Northwest Atlantic Fisheries Organization

Serial No. N209

NAFO SCR Doc. 80/IX/135
(Corrigendum)

ANNUAL MEETING OF SCIENTIFIC COUNCIL - SEPTEMBER 1980

Estimates of Herring Spawning Stock Biomass and Egg Production for the Georges Bank-Gulf of Maine Region

by

V. C. Anthony and G. T. Waring
National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole, Massachusetts, USA 02543

The following Table, which replaces Table 2 on page 20 of SCR Doc. 80/IX/135, was received at the Secretariat after the original document was printed and distributed:

Table 2. Catch in tons by month and year for the Gulf of Maine adult herring fishery.*

	YEARS															
MONTH	67	68	69	70	71	72	73	74	75	76	77	78	79	80	%	TOTAL
JAN	146	49	2360	1259	1197	1025	983	1017	2260	1068	2717	2896	2538	563	5.07	20078
FEB	96	260	519	155	418	597	1623	1713	2168	985	3584	5764	1499	4583	6.04	23964
MAR	669	212	363	391	360	829	3617	3107	3590	2965	3128	3664	3455	5937	8.16	32287
APR	113	180	1444	159	612	2059	3108	3099	1555	3746	2789	280	129	335	4.96	19608
MAY	424	356	808	1349	605	3632	1887	181	191	645	1094	477	6	146	2.98	11801
JUN	170	1594	88	421	1668	2900	2132	96	71	3	4	510	32	2606	3.11	12295
JUL	91	6780	1301	2306	2706	4794	581	4082	2619	1297	146	41	1603	5803	8.63	34150
AUG	100	6410	6162	5000	8403	11007	1611	2383	1728	1930	1808	46	8204	5833	15.32	60625
SEP	3156	8296	11722	5838	16696	6116	515	679	2794	3817	1285	2106	7094	4814	18.93	74927
OCT	2093	5529	5334	13970	5232	10493	3490	1410	3167	2335	671	1462	50	5931	15.46	61167
NOV	1755	2765	1513	6310	1481	1863	461	1517	3662	1957	654	2419	1	240	6.72	26598
DEC	205	227	4460	5040	2020	401	542	2183	1654	117	392	1005	37	--	4.62	18283
TOTAL	9018	32658	36074	42198	41398	45716	20550	21468	25457	20865	18272	20670	24648	36791		395783

*INCLUDES USA CATCHES TAKEN IN 5Z & 6

Northwest Atlantic Fisheries Organization

Serial No. N209 NAFO SCR Doc. 80/IX/135

ANNUAL MEETING OF SCIENTIFIC COUNCIL - SEPTEMBER 1980

Estimates of Herring Spawning Stock Biomass and Egg Production for the Georges Bank-Gulf of Maine Region

by

V. C. Anthony and G. T. Waring
National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole, Massachusetts 02543, USA

Introduction

Following the recommendation of the herring working group, an international larval herring survey of the Georges Bank - western Gulf of Maine region was initiated in September 1971 (ICNAF 1971). One of the objectives was to estimate the relative size of the spawning groups in the respective areas based on larval abundance indices. In order to allow verification of larval abundance indices, this paper reports the estimates of the spawning biomass and the amount of eggs produced in both the Georges Bank and the western Gulf of Maine areas (Figure 1) for those years in which a fishery was prosecuted. For Georges Bank, this is the period of 1961-1977 (Table 1) and for the western Gulf of Maine area years 1967-1979 (Table 2). Virtual population analyses was applied to annual catch for the period October 1 to September 30 instead of January 1 to December 31. Thus population estimates were for October 1 of each year, which corresponds to the peak of spawning. Based on assumptions concerning maturity, sex ratios, and fecundity, the potential number of eggs deposited in each year is estimated.

In order to estimate herring egg production in a particular year on a spawning ground, considerable information is necessary. There are a number of problems which complicate the analysis. The herring fisheries on Georges Bank and in the western Gulf of Maine have generally occurred during spawning season, thus, it has been difficult to determine the proportion of fish in the catch that have actually spawned. This spawning season fishery was more prevalent on Georges Bank than in the Gulf of Maine and in more recent on Georges Bank, in particular, significant quantities of herring were caught both immediately prior to and after spawning. Detailed sampling would have been

required on a weekly basis to determine quantities of spent or ripe and running herring in the catches. Additional problems in trying to determine the amount of herring that actually spawned in a given year relate to the true rate of maturity and availability of the herring to the fishery. Many herring which are immature might not recruit to the spawning area where the fishery is taking place. If maturity studies were only conducted in the fishing area, the results would overestimate the proportion of the population that was mature and, therefore, an overestimate of egg production when percent mature estimates are applied to VPA results. Furthermore, a significant proportion of the mature population may be caught just prior to spawning.

