND B. C. BICKFORD.

1972. Autumnal distribution, abundance and dispersion of larval herring, Clupea harengus harengus Linnaeus, along the western coast of the Gulf of Maine in 1971. ICNAF Res. Doc. 72/7, Ser. No. 2690, 11 pp.

1973. Autumnal distribution, abundance and dispersion of larval herring along the western coast of the Gulf of Maine in 1972. ICNAF Res. Doc. 73/12, 33 pp.

GRAHAM, J. J., and P. M. W. Venno.

1968. Sampling larval herring from tidewaters with buoyed and anchored nets. J. Fish. Res. Board Can. 6: 1169-1179.

GRAHAM, M.

1935. Modern theory of exploiting a fishery and application to North Sea trawling. J. Cons. Perm. Int. Explor. Mer 10: 264-274.

1936. Investigations of the herring of Passamaquoddy and adjacent regions. J. Biol. Board Can. 2: 95-140.

1939. The sigmoid curve and the overfishing problem. Rapp. P.-v. ICES 110(2): 15-20.

1952. Overfishing and optimum fishing. Rapp. P.-v. ICES 132(1): 72-78.

GRAUMAN, G. B.

1973. Investigations of factors influencing fluctuations in abundance of Baltic cod. Rapp. Proc.-v. ICES 164: 73-76.

GRIMM, S. K.

1973. Preliminary results of Georges Bank-Gulf of Maine ICNAF larval herring cruise, Wieczno, 2-28 October, 1972. ICNAF Res. Doc. 73/16, Ser. No. 2918, 3 p.

1974. Larval herring distribution in the Gulf of Maine and on Georges Bank, 29 Sept.-20 Oct. 1973. ICNAF Res. Doc. 74/18, Ser. 3164, 4 p.

GRIMM, S. K., W. MASTO, AND M. PASTUSZAK.

1975. Report on larval herring distribution in the Gulf of Maine and on Georges Bank, 27 September-18 October 1974. ICNAF Res. Doc. 75/109, Ser. NO. 3602, 17 pp.

GROSSLEIN, M. D.

1969. Groundfish survey program of BCF Woods Hole. Commer. Fish. Rev. 31(8-9): 22-35.

1974. Bottom trawl survey methods of the Northeast Fisheries Center, Woods Hole, Massachusetts, U.S.A. ICNAF Res. Doc. 74-96, Ser. No. 3332, 27 pp.

GROSSLEIN, M. D., AND E. BOWMAN.

1973. Mixture of species in Subareas 5 and 6. ICNAF Redbook 1973, Part III, pp. 163-207.

GROSSLEIN, M. D., AND S. H. CLARK.

1976. Distribution of selected fish species and status of major fisheries in the Northwest Atlantic. Technical reference document for bilateral negotiations between USA and Canada. Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 76/12, 171 pp.

GROSSLEIN, M. D., R. W. LANGTON, AND M. P. SISSENWINE.

1978. Recent fluctuations in pelagic fish stocks of the Northwest Atlantic, Georges Bank region, in relationship to species interactions. ICES Sympos. on Biol. Basis of Pelagic Fish Stock Mgmt. Doc. No. 25, 52 pp.

GULLAND, J. A.

1955. Estimation of growth and mortality in commercially exploited fish populations. Fishery Invest. Lond., Ser. 2, 18(9): 46 pp.

1961. Fishing and the stocks of fish at Iceland. Min. Agr. Fish. and Food (G.B.). Fish. Invest. Lond., Ser. 2, 23(4): pp. 1-32.

1964. Manual of methods of fish population analysis. F.A.O. Fish. Tech. Pap. 40, 63 pp.

1965. Estimation of growth and mortality in commercial fish populations. Fishery Invest. Lond., Ser. 2, 18(9).

1969. Fishery management and the limitation of fishing. F.A.O. Fish. Tech. Pap. 92, 13 pp.

1971. Science and fishery management. J. Cons. Perm. Int. Explor. Mer 33(3): 411-477.

1977. Goals and objectives of fishery management. F.A.O. Fish. Tech. Pap. 166, 14 pp.

GULLAND, J. A., AND L. K. BOEREMA.

1973. Scientific advice on catch levels. Fish. Bull., U.S. 71: 325-335.

HACHEY, H. B., F. HERMANN, AND W. B. BAILEY.

1954. The waters of the ICNAF convention area. ICNAF Ann. Proc. 4, pp. 67-102.

HAIGHT, F. J.

1942. Coastal currents along the Atlantic Coast of the United States. U. S. Coast and Geodetic Sur. Spec. Pub. No. 230: 73 pp., 33 figs.

HALLIDAY, R. G., AND W. G. DOUBLEDAY.

1975. Catch and effort trends for the finfish resources of the Scotian Shelf and an estimate of the maximum sustainable yield of groundfish. ICNAF Res. Doc. 75/43, 19 pp.

HARDEN-JONES, F. R.

1968. Fish Migration. Edward Arnold Publ. Ltd., London.

HARDY, A., SIR.

1959. The Open Sea: II. Fish and Fisheries. Collins, (St. James Place), London, 322 pp.

HART, J. L.

1937-1946. The tagging of herring (Clupea pallasii) in British Columbia: methods, apparatus, insertions, and recoveries during 1936-37 and 1945-46. Rept. Fish. Dept. B. C. 1936-45, 1937-46.

1965. Reports on researches in the ICNAF area in 1964. B. Subareas 4 and 5. ICNAF Redbook 165, II: 20-35. Fish. Res. Board Studies No. 1024.

HART, J. L., AND A. L. TESTER.

1935. Quantitative studies on herring spawning. Trans. Am. Fish. Soc. 64: 307-312.

HART, J. L., AND D. J. MCKERNAN.

1960. International Passamaquoddy Fisheries Board fisheries investigations 1956-59. Introductory account. J. Fish. Res. Board Can. 17: 127-131.

HEMMINGS, C. C.

1965. Underwater observations on a patch of herring spawn. Scot. Fish. Bull. 23: 21-22.

HEMPEL, G.

1964. Die Filterleistung der Planktonröhre "Hai" bei verschiedener Schleppgeschwindigkeit. Helgol. Wiss. Meeresunters. 11: 161-167.

1965. On the importance of larval survival for the population dynamics of marine food fish. Calif. Coop. Oceanic Fish. Invest. Repts. 10: 13-23.

1971. Egg production and egg mortality in herring. Rapp. P.-v. ICES 160: 8-11.

HEMPEL, G. (ed.).

1978. North Sea fish stocks - recent changes and their causes. Rapp. P.-v. ICES 172, 449 p.

HEMPEL, G., AND J. H. S. BLAXTER.

1961a. On the condition of herring larvae. ICES Doc. CM1961/Herring Sympos. No. 34, 6 pp.

1961b. The experimental modification of meristic characters in herring (Clupea harengus L.). J. Cons. Perm. Int. Explor. Mer 26: 336-346.

HEMPEL, I., AND G. HEMPEL.

1971. An estimate of mortality in eggs of North Sea herring (Clupea harengus L.). Rapp. P.-v. ICES 160: 24-26.

HENNEMUTH, R. C.

1975. Earnest Haeckel joint cooperative herring work in Subarea 5. ICNAF Res. Doc. 75/47, Ser. No. 3526, 1 p.

HENTSCHEL, E.

1950. Die Nahrung der Heringslarven. Helgol. Wiss. Meeresunters. 3: 59-81.

HJORT, J.

1914. Fluctuations in the great fisheries of northern Europe. Rapp. Proc.-v. ICES 20: 1-228.

1926. Fluctuations in the year classes of important food fishes. J. Cons. Perm. Int. Explor. Mer 1: 5-38.

HODDER, V. M.

1966. Recent herring investigations in Newfoundland waters. (Proc. Canadian Atlantic Herring Conf., Fredericton, N. B., May 5-7, 1966). Can. Fish. Rep. No. 8, pp. 39-54.

1969. Herring landings and distribution of catches in Newfoundland 1967-68. Fish. Can. 22(4): 3-6.

1970. Recent developments in the Newfoundland herring fishery. Fish. Res. Board Can., St. John's Station Circ. No. 18: 1-19.

1971. Status of the southwest Newfoundland herring stocks, 1965-70. ICNAF Res. Doc. 71/121, Ser. 2619, 9 pp.

1972. The fecundity of herring in some parts of the Newfoundland area. ICNAF Res. Bull. No. 9, pp. 99-107.

1976. Status of southwest Newfoundland herring stocks, 1965-70. ICNAF Redbook 1971 (Part III), pp. 105-114.

HODDER, V. M., AND L. S. PARSONS.

1970. A comparative study of herring taken at Magdalen Islands and along southwestern Newfoundland during the 1969 autumn fishery. ICNAF Res. Doc. 71/77, Ser. 2425, 5 pp.

HODDER, V. M., AND L. S. PARSONS.

1971a. Comparison of certain biological characteristics of herring from Magdalen Islands and southwestern Newfoundland. ICNAF Res. Bull. No. 8, pp. 59-65.

1971b. Preliminary comparison of Scotian Shelf and southwest Newfoundland herring taken during the winter of 1971. ICNAF Res. Doc. 71/120, 8 pp.

1971c. Some biological features of southwest Newfoundland and northern Scotian Shelf herring stocks. ICNAF Res. Bull. No. 8, pp. 67-74.

HODDER, V. M., L. S. PARSONS, C. I. BARBOUR, AND R. CHAULK.

1972. Length, age and weight of herring in the southwest Newfoundland winter fishery from 1965-66 to 1970-71. Fish. Res. Board Can. Tech. Rept. 339, 113 pp.

HODDER, V. M., L. S. PARSONS, AND J. H. C. PIPPY.

1972. The occurrence and distribution of "red" herring in Placentia Bay, February-April 1969. _In_ Effect of elemental phosphorous on marine life. Fish. Res. Board Can., Atl. Reg. Circ. 2, pp. 45-52.

HODDER, V. M., L. S. PARSONS, G. H. WINTERS, AND K. SPENCER.

1973. Fat and water content of herring in Newfoundland and adjacent waters, 1966-71. Fish. Res. Board Can., Tech. Rept. 365, 49 pp.

HODDER, V. M., AND G. H. WINTERS.

1970. Preliminary results of herring tagging in southwest Newfoundland, March 1970. ICNAF Res. Doc. 71/89, Ser. No. 2440, 2 pp.

1972. Distribution and size of larval herring and capelin, southern Gulf of St. Lawrence and southern Newfoundland, November 1969 and 1970. Fish. Res. Board Can., Tech. Rept. 315, 25 pp.

HODGSON, W. C.

1925. Investigations into the age, length and maturity of the herring of the southern North Sea. Part 1 - Some observations on the scales and growth of the English herring. Fishery Invest. Lond., Ser. 2, 7(8): 36 pp.

1932. The forecasting of the East Anglian herring fishery. J. Anim. Ecol. 1: 108-118.

1933. Further experiments on the selective action of commercial drift nets. J. Cons. Perm. Int. Explor. Mer 8: 344-354.

1957. The herring and its fishery. Routledge and Kegan Paul, London, 197 pp.

1958. On the interpretation of the East Anglian herring data 1923-1955. J. Cons. Perm. Int. Explor. Mer 23: 381-389.

HOLLIDAY, F. G. T.

1960a. The control of maturation in the herring. ICES Doc. CM(38): 3 pp.

1960b. The control of spawning in the herring. ICES Doc. CM(39): 3 pp.

HOLLIDAY, F. G. T., AND J. H. S. BLAXTER.

1960. The effects of salinity on the developing eggs and larvae of the herring. J. Mar. Biol. Ass. U.K. 39: 591-603.

1961. The effects of salinity on herring after metamorphosis. J. Mar. Biol. Ass. U.K. 41: 37-48.

HOLLIDAY, F. G. T., J. H. S. BLAXTER, AND R. LASKER.

1964. Oxygen uptake of developing eggs and larvae of herring (Clupea harengus L.). J. Mar. Biol. Ass. U.K. 44: 711-723.

HOLT, S. J.

1965. A note on the relation between the mortality rate and the duration of life in an exploited fish population. ICNAF Res. Bull. 2, pp. 73-75.

HOLT, S. J., AND L. M. TALBOT (EDS.).

1978. New principles for the conservation of wild living resources. Wildl. Monogr. No. 59, 33 pp., Suppl., J. Wildl. Mgmt. 43(2).

HONEY, K. A., AND S. B. CHENOWETH.

1972. Preliminary results of Georges Bank-Gulf of Maine ICNAF larval herring cruise, Delaware II, 21 Sept.-4 Oct. 1971. ICNAF Res. Doc. 72/8, Ser. No. 2691, 8 p.

HOURSTON, A. S.

1963. The Newfoundland herring fishery and implications concerning the resource. ICNAF Redbook 1968 (Part III), pp. 67-73.

HOURSTON, A. S., AND R. CHAULK.

1968. Herring landings and catches in Newfoundland and their implications concerning the distribution and abundance of the stocks. Fish. Res. Board Can. Tech. Rept. 58, 77 p.

HOURSTON, A. S., R. CHAULK, S. PARSONS, AND J. A. THOMSON.

1968. Herring sampling data and summary tabulations for Newfoundland, 1967-78. Fish. Res. Board Can. Tech. Rept. 97, 9 p.

HOURSTON, A. S., AND L. S. PARSONS.

1969. Opaque and hyaline otolith nuclei as indicators of spring and autumn spawning herring in Newfoundland waters. Fish. Res. Board Can. Tech. Rept. 138, 26 pp.

HOWE, M. R.

1962. Some direct measurement of the non-tidal drift on the Continental Shelf between Cape Cod and Cape Hatteras. Deep-Sea Res. 9: 445-455.

HUBBS, C. L.

1925. Racial and seasonal variation in the Pacific herring. Calif. Fish Game 8: 1-23.

HUNT, J. J., L. S. PARSONS, J. E. WATSON, G. H. WINTERS.

1973. Report of the Herring Ageing Workshop. ICNAF Res. Doc. 73/2, Ser. No. 2901, 27 pp.

HUNTSMAN, A. G.

1919. Growth of the young herring (so-called sardines) of the Bay of Fundy. Can. Fish. Exped. 1914-1915, p. 165-171. Dept. Naval Science, Ottawa, 495 pp.

ICES.

1970. Report of the working group on Atlanto-scandian herring. ICES Coop. Res. Rept. Ser. A, 17, pp. 1-43.

1971. Report of the meeting of the working group on Atlanto-scandian herring. App. to Coop. Res. Rept. Ser. A, 17, pp. 1-24.

ICNAF.

1972a. Report of Standing Committee on Research and Statistics, May 1972. App. II. Report of the Herring Working Group. ICNAF Redbook 1972, Part I, pp. 45-66.

1972b. Proceedings of the 22nd annual meeting. Spec. meeting herring. Proc. No. 4, App. IV, 206 pp.

1973. Report of Standing Committee on Research and Statistics - January 1973. App. II. Report of Herring Working Group. ICNAF Redbook 1973, Part I, pp. 31-49.

1975. Report of Standing Committee on Research and Statistics - May-June 1975. App. I. Report of Assessments Subcommittee. ICNAF Redbook 1975, pp. 23-63.

1976a. Report of Assessment Subcommittee, April 1976. ICNAF Summ. Doc. 76/6/22, Ser. No. 3865, 53 pp.

1976b. Report of ad hoc working group on planning for international herring tagging program. ICNAF Redbook 1976, App. VI, pp. 153-156.

ILES, T. D.

1964. The duration of maturation stages in herring. J. Cons. Perm. Int. Explor. Mer 29: 166-183.

1965. Factors determining or limiting the physiological reaction of herring to environmental changes. ICNAF Spec. Publ. No. 6, pp. 735-741.

ILES, T. D.

1967. Growth studies on North Sea herring. I. The second year's growth (1-group) of East Anglian herring, 1939-63. J. Cons. Perm. Int. Explor. Mer 31: 56-76.

1968a. Growth studies on North Sea herring. II. 0-group growth of East Anglian herring. J. Cons. Perm. Int. Explor. Mer 32: 98-116.

1968b. Growth data for herring of the Southern Bight, derived by back calculation of scales. Ann. Biol. Copenh. 23: 168-171.

1968c. Growth data for herring of the Southern Bight, derived by back calculation of scales. The 1967 East Anglian samples. Ann. Biol. Copenh. 24: 168-170.

1970. Vertebral numbers of the Bay of Fundy herring and the origin of New Brunswick sardines. ICNAF Redbook 1970, Part III, pp. 148-152.

1971. The retention inside the Bay of Fundy of herring larvae spawned off the southwest coast of Nova Scotia. ICNAF Redbook 1971, Part III, pp. 93-103.

1972a. Landings and catches in the Canadian Bay of Fundy herring fisheries, 1963-1971. Fish. Res. Board Can., Biol. Sta. St. Andrews, N. B., Can.).

1972b. The seasonal and area distribution of herring spawning off the southwest Nova Scotia coast as indicated by logbook records. ICNAF Contribution No. 9, Assessments Subcommittee Mid-year Meeting, Canada, 25 pp.

ILES, T. D.

1972c. The interaction of environment and parent stock size in determining recruitment of the Pacific sardine as revealed by the analysis of density-dependent 0-group growth. Rapp. P.-v. ICES 164: 288-340.

ILES, T. D., AND D. S. MILLER.

1973. Monthly length-weight relationships for the herring of the Bay of Fundy (Sub-Division 4X). ICNAF Res. Doc. 73/92, Ser. No. 3050, 3 p.

ILES, T. D., AND S. N. TIBBO.

1970a. Change from the traditional fixed gear operation using weirs, traps and gill nets for food and bait herring to one dominated increasingly by highly mobile purse-seine (and very recent M.W.T.). ICNAF Res. Doc. 70/78, 14 pp.

ILES, T. D., AND S. N. TIBBO.

1970b. Recent events in Canadian Atlantic herring fisheries. ICNAF Redbook 1970, Part III, pp. 134-147.

INGHAM, M. C.

1974. Variations in the shelf water front off the Atlantic coast between Cape Hatteras and Georges Bank. NMFS Status of Environment, 1974. In Environment of the United States Living Marine Resources, 1974. J. R. Goulet (ed.), MARMAP Contribution No. 104, 367 pp.

INTERNATIONAL PASSAMAQUODDY FISHERIES BOARD.

1959. Passamaquoddy Fisheries Investigations, 1957-1958. U.S. Fish Wildl. Serv., Sci. Rept., Fish. No. 360, 40 pp.

ISELIN, C. O'C.

1940. Preliminary report on long-period variations in the transport of the Gulf Stream system. Pap. Phys. Oceanogr. 8(1): 40 pp.

1955. Coastal currents and the fisheries. Papers in Marine Biology and Fisheries. Supp. to Vol. 3 of Deep-Sea Res., pp. 474-478.

JEAN, Y.

1956. A study of spring- and fall-spawned herring (*Clupea harengus* L.) at Grande Rivière, Bay of Chaleur, Quebec. Dep. Fish. Quebec Contr. No. 49, 76 pp.

1967. A comparative study of herring (*Clupea harengus* L.) from the Estuary and the Gulf of St. Lawrence. Nature, Can. 94: 7-27.

JENSEN, A. J. C.

1939. On the laws of decrease in fish stocks. Rapp. P.-v. ICES 110: 85-108.

JOAKIMSSON, G.

1976. Report of larval herring catches from the cruises of R/V *Walther Herwig* and R/V *Anton Dohrn* in March 1973-1976. ICNAF Res. Doc. 76/6/79, Ser. No. 3891, 7 p.

JONES, F. R. H.

1968. Fish migration. Edward Arnold, London, 325 pp.

JONES, R., AND J. RICHARDS.

1976. Some observations of the interrelationships between the major fish species in the North Sea. ICES Doc. CM1976/F:35, 13 p.

JOSSELYN, J.

1675. An account of two voyages to New England. Second Addition. G. Widdowes, London (Repr. in Coll. Massachusetts Hist. Soc., 1933, 3rd. ser. 3, pp. 211-354).

KARAULOVSKY, V. P.

1975a. Biochemical oxygen consumption in the waters of the Northwest Atlantic. ICNAF Res. Doc. 75/81, Ser. No. 3508, 7 pp.

1975b. Hydrochemical conditions in Georges Bank area in the Summer-Autumn period, 1971-1973. ICNAF Res. Doc. 75/80, 15 pp.

KATTY, M. K., AND J. Z. QUASIM.

1968. The estimation of optimum age of exploitation and potential yield in fish populations. J. Cons. Perm. Int. Explor. Mer 32: 249-255.

KATZ, M.

1947. The fecundity of herring from various parts of the North Pacific. Trans. Am. Fish. Soc. 75: 72-76.

KEYS, A., E. CHRISTENSEN, A. KROGH.

1935. The organic metabolism of sea water with special reference to ultimate food cycle in the sea. J. Mar. Biol. Assoc. U.K. 20: 1-181.

KHALIL, L. F.

1969. Larval nematodes in the herring (Clupea harengus) from British coastal waters and adjacent territories. J. Mar. Biol. Assoc. U.K. 49: 641-659.

KHARITONOVA, O. A.

1966. The behaviour of Okhotsk feeding herring in relation to fishing techniques and tactics. Vsesojuznaya konferentzia pa voprosu izuchenia povedenia ryb v sviazi s tekhnikoi i taktikoi promysla. Murmansk.

KOHLER, A. C.

1968. Fish stocks of the Nova Scotia banks and the Gulf of St. Lawrence. Fish. Res. Board Can., Tech. Rept. 80, 25 pp.

KOHLER, A. C., D. G. FABER, AND N. J. MCFARLANE.

1974. Eggs, larvae and juveniles of fishes from plankton collections in the Gulf of St. Lawrence. Fish. Mar. Serv. Res. Div. Tech. Rept. 490, 105 pp.

1969. USSR research report, 1968. ICNAF Redbook 1969, Part II, pp. 99-117.

KONSTANTINOV, K. G., AND A. S. NOSKOV.

1975. USSR Research Report, 1974. ICNAF Fish. Summ. Doc. 75/30, 33 pp.

KREFFT, G.

1954. Die Zahl der Kiemreusenfortsätze als Hilfsmittel bei morphologischen Heringsuntersuchungen. Ber. Dtsch. Komm. Meeresforsch. 14: 298-309.

1958. Counting of gill rakers as a method of morphological herring investigations. Rapp. P.-v. ICES 143: 22-25.

KURATA, H.

1959. Preliminary report on the rearing of the herring larvae. Bull. Hokkaido Reg. Fish. Res. Lab. 20: 117-138.

LANHAM, P.

1976a. Polish pelagic trawl fisheries. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 65-66.

1976b. Federal Republic of Germany pelagic fisheries. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 67-68.

LARKIN, P. A.

1972. A confidential memorandum on fisheries science. In B. J. Rothschild (ed.), World Fisheries Policy, Multidisciplinary Views. Univ. of Washington Press, Seattle, 272 p.

LARKIN, P. A., AND W. E. RICKER.

1964. Further information on sustained yields from fluctuating environments. J. Fish. Res. Board Can. 21: 1-7.

LASKER, R.

1974. A link between food chain studies and fisheries research: a larval fish bioassay. ICES Doc. CM1974/H:10, 34 pp (5 p. of tables).

1975, Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. U.S. Dept. Int., Fish Wildl. Serv., Fish Bull. 73(3): 453-462.

LASSEN, H.

1971. Estimation of strength of year classes and of fishing efficiency based on environmental assumptions in a self-generating population model. ICES Doc. CM1971/H: 17, 11 p.

LAUZIER, L. M.

1965. Long-term temperature variations in the Scotian Shelf area. ICNAF Spec. Pub. No. 6, pp. 807-816.

LAUZIER, L. M.

1967. Bottom residual drift on the continental shelf area of the Canadian Atlantic coast. J. Fish. Res. Board Can. 24: 1845-1859.

LAUZIER, L. M., AND J. A. HULL.

1962. Sea temperature along the Canadian Atlantic coast, 1958-1960. Prog. Rept. Atlant. Cst. Stns. (73).

LAUZIER, L. M., AND S. N. TIBBO.

1964. Water temperature and the herring fishery of Magdalen Islands, Quebec. ICNAF Spec. Pub. No. 6, pp. 591-596.

LEA, E.

1911. Report on the international herring investigations during the year 1910. III. A study on the growth of herrings. Publs. Circonst. ICES 61: 35-57.

1919. Age and growth of herring in Canadian waters. Dept. Naval Serv., Can. Fish. Exped. 1914-1915, 126 pp.

1929. The herring's scale as a certificate of origin. Its applicability to race investigations. Rapp. P.-v. ICES 54: 21-34.

LEBOUR, M. V.

1921a. The larval and post-larval stages of the pilchard sprat and herring from the Plymouth District. J. Mar. Biol. Ass. U.K. 12: 427-457.

1921b. The food of young clupeoids. J. Mar. Biol. Ass. U.K. 12: 548-567.

1922. The food of plankton organisms. J. Mar. Biol. Ass. U.K. 12: 644-477.

LEBOUR, M. V.

1923. The food of plankton organisms. J. Mar. Biol. Ass. U.K. 13: 70-92.

LEE, R. M.

1912. An investigation into the methods of growth determination in fishes. Publs. Circonst. ICES 63: 34 pp.

LEGARE, J. E. H., AND D. C. MACLELLAN.

1960. A qualitative and quantitative study of the plankton of the Quoddy region in 1957 and 1958 with special reference to the food of the herring. J. Fish. Res. Board Can. 17: 409-448.

LEIM, A. H.

1955. Herring mortalities in the Bay of Chaleur in 1955. Fish. Res. Board Can., Prog. Rept. Atl. Coast Stat. 62, 32 pp.

1957a. Fatness of herring in Canadian Atlantic waters. Fish. Res. Board Can., Atl. Prog. Rept. No. 111, pp. 177-184.

1957b. Summary of results under the Atlantic Herring Investigation Committee. Bull. Fish. Res. Board Can. 111: 1-16.

LEIM, A. H., S. N. TIBBO, AND L. R. DAY.

1957. Explorations for herring in Canadian Atlantic waters, 1945-1950. Bull. Fish. Res. Board Can. 111: 35-83.

LESLIE, P. H.

1948. Some further notes on the use of matrices in population mathematics. Biometrika 35: 213-245.

LETT, P. F.

1976. A review of density-dependent and independent processes which may affect recruitment in herring stocks. ICNAF Res. Doc. 76/6/75, Ser. No. 3887, 20 p.

LETT, P. F., AND W. G. DOUBLEDAY.

1976. The influence of fluctuations in recruitment on fisheries management strategy, with special reference to southern Gulf of St. Lawrence cod. ICNAF Sel. Pap. No. 1, pp. 171-193.

LETT, P. F., AND A. C. KOHLER.

1974. Recruitment: a problem of multispecies interaction and environmental perturbations, with special reference to Gulf of St. Lawrence herring (*Clupea harengus harengus*). J. Fish. Res. Board Can. 33: 1353-1371.

LETT, P. F., AND A. C. KOHLER.

1976. Recruitment: a problem of multispecies interaction and environmental perturbation, with special reference to Gulf of St. Lawrence herring (*Clupea harengus* L.). ICNAF Res. Doc. 76/6/4, Ser. No. 3763, 40 pp.

LETT, P. F., A. C. KOHLER, AND D. N. FITZGERALD.

1975a. The influence of temperature on the interaction of the recruitment mechanisms of Atlantic herring and mackerel in the Gulf of St. Lawrence. ICNAF Res. Doc. 75/33, Ser. No. 3512, 16 pp.

1975b. Role of stock biomass and temperature in recruitment of southern Gulf of St. Lawrence Atlantic cod, *Gadus morhua*. J. Fish. Res. Board Can. 32: 1613-1627.

LETT, P. F., W. T. STOBO, AND W. G. DOUBLEDAY.

1975. A system simulation of the Atlantic mackerel fishery in ICNAF Subareas 3, 4, and 5 and Statistical Area 6; with special reference to stock management. ICNAF REs. Doc. 75/32, Ser. No. 3511, 16 pp.

L'HERROU, R., AND J. P. MINET.

1971. Environmental studies in ICNAF Div. 3P and 4V in spring 1970. ICNAF Res. Doc. 71/82, Ser. No. 2585, 13 p.

LEWIS, R. D., AND G. J. RIDGWAY.

1972. Biochemical studies on the stock structure of herring in the Gulf of Maine, Georges Bank and adjacent areas. ICNAF Res. Doc. 72/20, Ser. No. 2711, 15 pp.

LIE, U.

1961. Zooplankton in relation to herring in the Norwegian Sea, June 1959. Fiskeridirektoratets Skrifter Series Havundersokelser 13(1): 5-14.

LILLELUND, K., AND R. LASKER.

1971. Laboratory studies of predation by marine copepods on fish larvae. Fish. Bull., U.S. 69: 655-667.

LINDÉN, O.

1976. The influence of crude oil and mixtures of crude oil/dispersants on the ontogenic development of the Baltic herring, Clupea harengus membras L. Ambio 5(3): 136-140.

LINDSEY, J. K., D. F. ALDERDICE, AND L. V. PIENAAR.

1970. Analysis of nonlinear models -- the nonlinear response surface. J. Fish. Res. Board Can. 27: 765-791.

LINDSEY, J. K., AND A. M. SANDNES.

1970. Program for the analysis of nonlinear response surfaces (extended version). Fish. Res. Baord Can. 173: 131 pp.

LISIVNENKO, L. N.

1960. The influence of environmental factors on the Baltic herring survival. Trudy VNIRO, vol. 42: 142-166.

1961. The plankton and feeding of larval Baltic herring in the Riga Bay. Trudy SIIRHK SNKH, Latvian SSR, III, Acad. of Sciences of Latvian SSR, Riga, pp. 105-138.

LISSNER, H.

1925. Die Altersbestimmung beim Hering mit Hilfe der Otolithen. Ber. Deutsch. Wiss. Komm. Meeresforsch. N. F., 1(2): 184-198.

LIVINGSTONE, R., JR., AND P. HAMER.

1978. Age and length at first maturity of herring in the Georges Bank and Gulf of Maine stocks: An update. Northeast Fisheries Center, Woods Hole Laboratory (unpublished report), 8 pp.

LONGWELL, A. C.

1976. Chromosome mutagenesis in developing mackerel eggs sampled from the New York Bight. NOAA Tech. Memo ERL-MESA 7, 61 pp.

LOUGH, R. G.

1975a. U.S. Report of fall-winter 1974-75 larval herring cruises. ICNAF Res. Doc. 75/49, 28 pp.

1975b. A preliminary report of the vertical distribution of herring larvae on Georges Bank. ICNAF Res. Doc. 75/50, Ser. No. 3529, 9 pp.

LOUGH, R. G.

1976a. Analysis of various length measurements on larvae collected by the ICNAF larval herring surveys. ICNAF Res. Doc. 76/6/58, Ser. No. 3845, 6 pp.

1976b. The distribution and abundance, growth and mortality of Georges Bank-Nantucket Shoals herring larvae during the 1975-76 winter period. ICNAF Res. Doc. 75/6/123, Ser. No. 4004, 30 pp.

1976c. Mortality and growth of Georges Bank-Nantucket Shoals herring larvae during three winters. ICES Doc. CM1976/L:37, 9 pp.

1978. Larval herring studies in the Georges Bank-Gulf of Maine area. Georges Bank patch experiment, fall, 1978: a strategy for combining micro-mesoscale observations in larval fish studies. ICES 1978 Rept. Larval Fish Working Group, 9 pp.

LOUGH, R. G., G. R. BOLZ, M. D. GROSSLEIN, AND D. C. POTTER.

1978. Abundance of sea herring (Clupea harengus harengus L.) larvae in relation to spawning stock size and recruitment for the Georges Bank area, 1968-1977 seasons, and the role of various ecological factors affecting larval survival. Contribution to the 1979 ICES Sympos. Early Life History of Fish, 2 p.

LOUGH, R. G., AND M. D. GROSSLEIN.

1975. Winter mortality of Georges Bank herring larvae. ICNAF Res. Doc. 75/113, Ser. No. 3606, 39 pp.

LOUGH, R. G., T. L. M. MORRIS, JR., AND D. C. POTTER.

1975. U. S. Report of fall 1974 larval herring cruises. ICNAF Res. Doc. 75/49, Ser. No. 3628, 28 pp.

LUBIENIECKI, B.

1973. Note on the occurrence of larval *Anisakis* in adult herring and mackerel from Long Island to Chesapeake Bay. ICNAF Res. Bull. No. 10, pp. 79-82.

LUSH, I. E.

1969. Polymorphism of a phosphoglucomutase isoenzyme in the herring (*Clupea harengus*). Comp. Biochem. Physiol. 30: 391-395.

MACKAY, K. T.

1967. An ecological study of mackerel, *Scomber scombrus* (Linnaeus), in the coastal waters of Canada. Fish. Res. Board Can., Tech. Rept. 31, 127 pp.

1976. Synopsis of biological data on the northern population of Atlantic mackerel. Chapter I. *In* Analysis of the Bioenergetics of the northern population of Atlantic mackerel. Ph.D. Thesis, Dalhousie Univ., Halifax, 220 pp.

MARAK, R. R.

1960. Food habits of larval cod, haddock, and coalfish in the Gulf of Maine and Georges Bank area. J. Cons. Perm. Int. Explor. Mer 25: 147-157.

MARAK, R. R., AND J. B. COLTON, JR.

1962. Distribution of fish eggs and larvae, temperature and salinity in the Georges Bank-Gulf of Maine area 1953. U.S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 398: 61 pp.

MARAK, R. R., J. B. COLTON, JR., D. B. FOSTER, AND D. MILLER.

1962. Distribution of fish eggs and larvae, temperature and salinity in the Georges Bank-Gulf of Maine area, 1956. U.S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 412: 95 pp.

MARR, J. C.

1956. The "critical period" in the early life history of marine fishes. J. Cons. Perm. Int. Explor. Mer 21: 160-170.

1957. The problem of defining and recognizing subpopulations of fishes. _In_ Contribution to the study of subpopulations of fishes, pp. 1-6. U.S. Fish Wildl. Serv., Spec. Sci. Rept., Fish. No. 208: 129 pp.

MARTIN, J. H.

1968. Phytoplankton-zooplankton relationship in Narragansett Bay. III. Seasonal change in zooplankton excretion rate relative to phytoplankton abundance. Limnol. and Oceanogr. 13: 63-71.

MAURER, R.

1975. A preliminary description of some important feeding relationships. ICNAF Res. Doc. 75/9/130, Ser. No. 3681, 15 pp.

1976. A preliminary analysis of inter-specific trophic relationships between the sea herring, _Clupea harengus_ Linnaeus and the Atlantic mackerel, _Scomber scombrus_ Linnaeus. ICNAF Res. Doc. 76/6/121, Ser. No. 3967, 22 pp.

MAURER, R. O., AND R. E. BOWMAN.

1975. Food habits of marine fishes of the northwest Atlantic - data report. Northeast Fisheries Center, Woods Hole Laboratory, Lab. Ref. No. 75-3, 90 pp.

MAY, R. C.

1974. Larval mortality in marine fishes and the critical period concept. In J. H. S. Blaxter (ed.), The early life history of fish, pp. 3-19. Springer-Verlag, New York.

MCCARTHY, J. J.

1972. The uptake of urea by natural populations of marine phytoplankton. Limnol. and Oceanogr. 17: 738-748.

MCHUGH, J. L.

1942. Vertebral number of young herring in southern British Columbia. J. Fish. Res. Board Can. 5: 474-484.

MCKENZIE, R. A.

1950. A new celluloid opercular tag. Trans. Am. Fish. Soc. 78: 114-116.

1964. Observations on herring spawning off southwest Nova Scotia. J. Fish. Res. Board Can. 21: 203-205.

MCKENZIE, R. A., AND B. E. SKUD.

1958. Herring migrations in the Passamaquoddy region. J. Fish. Res. Board Can. 15: 1329-1343.

MCKENZIE, R. A., AND S. N. TIBBO.

1960. Herring fishery in southern New Brunswick. J. Fish. Res. Board Can. 17: 169-173.

1961. Herring movements in the Bay of Fundy and Gulf of Maine, 1957 and 1958. J. Fish. Res. Board Can. 18: 221-252.

MCNAIRN, N. A.

1933. Herring races of the Bay of Fundy. Fish. Res. Board Can., Ann. Rept. 1932, p. 29.

MEFFT, G.

1958. Counting of gill rakers as a method of morphological herring investigations. In Contributions to special herring meetings 1966 on herrings "races". Rapp. P.-v. ICES 148(2): 22-25.

MENZEL, D. W., AND J. H. RYTHER.

1964. The composition of particulate organic matter in the western North Atlantic. Limn. Oceanog. 9(2).

MESSIEH, S. N.

1969. Similarity of otolith nuclei in spring- and autumn-spawning Atlantic herring in the southern Gulf of St. Lawrence. J. Fish. Res. Board Can. 26: 1889-1898.

1970. Immature herring populations in the Bay of Fundy. ICNAF Res. Bull. No. 7, pp. 59-66.

1973. Biological characteristics of spring and autumn herring populations in the Gulf of St. Lawrence and their interrelations. Ph.D. Thesis, McGill Univ., Montreal, Quebec, 190 pp.

1974a. Growth of the otoliths of young herring (*Clupea harengus harengus* L.) in the Bay of Fundy (ICNAF Div. 4X). ICNAF Res. Doc. 74/60, Ser. No. 3244, 7 p.

1974b. The structure of herring populations on the Atlantic coast of Cape Breton Island, ICNAF Div. 4Vn and Division 4Wa. ICNAF Res. Doc. 74/62, 14 pp.

1974c. Problems of ageing Atlantic herring (*Clupea harengus harengus* L.) in the ICNAF Area. ICNAF Res. Doc. 74/59, Ser. No. 3273, 6 p.

MESSIEH, S. N.

1975. Delineating spring and autumn herring populations in the southern Gulf of St. Lawrence by discriminant function analysis. J. Fish. Res. Board Can. 32: 471-477.

1976. Fecundity studies on Atlantic herring from the southern Gulf of St. Lawrence and along the Nova Scotia coast. Trans. Am. Fish. Soc. 105(3): 384-394.

MESSIEH, S. N., C. D. BURNETT, AND S. N. TIBBO.

1968. Length and age structure of herring stocks in the Bay of Fundy (Division 4X). ICNAF Ann. Meet. 1968, Res. Doc. 68/68, Ser. No. 2055.

1968. Length, age distribution, Bay of Fundy herring. Fish. Res. Board Can., Tech. Rept. No. 57, pp. 1-64.

MESSIEH, S. N., AND S. N. TIBBO.

1971. Discreteness of Atlantic herring (Clupea harengus harengus) populations in spring and autumn fisheries in the southern Gulf of St. Lawrence. J. Fish. Res. Board Can. 28: 1009-1014.

MESSIEH, S. N., S. N. TIBBO, AND L. M. LAUZIER.

1971. Distribution, abundance, and growth of larval herring (Clupea harengus L.) in Bay of Fundy-Gulf of Maine areas. Fish. Res. Board Can., Tech. Rept. No. 277, 23 pp.

MEYER, T. L., R. A. COOPER, AND R. W. LANGTON.

1978. Observations on the relative abundance, behavior, and food habits of the American sand lance, Ammodytes americanus DeKay (1842) from the Gulf of Maine. Northeast Fisheries Center, Woods Hole Laboratory, Woods Hole, Mass. (Unpublished MS).

MILLER, D. S.

1977. ICNAF Division 5Y herring and ICNAF Division 5Z and Statistical Area 6 herring stock assessments. CAFSAC Res. Doc. 77/6, 7 pp.

MILLER, D. S., AND R. G. HALLIDAY.

1974. An assessment of the Div. 4XW(b) herring stock. ICNAF Res. Doc. 74/13, 38 pp.

MILLER, D. S., AND W. T. STOBO.

1977. Herring assessment in ICNAF Div. 4WX. CAFSAC Res. Doc. 77/11, 6 pp.

MILROY, T. H.

1908. Changes in the chemical composition of the herring during the reproductive period. Biochem. J. 3: 366-390.

MINET, I. P., G. PAULMIER, AND J. C. POULARD.

1974. Distribution of larval herring on Georges Bank and off southern Nova Scotia, September 1973. ICNAF Res. Doc. 74/57, Ser. No. 3270, 18 p.

MØLLER, D.

1971. Concepts used in the biochemical and serological identification of fish stocks. Rapp. P.-v. ICES 161: 7-9.

MOORE, H. F.

1898. Observations of the herring and herring fisheries of the northeast coast, with special reference to the vicinity of Passamaquoddy Bay. Rep. U.S. Fish. Comm. 22: 387-442.

MOORES, J. A., G. H. WINTERS, AND L. R. PARSONS.

1975. Migrations and biological characteristics of Atlantic mackerel (Scomber scombrus) occurring in Newfoundland waters. J. Fish. Res. Board Can. 32: 1347-1357.

MOTUDA, S., AND Y. HIRANO.

1963. Review of Japanese herring investigations. Rapp. P.-v. ICES 154: 249-261.

MURPHY, G. I.

1965. A solution of the catch equation. J. Fish. Res. Board Can. 22: 191-202.

1966. Population biology of the Pacific sardine (Sardinops caerulea). Proc. Ca. Acad. Sci. 34(1): 1-84.

1967. Vital statistics of the Pacific sardine (Sardinops caerulea) and the population consequences. Ecology 48: 731-736.

1973. Clupeoid fishes under exploitation with special reference to the Peruvian anchovy. Hawaii Inst. of Marine Biology, Tech. Rept. No. 30, pp. 1-73.

MUZINIC, R., AND B. B. PARRISH.

1960. Some observations on the body proportions of North Sea autumn spawning herring. J. Cons. Perm. Int. Explor. Mer 25: 191-203.

NAEVDAL, G.

1969. Studies on serum esterase in herring and sprat. Fish. Dir. Skr. Ser. Havundersøk 15: 83-90.

1971. Distribution of multiple forms of lactate dehydrogenase, aspartate aminotransferase and serum esterase in herring from Norwegian waters. Rapp. P.-v. ICES 161: 1 p.

NAEVDAL, G., AND D. S. DANIELSEN.

1967. A preliminary report on studies of esterase phenotypes in herring. ICES CM1967/H:24, 6 pp.

NAEVDAL, G., AND G. S. HARALSDVIK.

1966. A preliminary report on electrophoretic studies on herring serum proteins. ICES Doc. CM1966/H: 24, 8 pp.

NAGASAKI, F.

1958. The fecundity of Pacific herring (Clupea pallasi) in British Columbia coastal waters. J. Fish. Res. Board Can. 15: 313-330.

NAKAI, Z.

1960. Changes in the population and catch of the Far East sardine area. In Rosa, H. and G. Murphy (eds.), Proc. World Sci. Meeting on the biology of sardines and related species, 3, pp. 807-853.

NEW ENGLAND REGIONAL FISHERY MANAGEMENT COUNCIL (NERFMC).

1978. Draft environmental impact statement/fishery management plan for the Atlantic herring fishery of the Northwestern Atlantic, April, 1978, 371 pp.

NIKOLAEV, V. M.

1979. Herring stocks in 1978 -- Introduction to Annales Biologiques. Vol. 35 (for 1978). ICES Doc. CM1979/H:35, 4 pp.

NIKOLSKY, G. V.

1969. Theory of the fish population dynamics as a biological background for rational exploitation and management of fishery resources. Oliver and Boyd, London, 382 pp.

NOSKOV, A. S.

1956. On determination of condition factor in the fishes. Trudy Balt. NIRO 2: 90-94.

NOSKOV, A. S., A. L. NOVIKOV, AND A. N. ROMANCHENKO.

1977. Results of distribution and abundance survey of herring larvae in the Georges Bank area in September-October 1975. ICNAF Res. Doc. 77/6/43, Ser. No. 5068, 14 p.

NOSKOV, A. S., V. I. RIKHTER, AND V. A. ISAKOV.

1976. A brief description of the Soviet herring, mackerel, silver hake and red hake fisheries in ICNAF Subarea 5 and Statistical Area 6. ICNAF Res. Doc. 76/12/167, Ser. No. 4063, 5 p.

NOSKOV, A. S., V. I. VINOGRADOV, AND L. G. PTITSINA.

1978. The studies on the feeding habits of larval herring (Clupea harengus) in the Georges Bank area, 1965-1975. ICNAF Res. Doc. 78/6/73, Ser. No. 5244, 14 pp.

NOSKOV, A. S., AND V. N. ZINKEVICH.

1967. Abundance and mortality of herring, Clupea harengus Linnaeus, on Georges Bank according to the results of egg calculation in spawning areas in 1964-66. ICNAF Res. Doc. 67/98, Ser. No. 1897, 16 pp.

NOSKOV, A. S., AND V. N. ZINKEVICH.

1970. The numbers of herring (Clupea harengus L.) and their mortality on Georges Bank according to results of egg counts on the spawning ground from 1964-1966. Trans. Atl. Res. Inst. Fish Oceanogr. 28: 135-146.

NOSKOV, A. S., V. I. VINOGRADOV, AND L. G. PTITSINA.

1978. The studies on the feeding habits of larval herring (Clupea harengus) in the Georges Bank area, 1965-1975. ICNAF Res. Doc. 78/6/73, Ser. No. 5244, 14 pp.

ODENSE, P. H., T. M. ALLEN, AND T. C. LEUNG.

1966a. Multiple forms of lactate dehydrogenase and aspartate aminotransferase in herring (Clupea harengus harengus L.). Can. J. Biochem. Physiol. 44: 1319-1326.

ODENSE, P. H., T. M. ALLEN, AND T. C. LEUNG.
1966b. The distribution of multiple forms of lactate dehydrogenase and aspartate aminotransferase in samples of two Canadian herring populations. ICES Doc. CM1966/H:19, 7 pp.

ODENSE, P. H., AND T. M. ALLEN.
1971. A biochemical comparison of some Atlantic herring populations. Rapp. P.-v. ICES 161, 1 p.

ODENSE, P. H., T. C. LEUNG, AND C. AMAND.
1973. Isozyme systems of some Atlantic herring populations. ICES Doc. 1973/H:21, 13 pp.

OLSEN, S.
1959. Mesh selection in herring gill nets. J. Fish. Res. Board Can. 16: 339-349.

OLSON, F. C. W.
1964. The survival value of fish schooling. J. Cons. Perm. Int. Explor. Mer 29(1): 115-116.

ØSTVEDT, O. J.
1964. Growth and maturation of the Norwegian herring. ICES Doc. CM1964/141, 8 pp.

PACIORKOWSKI, A., AND M. GIEDZ.
1975. Polish observations on the course of Georges Bank herring spawning in relation to catch per tow, 1972-1974. ICNAF Res. Doc. 75/37, Ser. No. 3516, 6 pp.

PAKHORUKOV, V. I., A. T. WILSON, AND I. K. BENKO.
1964. The condition for herring fishery on Georges Bank. Trudy PINRO, No. 15, Murmansk.

PANKRATOV, A. M., I. K. SIGAJEV.

1973. Studies on Georges Bank herring spawning in 1970. ICNAF Res. Bull. No. 10, pp. 125-129.

PARKER, R. P., AND P. A. LARKIN.

1959. A concept of growth in fishes. J. Fish. Res. Board Can. 16: 721-745.

PARRISH, B. B.

1962. Problems concerning the population dynamics of the Atlantic herring (Clupea harengus L.) with special reference to the North Sea, p. 3-28. In LeCren, E. D. and M. W. Holdgate, eds. The exploitation of natural animal populations. Blackwell Sc. Publ., Oxford.

1964. Notes on the identification of sub-populations of fish by serological and biochemical methods, the status of techniques and problems of their future application. FAO Fish. Tech. Pap. 30, pp. 1-9.

PARRISH, B. B. (ed.).

1973. Fish stocks and recruitment. Proc. of a symposium held in Aarhus 7-10 July 1970. Rapp. P.-v. ICES 164: 1-372.

PARRISH, B. B., J. H. S. BLAXTER, AND F. G. T. HOLLIDAY.

1958. Herring (Clupea harengus L.) in aquaria. I. Establishment. Mar. Res. Scot. 1958, No. 5.

PARRISH, B. B., AND G. MCPHERSON.

1963. Notes on external tagging methods in European herring research. ICNAF Spec. Pub. 4, pp. 336-341.

PARRISH, B. B., A. SAVILLE, R. E. CRAIG, I. G. BAXTER, AND R. PRIESTLEY.

1959. Observations on herring spawning and larval distribution on the Firth of Clyde in 1958. J. Mar. Biol. Assoc. U.K. 38: 445-453.

PARRISH, B. B., AND A. SAVILLE.

1965. The biology of Northeast Atlantic herring populations. Oceanogr. Mar. Biol. Ann. Rev. 3: 323-373.

PARRISH, B. B., AND A. SAVILLE.

1967. Changes in the fisheries of North Sea and Atlanto-Scandian herring stocks and their causes. Oceanog. Mar. Biology Ann. Rev. 5: 409-447.

PARRISH, B. B., AND D. P. SHARMAN.

1958. Some remarks on methods used in herring "racial" investigations with special reference to otolith studies. Rapp. P.-v. ICES 143(II(1): 66-80.

PARRISH, J. P.

1975. Marine trophic interactions by dynamic simulation of fish species. Fish. Bull., U. S. 73: 695-716.

PARRISH, J. P., AND S. B. SAILA.

1970. Interspecific competition, predation and species diversity. J. Theor. Biol. 27: 207-220.

PARRY, G., F. G. T. HOLLIDAY, AND J. H. S. BLAXTER.

1959. Chloride-secretory cells in the gills of teleosts. Nature 183: 1248-1249.

PARSONS, L. S.

1970. Herring investigations in northeast Newfoundland and Labrador. Fish. Res. Board Can., Biol. Sta. St. John's, Newfoundland, Circ. 18: 25-28.

PARSONS, L. S.

1972a. Meristic characteristics of Atlantic herring (*Clupea harengus harengus* L.) stocks in Newfoundland and adjacent waters. ICNAF Res. Doc. No. 72/37, Ser. No. 2790, 33 pp.

1972b. Use of meristic characters and a discriminant function for classifying spring and autumn-spawning Atlantic herring. ICNAF Res. Bull. No. 9, pp. 5-9.

1975. Morphometric variation in Atlantic herring from Newfoundland and adjacent waters. ICNAF Res. Bull. No. 11, pp. 73-92.

PARSONS, L. S., AND V. M. HODDER.

1971a. Meristic differences between spring- and autumn-spawning Atlantic herring (*Clupea harengus* L.) from southwestern Newfoundland. J. Fish. Res. Board Can. 28: 553-558.

1971b. Variation in the incidence of larval nematodes in herring from Canadian Atlantic waters. ICNAF Res. Bull. No. 8, pp. 5-14.

1972. Offshore herring survey of the Nova Scotia banks, *J. B. Nickerson*, March 1971. Fish. Res. Board Can., Tech. Rept. 291, 22 pp.

1973. Biology of the southwest herring stocks 1965-71. ICNAF Res. Doc. 73/29, Ser. No. 2962, 15 pp.

1975. Biological characteristics of southwest Newfoundland herring, 1965-71. ICNAF Res. Bull. No. 11, pp. 145-160.

PARSONS, L. S., AND G. H. WINTERS.

1972. ICNAF Herring Otolith Exchange 1971-72. ICNAF Res. Doc. 72/92, Ser. No. 2816, 23 pp.

PATTEN, B. C.

1971. Systems analysis and simulation in ecology. Vol. 1. Academic Press, New York, 607 p.

PAULIK, G. J.

1973. Studies of the possible form of the stock-recruitment curve. Rapp. P.-v. ICES 164: 302-315.

PAULIK, G. J., AND W. H. BAYLIFF.

1967. A generalized computer program for the Ricker model of equilibrium yield per recruit. J. Fish. Res. Board Can. 24.

PAULMIER, G., AND D. BRIAND.

1975. Environment and distribution of herring larvae on Georges Bank and the Nova Scotia Shelf in September 1974. ICNAF Res. Doc. 75/71, Ser. No. 3555, 22 pp.

PAULMIER, G., AND P. DECAMPS.

1975. Environment and distribution of herring larvae on Georges Bank and the Nova Scotia Shelf in September 1974. ICNAF Res. Doc. 75/71, Ser. No. 3555, 22 pp.

PAVSHTICS, Y. A.

1963. Distribution of plankton and summer feeding of herring in the Norwegian Sea and on Georges Bank. ICNAF Spec. Pub. No. 6, pp. 583-590.

PAVSHTICS, Y. A., AND M. A. GOGOLEVA.

1964. Distribution of plankton on Georges and Browns Banks in 1962. Trudy PINRO, No. 16, Moscow.

PELLA, J. J., AND P. K. TOMLINSON.

1969. A generalized stock production model. Inter-Amer. Trop. Tuna Comm. Bull. 13(3): 419-496.

PERKINS, F. E.

1968. Age, length and maturity of adult herring in Subareas 4 and 5, 1967. ICNAF Ann. Meet. 1968, Res. Doc. 68/35, Ser. No. 2012, 6 p.

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. ICNAF Redbook 1969, Part III: 33-38.

PERLEY, M. H.

1850. Report on the sea and river fish-ries of New Brunswick within the Gulf of St. Lawrence or Bay of Chaleur. J. Simpson, Frederickton, N. B.: 137 pp.

PEUVION, A.

1966. Winter herring fishing on the south coast of Newfoundland. Proc. Can. Atl. Herring Fishery Conference, May 1966: 73-82.

PIPPY, J. H. C., V. M. HODDER, AND L. S. PARSONS.

1972. Symptoms of "red" herring in relation to mass mortalities in Placentia Bay, February-April 1969. In Effects of elemental phosphorous on marine life. Fish. Res. Board Can., Atl. Reg. Circ. 2: 187-191.

PLUNKETT, M. A., AND N. RAKESTRAW.

1955. Dissolved organic matter in the sea. Deep-Sea Res., Supp. to Vol. 3.

POKROVSKAYA, I. S.

1955. The feeding of larval herring off the southwest coast of Sakhalin. TINRO Proc., vol. 43: 202-204.

PONTECORVO, G., AND L. W. SCATTERGOOD.

1963. Economic surveys of the U.S. fisheries in the Passamaquoddy Region, 1956-57. U.S. Fish and Wildl. Serv., Spec. Sci. Rept., Fish. No. 473: 14 pp.

POPE, J. A., AND W. B. HALL.

1970. A statistical analysis of morphometric characters in the Buchan and Kobbergrund herring. ICES Doc. CM1970/H:32, 7 p.

POPE, J. A., AND B. B. PARRISH.

1964. The importance of fishing power studies in abundance estimation. Rapp. P.-v. ICES 155: 81-89.

POPE, J. G.

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

1976. The effect of biological interactions on the theory of mixed fisheries. ICNAF, Sel. Pap. 1: 157-162.

POPE, J. G., AND O. C. HARRIS.

1975. The South African pilchard and anchovy stock complex - an example of the effects of biological interactions between species on management strategy. ICNAF, 7th Spec. Comm. Mtg., Res. Doc. 75/9/133, Ser. No. 3685, 7 p.

POPIEL, J.

1955. Z biologii sledzi baltyckich. Prace Morsk. Inst. Ryb. w. Gdyni 8: 5-68.

POSTUMA, K. H.

1971. The effect of temperature in the spawning nursery areas on recruitment of autumn spawning herring in the North Sea. Rapp. P.-v. ICES 160: 175-183.

POSTUMA, K. H., J. J. ZIJLSTRA, AND N. DAS.

1965. On the immature herring of the North Sea. J. Cons. Perm. Int. Explor. Mer 29: 256-276.

POSTUMA, K. H., AND J. J. ZIJLSTRA.

1974. Larval abundance in relation to stock size, spawning potential and recruitment in North Sea herring. In J. H. S. Blaxter (ed.), Early life history of fish, pp. 113-128. Springer-Verlag, New York.

RAMEY, C. W., AND W. P. WICKETT.

1973. Empirical relations between physical factors in coastal waters and herring population sizes. Fish. Res. Board Can., Tech. Rept. No. 381: 55 pp.

RECKSIEK, C. W., AND J. P. MCCLEAVE.

1973. Distribution of pelagic fishes in the Sheepscot River-Back River Estuary, Wiscasset, Maine. Trans. Amer. Fish. Soc. 102(3): 541-551.

REDFIELD, A. C., AND A. BEALE.

1940. Factors determining the distribution of chaetognaths in the Gulf of Maine. Biol. Bull., Woods Hole 79(3): 459-487.

RENO, P. W., M. PHILIPPON-FRIED, B. L. NICHOLSON, AND S. W. SHELBURNE.

1978. Ultrastructural studies of piscine erythrocytic necrosis of herring (*Clupea harengus harengus*). J. Fish. Res. Board Can. 35: 148-154.

RICHARDSON, S. W.

1976. Mixed species schooling of postlarvae of Ammodytes herapterus and Clupea harengus harengus. J. Fish. Res. Board Can. 33: 843-844.

RICKER, W. E.

1954. Stock and recruitment. J. Fish. Res. Board Can. 11(5): 559-623.

1958a. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can., Bull. 119: 1-300.

1958b. Maximum sustained yields from fluctuating environments and mixed stocks. J. Fish. Res. Board Can. 15(5): 991-1006.

RIDGWAY, G. J.

1971. Problems in the application of serological methods to population studies on fish. Rapp. P.-v. ICES 161: 10-14.

1975. A conceptual model of stocks of herring (Clupea harengus) in the Gulf of Maine. ICNAF Res. Doc. 75/100, Ser. No. 3586, 17 pp.

RIDGWAY, G. J., D. AU, H. C. BOYAR, J. B. COLTON, J. J. GRAHAM, R. R. MARAK, D. MILLER, AND D. SCHNACK.

1972. Working group on joint survey of larval herring in the Georges Bank-Gulf of Maine areas (ICNAF Subareas 4X, 5Y and 5Z). ICNAF Res. Doc. 72/123, Ser. No. 2852, 39 pp.

RIDGWAY, G. J., R. D. LEWIS, AND S. W. SHERBURNE.

1971. Serological and biochemical studies of herring populations in the Gulf of Maine. Rapp. P.-v. ICES 161: 21-25.

RIDGWAY, G. J., S. W. SHERBURNE, AND R. D. LEWIS.

1970. Polymorphism in the esterases of Atlantic herring. In Symposium on cytogenetics of fishes. Trans. Am. Fish. Soc. 99: 147-151.

RILEY, G. A.

1941. Plankton studies. IV. Georges Bank. Bull. Bingham Oceanogr. Coll. 7(4): 1-73.

1946. Factors controlling phytoplankton populations on Georges Bank. J. Mar. Res. 6: 54-73.

1947. A theoretical analysis of the zooplankton population on Georges Bank. J. Mar. Res. 6: 104-113.

1963. Theory of food-chain relations in the ocean. In M. N. Hill (ed.), The Sea, Vol. II, pp. 438-463. John Wiley and Sons, New York.

RILEY, G. A., AND D. F. BUMPUS.

1946. Phytoplankton-zooplankton relationships on Georges Bank. J. Mar. Res. 6(2): 54-73.

ROBSON, D. A., AND D. G. CHAPMAN.

1961. Catch curves and mortality rates. Trans. Am. Fish. Soc. 90: 181-189.

RODEWALD, M.

1973. Sea-surface temperatures of the North Atlantic ocean during the decade 1951-60, their anomaly and development in relation to atmospheric circulation. WMO-UNESCO Rome Symposium, Changes in climate. UNESCO, Paris, pp. 97-107.

ROEDEL, P. M.

Optimum sustainable yield as a concept in fishery management. Spec. Publ. Am. Fish. Soc. 9, 89 pp.

ROSENTHAL, H.

1967. Parasites in larvae of the herring (Clupea harengus L.) fed with wild plankton. Marine Biol. 1: 10-15.

1968. Swimming behavior and speed of herring larvae, Clupea harengus. Helgol. Wiss. Meeresunters. 18: 453-486.

1971. Wirkungen von "Rotschlamm" auf Embryonen und Larven des Herings Clupea harengus. Helgol. Wiss. Meeresunters. 22: 366-376.

ROSENTHAL, H., AND D. F. ALDERDICE.

1976. Sublethal effects of environmental stressors, natural and pollutional, on marine fish eggs and larvae. J. Fish. Res. Board Can. 33: 2047-2065.

ROSENTHAL, H., AND R. STELZER.

1970. Wirkungen von 2,4- und 2,5-Dinotrophenol auf die Embryonalentwicklung des Herings Clupea harengus. Mar. Biol. 5: 325-336.

ROSENTHAL, H., H. VON WESTERNHAGEN, AND V. DETHLEFSEN.

1975. Cadmium uptake by marine fish larvae. ICES Doc. CM75/E:30, 13 pp.

ROUNSEFELL, G. A.

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

ROUNSEFELL, G. A., AND E. H. DAHLGREN.

1932. Fluctuations in the supply of herring (Clupea pallasii) in Prince William Sound, Alaska. Fish. Bull, U.S. 47: 263-291.

ROYCE, W. F.

1957. Statistical comparisons of morphological data. pp. 7-28. In Marr, J. C. (ed.), Contributions to the study of subpopulations of fishes. Spec. Sci. Rept. U.S. Fish Wildl. Serv., Fish. No. 208, 129 p.

RUNNESTRØM, S.

1941. Quantitative investigations of herring spawning and its yearly fluctuations on the west coast of Norway. Fish. Dir. Skr. Ser. Havundersøk 6(8): 71 pp.

RUSSEL-HUNTER, W. D.

1970. Aquatic Productivity. MacMillan Co., London, 306 pp.

SABINE, L.

1853. Report on the principal fisheries of the American seas. Robert Armstrong, Washington, 316 pp.

SAILA, S. B., AND J. P. PARRISH.

1972. Exploitation effects upon interspecific relationships in marine ecosystems. Fish. Bull., U.S. 70: 383-393.

SAMEOTO, D. D.

1971. The distribution of herring (Clupea harengus L.) larvae along the southern coast of Nova Scotia with some observations on the ecology of herring larvae and the biomass of macrozooplankton on the Scotian Shelf. Fish. Res. Board Can., Tech. Rept. No. 252.

1972. Distribution of herring (Clupea harengus) larvae along the southern coast of Nova Scotia with observations on growth and condition factor. J. Fish. Res. Board Can. 29: 507-515.

SAMUEL, A. M.

1918. The herring; its effect on the history of Britain. J. Murray, London, 199 pp.

SAMYSHEV, E. Z., AND L. G. PTITSINA.

1976. The feeding of larval herring, silver and red hakes in the Georges Bank area. Trudy Atlant NIRO, iss. 60, pp. 138-142.

SANDERS, H. L.

1952. The herring (Clupea harengus) of Block Island Sound. Bull. Bingham Oceanogr. Coll. 13: 220-237.

SANGALANG, G. B., B. TRUSCOTT, AND D. R. IDLER.

1972. A comparison of steroidogenesis in vitro in two teleosts, the marine herring Clupea and the freshwater Atlantic salmon Salmo. J. Endocr. 53: 433-446.

SAVAGE, R. E., AND W. C. HODGSON.

1934. Lunar influence on the East Anglian herring fishery. J. Cons. Perm. Int. Explor. Mer 9: 223-239.

SAVAGE, R. E., AND R. S. WIMPENNY.

1936. Phytoplankton and the herring. Part II. 1933 and 1934. Ministry of Agriculture and Fishery Investigations, Series II, Vol. 15(1): 1-88.

SAVILLE, A.

1964. Estimation of the abundance of a fish stock from egg and larval surveys. Rapp. P.-v. ICES 155: 164-170.

1971. The larval stage. In Symposium on the biology of early stages and recruitment mechanisms of herring. Rapp. P.-v. ICES 160, Section 2: 52-55.

SAVILLE, A., I. G. BAXTER, AND D. W. MCKAY.

1974. Relations between egg production, larval production and spawning stock size in Clyde herring. In J. H. S. Blaxter (ed.), Early life history of fish, pp. 129-138. Springer-Verlag, New York.

SCATTERGOOD, L. W.

1949. The production and the fishing methods of the Maine herring industry with notes on the 1947 season. U.S. Dept. Int., Fish Wildl. Serv., Spec. Sci. Rept. 67, 26 pp.

1952. The maturity of the Maine herring (Clupea harengus). Maine Dept. Sea and Shore Fish. No. 7: 2-11.

SCATTERGOOD, L. W., AND L. J. LOZIER.

1965. Herring fishery of the U.S. Passamaquoddy region. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish. 476, 21 pp.

SCATTERGOOD, L. W., C. J. SINDERMANN, AND B. E. SKUD.

1959. Spawning of North American herring. Trans. Am. Fish. Soc. 88: 164-168.

SCATTERGOOD, L. W., AND S. N. TIBBO.

1959. The herring fishery of the Northwest Atlantic. Fish. Res. Board Can. Bull. No. 121, 42 pp.

SCATTERGOOD, L. W., AND P. S. TREFETHEN.

1952. A statistical summary of the Maine herring fishery in 1948 and 1949. Maine Dept. Sea and Shore Fish. Res. Bull. 5: 62 pp.

SCHAAF, W. E., AND G. R. HUNTSMAN.

1972. Effects of fishing on the Atlantic menhaden stock, 1955-1969. Trans. Am. Fish. Soc. 101: 290-301.

SCHAEFER, M. B.

1954. Some aspects of the dynamics important to the management of the commercial marine species. Int. Am. Trop. Tuna Comm. Bull. 1(2): 26-56.

1967. Dynamics of the fishery for the anchoveta Engraulis ringens, off Peru. Bull. Inst. del Mar del Peru 1(5): 191-203.

SCHAEFER, M. B., AND R. J. H. BEVERTON.

1963. Fishery dynamics - their analysis and interpretation. In Hill, M. N. (ed.), The sea, Vol. 2, pp. 464-483. Interscience Publishers, New York.

SCHEFFE, H.

1959. The analysis of variance. John Wiley and Sons, New York, 477 pp.

SCHLITZ, R.

1975. A preliminary summary of hydrographic data collected on ICNAF larval herring surveys, 1971-1973. ICNAF Res. Doc. 75/111, Ser. No. 3604, 29 pp.

SCHNACK, D.

1972. Nahrungsökologische Untersuchungen an Heringslarven. Ber. Deut. Wiss. Komm. Meeresforsch. N.F. 22(3): 273-343.

1974a. On the biology of herring larvae in the Schlei Fjord, Western Baltic. Rapp. P.-v. ICES 166: 114-123.

1974b. Summary report on the 1973 ICNAF joint larval herring survey in Georges Bank-Gulf of Maine areas. ICNAF Res. Doc. 74/105, 23 pp.

1975. Summary of the ICNAF joint larval herring survey in Georges Bank-Gulf of Maine areas, September-December 1974. ICNAF Res. Doc. 75/112, Ser. No. 3605, 23 pp.

SCHNACK, D., AND G. HEMPEL.

1971. Notes on sampling herring larvae by Gulf III samplers. Rapp. P.-v. ICES 160: 56-59.

SCHNACK, D., E. JOAKIMSSON, AND J. E. KRETZLER.

1973. Preliminary results of ICNAF larval herring cruise, Anton Dohrn, 30 October-13 November 1972 in Georges Bank and Gulf of Maine area. ICNAF Res. Doc. 73/19, 9 pp.

SCHNACK, D., AND G. JOAKIMSSON.

1975. Report of the ICNAF larval herring cruise, Anthon Dohrn, November 1974, in Georges Bank-Gulf of Maine areas. ICNAF Res. Doc. 75/67, Ser. No. 3551, 15 pp.

SCHNACK, D., G. JOAKIMSSON, AND J. NEUMAN.

1974. Report of ICNAF larval herring cruise, Walther Herwig, October-November 1973 in Georges Bank-Gulf of Maine areas. ICNAF Res. Doc. 74/16, Ser. No. 3162.

1978. Some physical oceanographic features relevant to larval herring distribution on Georges Bank. ICNAF Res. Doc. 78/6/79, Ser. No. 5266.

Schnack, D., and W. T. Stobo.

1973. ICNAF joint larval herring survey in Georges Bank-Gulf of Maine areas in 1972 - preliminary summary. ICNAF Res. Doc. 73/115, Ser. No. 3081, 55 pp.

SCHNACKENBECK, W.

1927. Rassenuntersuchungen am Hering. Ber. Deut. Wiss. Komm. Meeresforsch. N.F. 3, pp. 91-205.

SCHULTZ, H.

1974. The fecundity of Georges Bank herring in 1971. ICNAF Res. Doc. 74/119, Ser. No. 3372, 8 pp.

SCHUMACHER, A., AND H. DORNHEIM.

1971. Estimation of fishing mortality in the Georges Bank herring stock. ICNAF Res. Doc. 71/126, Ser. No. 2625, 6 pp.

SCHUMACHER, A., AND V. C. ANTHONY.

1972. Georges Bank (ICNAF Div. 5Z and Subarea 6) herring assessment. ICNAF Res. Doc. 72/24, 38 pp.

SCOTT, J. S.

1968. Morphometrics, distribution, growth, and maturity of offshore sand lance (A. dubius) on the Nova Scotia banks. J. Fish. Res. Board Can. 25: 1775-1785.

1972a. Eggs and larvae of northern sand lance (Ammodytes dubius) from the Scotian Shelf. J. Fish. Res. Board Can. 29: 1667-1671.

1972b. Morphological and meristic variation in northwest Atlantic sand lance (Ammodytes). J. Fish. Res. Board Can. 29: 1673-1678.

SEARS, M.

1941. Notes on the phytoplankton of Georges Bank in 1940. J. Mar. Res. 4: 247-257.

SELIVERSTOV, A. S.

1974. Vertical migrations of larvae of the Atlanto-Scandian herring (Clupea harengus L.). In J. H. S. Blaxter (ed.), The early life history of fish, pp. 253-262. Springer-Verlag, New York.

SETTE, O. E.

1943. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 1. Early life history, including growth, drift, and mortality of the egg and larvae populations. U.S. Fish Wildl. Serv., Fish. Bull. 50: 149-237.

SETTE, O. E.

1950. Biology of the Atlantic mackerel (Scomber scombrus) of North America. Part 2. Migrations and habits. U.S. Fish Wildl. Serv., Fish. Bull. 51: 251-358.

SHERBURNE, S. W.

1973. Erythrocyte degeneration in the Atlantic herring, Clupea harengus harengus L. Fish. Bull., U.S. 71: 125-134.

SHERMAN, K.

1965. Seasonal and areal distribution of Maine coastal zooplankton 1963. ICNAF Spec. Publ. No. 6, pp. 611-624.

1966. Copepods of Gulf of Maine coastal waters. Maine Field Naturalist 22, pp. 94-97.

1966. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1964. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish. No. 530, 11 pp.

1968. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1965 and 1966. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish. No. 562, 11 p.

1970. Seasonal and areal distribution of zooplankton in coastal waters of the Gulf of Maine, 1967 and 1968. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish. No. 594, 8 pp.

1971. Seasonal variations in the food of larval herring in coastal waters of central Maine. J. Cons. Perm. Int. Explor. Mer 160: 121-124.

1976. Density distribution of copepods in coastal feeding grounds on herring. ICNAF Res. Doc. 76/6/82, Ser. No. 3894, 41 pp.

SHERMAN, K., J. B. COLTON, JR., J. M. ST. ONGE-BURNS, AND E. HOWARD.

1976. Areal variations in zooplankton volumes on the northeast continental shelf in spring and autumn 1973. ICNAF Res. Doc. 76/6/83, Ser. No. 3895, 6 pp.

SHERMAN, K., AND K. A. HONEY.

1971. Seasonal variations in the food of larval herring in coastal waters of central Maine. Rapp. P.-v. ICES 160: 121-124.

SHERMAN, K., AND H. C. PERKINS.

1971. Seasonal variations in the food of juvenile herring in coastal waters of Maine. Trans. Am. Fish. Soc. 100: 121-124.

SHKINDER, V. K.

1963. Some results of hydrobiological observations made on Georges Bank from 1960 to 1961. Trudy Atlant. NIRO No. 10. Kaliningrad.

SHULMAN, S. S.

1956. Parasite fauna of Clupea harengus, Osmerus eperlanus, and Eleginus navaga in the White Sea. Tr. Karelo-Finsk. fil. AN SSR 4 (cited by Dogiel et al. 1958).

SIGAJEV, I. K.

1974. Characteristic features of the hydrological conditions on the Nova Scotia Shelf and Georges Bank, 1972. ICNAF Res. Doc. 74/51, 14 pp.

SIJLSTRA, J. J., AND J. J. W. POLDER.

1959. Fecundity in the North Sea herring. ICES Doc. CM1959(84), 10 pp.

SILLIMAN, R. P., AND F. N. CLARKE.

1945. Catch per-unit-effort in California waters of the sardine (Sardinops caerulea) 1932-1942. Calif. Div. Fish and Game, Fish. Bull. 62: 76 pp.

SILLIMAN, R. P., AND J. S. GUTSELL.

1958. Experimental exploitation of fish populations. U.S. Fish Wildl. Serv., Fish. Bull. 133.

SIMONARSON, B., AND D. C. WATTS.
1971. Muscle esterase and protein variation in stocks of herring from Blackwater, Dunmore and Ballantrae. Rapp. V.-v. ICES 161: 27-31.

SINDERMANN, C. J.
1954. Disease of fishes of the western North Atlantic. III. Mortalities of sea herring (Clupea harengus) caused by larval trematode invasion. Maine Dept. Sea and Shore Fish., Res. Bull. 21, 16 pp.

1956. Diseases of fishes of the western North Atlantic. IV. Fungus disease and resultant mortalities of herring in the Gulf of St. Lawrence in 1955. Maine Dept. Sea and Shore Fish., Res. Bull. 25, 23 pp.

1957a. Diseases of fishes of the western North Atlantic. V. Parasites as indicators of herring movements. Maine Dept. Sea and Shore Fish., Res. Bull. 2-, 30 pp.

1957b. Diseases of fishes of the western North Atlantic. VI. Geographic discontinuity of myxosporidiosis in immature herring from the Gulf of Maine. Maine Dept. Sea and Shore Fish., Res. Bull. 29, 20 pp.

1958. An epizootic in Gulf of St. Lawrence fishes. Trans. N. Am. Wildl. Conf. 23, pp. 349-360.

1959. Population studies of herring using parasitological and serological methods. Int. Pass. Fish. Bd., Rept. Int. Joint Comm. 4: 1-15.

1961. Parasitological tags for redfish of the western North Atlantic. Rapp. P.-v. ICES 150: 111-117.

1962. Serology of Atlantic clupeoid fishes. Am. Nat. 96: 225-231.

SINDERMANN, C. J.

1963. Disease in marine populations. Trans. N. Am. Wildl. Conf. 28, pp. 221-245.

1963. Use of plant haemagglutinins in serological studies of clupeoid fish. Fish Wildl. Serv., Fish. Bull. 63: 137-141.

1964a. Effects of environment on several diseases of herring from the western North Atlantic. ICNAF Spec. Pub. No. 6, pp. 603-610.

1964b. Immunogenetic and biochemical approaches to the identification of marine subpopulations. Proc. Symp. Expl. Mar. Ecol., Occ. Publ. No. 2, Grad. Sch. Oceanogr., Univ. R.I. 33-38(2): 33-38.

1970. Principal diseases of marine fish and shellfish. Acad. Press, NY.

SINDERMANN, C. J., AND A. E. FARRIN.

1962. Ecological studies of Cryptocotyle lingua (Trematoda: Heterophidae) whose larvae cause "pigment spots" of marine fish. Ecology 43: 69-75.

SINDERMANN, C. J., AND D. F. MAIRS.

1959. A major blood group system in Atlantic sea herring. Copeia 1959(3): 228-232.

1961. A blood group system for spiny dogfish, Squalus acanthias. Biol. Bull., Woods Hole 120(3): 401-410.

SINDERMANN, C. J., AND A. ROSENFIELD.

1954. Diseases of fishes of the western North Atlantic. I. Diseases of the sea herring (Clupea harengus). Maine Dept. Sea and Shore Fish., Res. Bull. 18, 23 pp.

SINDERMANN, C. J., AND L. W. SCATTERGOOD.

1954. Diseases of fishes of the western North Atlantic. II. Ichthyosporidium disease of the sea herring (Clupea harengus). Maine Dept. Sea and Shore Fish., Res. Bull. 19, 40 pp.

SISSENWINE, M. P.

1976. Description of the ecosystem. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 1-3.

SISSENWINE, M. P., B. E. BROWN, AND J. BRENNAN-HOSKINS.

1978. Brief history and state of the art of fish production models and some applications to fisheries off the northeastern United States. Proc. Climate and Fisheries Workshop, Univ. R.I., March 1978, 48 pp.

SISSENWINE, M. P., AND G. T. WARING.

1978. Analysis of sea herring fisheries of the Northwest Atlantic from Cape Hatteras to southwest Nova Scotia. ICES Doc. CM1978/H:56, 28 pp.

SKUD, B. E.

1964. Herring and the environment in the ICNAF area. ICNAF Spec. Pub. No. 6, pp. 15-18.

1970. Management of North American herring stocks, pp. 195-207. In N. G. Benson (ed.), A century of fisheries in North America. Spec. Publ. No. 7, Am. Fish. Soc., 330 p.

SLOBODKIN, L. B.

1962. Growth and regulation of animal populations. Holt, Rinehart and Winston, New York, 184 p.

SMITH, J.

1624. The general history of Virginia, New-England, and the Summer Isles with the names of the Adventurers, Planters and Governours from their first beginning An: 1584 to this present 1624. I.D. and I.H. for Michael Sparkes, London, viii + 248 pp.

SMITH, J. V. C.

1833. Natural history of the fishes of Massachusetts embracing a practical essay on angling. Allen and Ticknor, Boston: vii and 399 pp.

SMITH, K.

1963. Exploratory fishing for Maine herring. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish. No. 463, 9 pp.

SMITH, P. E.

1973. The mortality and dispersal of sardine eggs and larvae. Rapp. P.-v. ICES 164: 282-292.

SMITH, W. G., AND L. SULLIVAN.

1978. Annual changes in the distribution and abundance of sand lance, *Ammodytes* spp., on the northeastern continental shelf of the U.S. from the Gulf of Maine to Cape Hatteras. Northeast Fisheries Center, Sandy Hook Laboratory, Sandy Hook, N.J., Lab. Ref. No. SHL-78-22, 14 pp.

SNEDECOR, G. W.

1956. Statistical methods (fifth ed.). Iowa State College Press, 534 pp.

SPEIRS, G. D.

1977. Herring tagging in western Gulf of Maine. ICNAF Res. Doc. 77/6/50, 26 pp.

SPRAGUE, L. M., AND A. M. VROOMAN.

1962. A racial analysis of the Pacific sardine (*Sardinops caerulea*) based on studies of erythrocyte antigens. Ann. N.Y. Acad. Sci. 97, pp. 131-138.

SOLDAT, V. T.

1976. Distribution of herring from the Nova Scotia Shelf. ICNAF Res. Doc. 76/1/1, 13 pp.

STANDER, G. H., AND P. J. LEROUX.

1968. Notes on fluctuations of the commercial catch of the South African pilchard (Sardinops ocellata), 1950-1965. Rept. of S.A. Div. Sea Fish. Inv., Rept. No. 65: 1-14.

STEARNS, F.

1965. Sea-surface temperature anomaly study of records from Atlantic coast stations. J. Geophys. Res. 70: 283-296.

STEEMAN-NIELSON, E.

1960. Productivity of the oceans. Ann. Rev. Plant Physiol. 11: 341-362.

STELZER, R., H. ROSENTHAL, AND D. SIEBERS.

1971. Einfluss von 2,4 Dinitrophenol auf die Atmung und die Konzentration einiger Metabolite bei Embryonen des Herings Clupea harengus. Mar. Biol. 11: 396-378.

STEVENSON, J. C.

1955. The movement of herring in British Columbia waters as determined by tagging. Rapp. P.-v. ICES 140: 33-34.

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

STEWART, H. B., AND G. F. JORDAN.

1964. Underwater sand ridges on Georges Shoals. In Papers in Marine Geology, pp. 102-114. Macmillan Co., New York, 531 pp.

STICKNEY. A. P.

1959. Ecology of the Sheepscot River estuary. U.S. Fish Wildl. Serv., Spec. Sci. Rept.-Fish No. 309, 21 pp.

STICKNEY, A. P.

1967. Aquarium susceptibility of tagged and untagged Atlantic herring to predation. Trans. Am. Fish. Soc. 96(3): 359-361.

1969. Orientation of juvenile Atlantic herring (Clupea harengus L.) to temperature and salinity. In Proc. of the FAO Conf. on fish behavior in relation to fishing techniques and tactics. FAO Fisheries Reports No. 62(2): 323-342.

1972. The locomotor activity of juvenile herring (Clupea harengus harengus L.) in response to changes in illumination. Ecology 53: 438-445.

STOBO, W. T.

1974. The Canadian 4VWa herring fishery: analysis of the 1973-74 catch, and the distribution of fishing activity and catch per unit effort from 1971-74. ICNAF Res. Doc. 74/95, 17 pp.

1975. The 1974-75 Canadian Cape Breton (4VWa) herring fishery. ICNAF Res. Doc. 75/39, Ser. No. 3513, 12 pp.

1976a. Canadian herring fishery in Division 4V. ICNAF Res. Doc. 76/6/22, 2 pp.

1976b. Movements of herring tagged in the Bay of Fundy - update. ICNAF Res. Doc. 76/6/48, Ser. No. 3834, 16 pp.

1976c. Some techniques and procedures used to tag herring in ICNAF Subarea 4. ICNAF REs. Doc. 76/6/101, Ser. No. 3924, 12 pp.

STOBO, W. T., J. J. HUNT, AND T. D. ILES.

1973. A preliminary report on the herring fishery in ICNAF Divisions 4V and 4Wa. ICNAF Res. Doc. 73/94, Ser. No. 3052, 20 pp.

STOBO, W. T., AND T. D. ILES.

1973. Larval herring distribution in the Bay of Fundy. ICNAF Res. Doc. 73/93, Ser. No. 3051, 9 pp.

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, Ser. No. 3517, 24 pp.

STOMMEL, H.

1958. The Gulf Stream: a physical and dynamical description. U. Calif. Press, Berkeley and Los Angeles, 200 pp.

STORER, D. H.

1839. A report on the fishes of Massachusetts. Boston J. Nat. Hist. 2(3-4): 289-558.

STRUHSAKER, J., M. B. ELDRIDGE, AND T. ESCHEVERRIA.

1974. Effects of benzene (a water-soluble component of crude oil) on eggs and larvae of Pacific herring and northern anchovy. In Vernberg, J. and W. Vernberg (eds.), Pollution and physiology of marine organisms, pp. 253-284. Acad. Press, New York.

STRZYZEWSKI, W.

1961. Preliminary note on the herring trawl selectivity. Experiments carried out in summer 1961. ICES CM1961/142, 3 p.

STUDENETSKY, S. A.

1969. Present stock condition and some problems of regulation of the Atlantic herring fishery. ICNAF Ann. Meet. 1969, Res. Doc. 69/91, Ser. No. 2257, 12 p.

TÅNING, Å. V.

1952. Experimental study of meristic characters in fishes. Biol. Rev. (Cambridge) 27: 169-193.

TAYLOR, C. C.

1962. Growth equation with metabolic parameters. J. Cons. Perm. Int. Explor. Mer 27: 270-286.

TAYLOR, C. C., H. B. BIGELOW, AND H. W. GRAHAM.

1957. Climatic trends and the distribution of marine animals in New England. U.S. Fish Wildl. Serv., Fish. Bull. 57: 293-345.

TESTER, A. L.

1937. Populations of herring (Clupea pallasi) in the coastal waters of British Columbia. J. Biol. Board Can. 3: 108-144.

1938. Variation in the mean vertebral count of herring (Clupea pallasi) with water temperature. J. Cons. Perm. Int. Explor. Mer 15: 71-75.

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.

THEILACKER, G. H., AND R. LASKER.

1974. Laboratory studies of predation by euphasiid shrimps on fish larvae. In J. H. S. Blaxter (ed.), The early life history of fish, pp. 287-299. Springer-Verlag, New York.

TIBBO, S. N.

1956. Populations of herring (Clupea harengus L.) in Newfoundland waters. J. Fish. Res. Board Can. 13: 449-466.

TIBBO, S. N.

1957a. Herring populations on the south and west coasts of Newfoundland. Bull. Fish. Res. Board Can. 111: 153-164.

1957b. Contribution to the biology of herring (Clupea harengus L.) on the Atlantic coast of Nova Scotia. Fish. Res. Board Can., Atl. Prog. Rept. No. 111: 139-151.

1957c. Herring of the Chaleur Bay area. Bull. Fish. Res. Board Can. 111: 85-102.

1964. Effect of light on movements of herring in the Bay of Fundy. ICNAF Spec. Pub. No. 6, pp. 579-582.

1966. The Canadian Atlantic herring fishery. (Proc. Canadian Atlantic Herring Fishery Conf., Fredericton, N.B., May 5-7, 1966). Can. Fish. Rept. No. 8, pp. 7-16.

1968a. On the origin of herring stocks in the Bay of Fundy, A review. Paper presented at the symposiun on the biology of early stages and recruitment mechanisms of herring. ICES Doc. CM1968/31, 9 pp.

1968b. Herring otolith exchange 1967. ICNAF Res. Doc. 68/60, Ser. No. 2043, 7 pp.

1969. ICNAF scale and otolith exchange program 1968-1969. ICNAF Res. Doc. 69/29, 3 pp.

1970a. ICNAF scale and otolith exchange program 1969-70. ICNAF Res. Doc. 70/55, Ser. No. 2389, 7 pp.

1970b. Herring - the 'golden goose' of the sea. Fish. Res. Board Can., Biol. Sta., St. Andrews, N.B., Gen. Ser. Circ. No. 55, April, 1970, 5 pp.

TIBBO, S. N., AND V. M. BRAWN.

1960. Explorations for herring in the Bay of Fundy and Gulf of Maine. J. Fish. Res. Board Can. 17: 735-737.

TIBBO, S. N., AND T. R. GRAHAM.

1963. Biological -changes in herring stocks following an epizootic. J. Fish. Res. Board Can. 20: 435-449.

TIBBO, S. N., AND L. M. LAUZIER.

1968. Abnormal water temperatures affect herring fisheries. Fish. Can. 20(7): 7-9.

1970. Seasonal distribution of larval herring in the Bay of Fundy and Gulf of Maine. ICNAF Res. Doc. 70/52, Ser. No. 2388, 6 pp.

TIBBO, S. N., AND J. E. H. LEGARE.

1960. Further study of larval herring (Clupea harengus L.) in the Bay of Fundy and Gulf of Maine. J. Fish. Res. Board Can. 17: 933-942

TIBBO, S. N., AND R. A. MCKENZIE.

1963. Review of literature on herring in the Canadian Atlantic. ICNAF Res. Doc. 63/45, 36 pp.

TIBBO, S. N., J. E. H. LEGARE, 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 Gulf of Maine. J. Fish. Res. Board Can. 15: 1451-1469.

TIBBO, S. N., S. N. MESSIEH, AND C. D. BURNETT.

1969. Catch statistics, length and age composition Gulf of St. Lawrence herring. Fish. Res. Board Can., Tech. Rept. No. 139, pp. 85-102.

TIBBO, S. N., D. J. SCARRATT, AND P. W. G. MCMULLON

1963. An investigation of herring (Clupea harengus L.) spawning using free-diving techniques. J. Fish. Res. Board Can. 20: 1067-1079.

TIBBO, S. N., AND E. G. SOLLOWS.

1953. Drift-net fishing for herring, 1950 to 1952. Rept. Fish. Res. Board Can. 505, 27 pp.

TRITES, R. W.

1961. Probable effects of proposed Passamaquoddy power projects on oceanographic conditions. J. Fish. Res. Board Can. 18: 163-201.

1962. Temperature and salinity in the Quoddy Region, Bay of Fundy. J. Fish. Res. Board Can. 19: 975-978.

TRITES, R. W., AND D. G. MACGREGOR.

1962. Flow of water in the passage of Passamaquoddy Bay measured by the electromagnetic method. J. Fish. Res. Board Can. 19: 395-919.

TRUVELLER, C. A.

1971. A study of blood groups in herring (Clupea harengus L.) from the North Sea in connection with the problem of race differentiation. Rapp. P.-v. ICES 161: 33-39.

UCHUPI, E.

1968. The Atlantic continental shelf and slope of the United States - Physiography. U. S. Geol. Survey, Prof. Papers, 529-C, 30 pp.

U. S. DEPT. COMMERCE.

1977. Preliminary fishery management plan. Atlantic herring fishery of the Northwestern Atlantic. Federal Register, Feb. 22, 1977, Part 6: 10496-10538.

U. S. DEPT. COMMERCE, NATIONAL MARINE FISHERIES SERVICE, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION.

1977. Public hearing on Atlantic herring, Peabody, Mass., April 19, 1977.

VIALOV, Y. A., AND B. E. KARASEV.

1967. Physico-geographical review and characteristic of fishing resources in the Northwest Atlantic. Rybolovstvo v Severo-Zapadnoi Atlantike. Kaliningrad.

VILSON, A. P.

1966. Size and age characteristics of Atlantic herring of Georges Bank and Banquereau in 1959-1962. Trudy PINRO 17: 293-301. From Ref. Zh. Biol. 1967, No. 5154 Trans.

VON BRANDT, A.

1962. Selectivity of herring in midwater-trawls. ICES Doc. CM1962/75.

VON WESTERNHAGEN, H., AND H. ROSENTHAL.

1979. Laboratory and _in situ_ studies on larval development and swimming performance of Pacific herring _Clupea harengus pallasi_. ICES Sympos. Early life history of fish, Doc. 1: 4, 22 p.

VOVK, A. N.

1972. Feeding habits of the North American squid, _Loligo pealei_ Les. Tr. Atl. Nauchno-I-sled. Inst. Rybn. Khoz. Okeanogr. 42: 141-151. (Translation Canada. Fisheries and Marine Services No. 3304).

WALFORD, L. A.

1946. New graphic method of describing the growth of animals. Biol. Bull., Woods Hole 90: 141-147.

WALKER, R.

1971. PEN, a viral lesion of fish erythrocytes. (Abstr.) Am. Zool. 11: 707.

WALTER, G. G.

1975. Graphical methods for estimating parameters in simple models of fisheries. J. Fish. Res. Board Can. 32: 2163-2168.

1976. Non-equilibrium regulation of fisheries. ICNAF, Sel. Pap. 1, pp. 129-140.

WANG, DER-HSIUNG, J. B. DIRLAM, AND V. J. NORTON.

1977. An econometric study of the Atlantic herring industry. Research Report submitted to NMFS, 1977.

WARE, D. M.

1975a. Growth, metabolism, and optimal swimming speed of a pelagic fish. J. Fish. Res. Board Can. 32: 33-41.

1975b. The relation between egg size, growth and natural mortality of larval fishes. J. Fish. Res. Board Can. 32: 2503-2512.

WARING, G. W.

1976a. U.S. juvenile herring fishery. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 42-48.

1976b. U.S.A. Div. 5Y adult herring fishery. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 43-44.

1976c. Canadian 5Y adult herring fishery. In ICNAF Res. Doc. 76/6/102, Ser. No. 3925, pp. 59-60.

1976d. USSR purse seine. In ICNAF Res. Doc. 76/6/102, Ser. No. 3025, pp. 63-64.

WATSON, E. E.

1936. Mixing and residual currents in tidal waters as illustrated in the Bay of Fundy. J. Fish. Res. Board Can. 2: 141-208.

WATSON, J. E.

1963. A method for tagging immature herring. U.S. Dept. Int., Fish Wildl. Serv., Spec. Sci. Rept.-Fish. No. 451, 7 pp.

1965. A technique for mounting and storing herring otoliths. Trans. Am. Fish. Soc. 94: 267-268.

WEIGHTS, D.

1973. Optimal fish cruising speed. Nature 245(4519): 48-50.

WHITE, A. W.

1977. Dinoflagellate toxins as probable cause of an Atlantic herring (Clupea harengus harengus) kill, and pteropods as apparent vector. J. Fish. Res. Board Can. 34: 2421-2424.

WHITCOMB, V. L.

1970. Oceanography of the mid-Atlantic bight in support of ICNAF, September-December 1967. U.S. Coast Guard Oceanographic Report, No. 33, 157 pp.

WIGLEY, R. L.

1968. Can submersible vehicles be used effectively in studies of cold water shelf fisheries? Fish. News Int. 7(3): 32-34.

WILIMOVSKY, N. J.

1963. A radioactive internal tag for herring. ICNAF Spec. Pub. 4, pp. 359-361.

WINTERS, G. H.

1970. Preliminary results of herring tagging in southwest Newfoundland coastal waters. Fish. Res. Board Can., St. John's Biol. Sta., Circ. No. 18: 20-24.

1971. Migrations of the southwest Newfoundland stock of herring as indicated by tag recapture. ICNAF Res. Doc. 71/108, Ser. No. 2591, 6 pp.

1971. Population estimates of the southwestern Newfoundland stock of herring from tag recaptures. ICNAF Res. Doc. 71/109, Ser. No. 2592, 7 pp.

1975. Population dynamics of the southern Gulf of St. Lawrence herring stock complex. Ph.D. Thesis, Dalhousie Univ., Halifax, N. S. 142 pp.

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

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. No. 11, pp. 43-59.

WINTERS, G. H., AND L. S. PARSONS.

1972. Interrelationship among Hawkes Bay southwest Newfoundland and southern Gulf of St. Lawrence herring stocks. ICNAF Res. Doc. 72/100, Ser. No. 2847, 10 pp.

1972. Present status of the southwest Newfoundland herring stocks. ICNAF Res. Doc. 72/88, Ser. No. 2791, 7 pp.

WOOD, R. J.

1959. Investigations on O-group herring. J. Cons. Perm. Int. Explor. Mer 24: 265-276.

1971. Some observations on the vertical distribution of herring larvae. Symposium on the biology of early stages and recruitment mechanisms of herring. Rapp. P.-v. ICES 160: 60-64.

WOOD, R. J., AND W. G. PARNELL.

1968a. The English herring fisheries in 1966. Annls. Biol., Copenh. 23: 163-166.

1968b. The English herring fisheries in 1967. Annls. Biol., Copenh. 24: 162-166.

WOODHEAD, P. M. J., AND A. D. WOODHEAD.

1955. Reactions of herring larvae to light: a mechanism of vertical migration. Nature, Lond. 176: 349-350.

WRIGHT, W. R.

1975. The limits of shelf water south of Cape Cod, 1941 to 1972. J. Mar. Res.

WRIGHT, W. R., AND L. V. WORTHINGTON.

1970. The water masses of the North Atlantic Ocean, a volumetric census of temperature and salinity. Serial Atlas of the Marine Environment, American Geographical Society, New York, Folio 19.

WYNNE-EDWARDS, V. C.

1929. The reproductive organs of the herring in relation to growth. J. Mar. Biol. Ass. U.K. 16: 49-65.

YUDANOV, I. G.

1963a. Herring of the northwestern part of the Atlantic Ocean, p. 361-370. In Yu. U. Marti (ed.), Soviet Fisheries Investigations in the Northwest Atlantic. Transl. and publ. for the U.S. Dept. of Interior and the National Science Foundation, Washington.

1963b. On herring fishing in the Western Atlantic. Herring fishing is based on spawning populations underutilized by the Canadian and Americans. RYBN KHOZ 39(2): 14-18.

1963c. Some characteristics of the biology of herring from the Northwest Atlantic. Ryb. Khoz. No. 4.

1966. Fecundity and efficiency of spawning of Atlantic herring in the Gulf of Maine. Trudy PINRO 17: 249-262.

ZENKIN, V. S.

1966. Notes on degree of genetic propinquity of autumn and spring herring from the southern Baltic. Scientific Thought, Kiev, p. 46.

1971. Immunogenetical studies of Baltic populations of herring. Rapp. P.-v. ICES 161: 40-44.

ZIJLSTRA, J. J.

1958. On the herring "races" spawning in the southern North Sea and English Channel. (Preliminary report). Rapp. P.-v. ICES 143: 134-145.

1963. On the recruitment mechanisms of North Sea autumn spawning herring. Rapp. P.-v. ICES 154: 198-202.

1970. Herring larvae in the central North Sea. Ber. Dtsch. Wiss. Komm. Meeresforsch. 21: 92-115.

ZIJLSTRA, J. J., AND L. K. BOEREMA.

1964. Some remarks on effects of variations in fish density in time and space upon abundance estimates, with special reference to the Netherlands herring investigations. Rapp. P.-v. ICES 155: 71-73.

ZIJLSTRA, J. J., AND J. J. W. POLDER.

1959. Fecundity in the North Sea herring. ICES Doc. CM1959/84, 10 pp.

ZINKEVICH, V. N.

1967. Observations on the distribution of herring, *Clupea harengus* L., on Georges Bank and in adjacent waters in 1962-65. ICNAF Res. Bull. No. 4, pp. 101-115.

ZITKO, V., D. E. AIKEN, S. N. TIBBO, K. W. T. BESCH, AND J. M. ANDERSON.

1970. Toxicity of yellow phosphorus to herring (*Clupea harengus*), Atlantic salmon (*Salmo salar*), lobster (*Homarus americanus*), and beach flea (*Gammarus oceanicus*). J. Fish. Res. Board Can. 27: 21-29.

ZUEV, G. V., AND K. N. NESIS.

1971. The role of squids in the food chains of the ocean. Transl. 1974, Fish. Mar. Serv., Can. Transl. Ser. No. 3315.