Another factor which complicates the estimation of spawning biomass is herring migration patterns, particularly along the western Gulf of Maine where herring that have spawned elsewhere migrate through the Jeffreys Ledge fishing area during the Jeffreys Ledge spawning season. Again, the spawning biomass would be overestimated. In addition, intermixture between SW Nova Scotia, Gulf of Maine and possibly Georges Bank fish in the winter-spring period will result in overestimating the stock sizes. Preliminary results of Canadian tagging studies (Stobo 1976) and the international herring tagging program (Almeida and Burns 1978) have shown SW Nova Scotia and Gulf of Maine fish do intermix, but the extent of this mixing is unknown.

Finally, the effect of fishing on the process of spawning is unknown. In the Georges Bank area the decline in recruitment during the 60's and 70's seems to be more related to the increase in fishing than to the decline in spawning stock size. As effort increased subsequent recruitment declined even though spawning biomass was a very high level. The very act of fishing on the spawning concentrations may directly reduce effectiveness of spawning in a manner not reflected by the catch rates.

It was not possible for this paper to investigate in detail the changes in growth, maturity, and fecundity that have taken place as the herring populations have declined. Many of the changes were so obvious, however, that they could not be ignored and are incorporated insofar as possible in the analyses.

Time of Spawning and Definition of Spawning Biomass

The time of spawning is critical to the determination of spawning biomass because the catches are large immediately prior to spawning and the herring

leave the spawning grounds (and the fishery) rapidly after spawning.

Early records indicate that spring spawning at one time was an important characteristic of the herring populations within the Gulf of Maine. In recent years, spring spawning, while occasionally detected, is of little significance. Herring spawn from August to November varying in their time of spawning by location and from year to year within a given area. Spawning begins near the end of August off Nova Scotia and progresses south and west along the coast of Maine, Jeffreys Ledge, Georges Bank, and finally at Nantucket Shoals in late October or early November. Noskov and Zinkevich (1967) reported spawning activity on Georges Bank in 1964 during Septmber 28-29. For 1965, they reported that spawning occurred in Area 1 (Figure 2) on September 11-12 and in Area 3 on September 23 to 25. For 1966 Noskov and Zinkevich reported that spawning occurred in Area 1 on September 19-20 and in Area 3 on September 28-29. The pattern of catches on Georges Bank suggest that the very good year classes of the early 1960's came from the spawning Areas 1 and 2 on the northeast peak of Georges Bank while the 1970 year class came from Area 4 to the west and that these areas may traditionally have had different spawning times. Based on 1972-74 Polish catch per tow data for maturity stages VI and VII herring, Paciorkowski and Giez (1975) determined the peak spawning periods were 24-26 September for 1972-73 and 2 October in 1974 on Georges Bank. It is likely that the peak of spawning occurred during the 60's in September and during the late 70's in October. However, Boyar (1968) determined that the peak spawning period on Georges Bank and off Nova Scotia was in October. Lough et. al (1979) estimated the time of spawning for the Georges Bank - Nantucket Shoals area for the years 1968-1977 from the presence of yolk sac larvae. The spawning period for the 1968-1973 period was between mid-September and late December and for the 1974-1977 period, it was from late September to mid-December.

Information on spawning condition for the Georges Bank herring was available from the research conducted by the Federal Republic of Germany (Dornheim 1980). These data are presented by maturity stages 5, 6, 7, and 8 for the months of August, September, and October in Table 3. The number sampled includes observations of other stages not presented in the table, therefore, the percentages do not total to 100. Prior to 1972, no prespawning herring were noted in October. For 1972 and 1973 (the only two years after 1970 for which October

data were available) the percent of herring in prespawning condition in October was 11% and 76%, respectively. The data suggest that spawning occurred as follows:

1967	late September or early October
1968	September
1969	late September - early October
1970	late September - early October
1971	late September - early October
1972	mostly October
1973	September, October, November
1974	late September, probably October
1975	October and/or November
1976	September - October

In the Jeffreys Ledge area of the western Gulf of Maine, herring spawning has traditionally occurred during the middle of October. The fishermen there have reported that Columbus Day (about October 12) is always the time of spawning for Jeffreys Ledge herring. Boyar (1973) stated that "the onset of spawning occurred in early September" in 1972 on Jeffreys Ledge but the peak spawning period was in early October. This indicates that in any particular year spawning can occur at different times over a prolonged period. During herring tagging studies conducted on Jeffreys Ledge in autumn 1976 and 1978, ripe and running herring were tagged in the second week of October for both years.

The heaviest fishing occurs during September (Tables 1 and 2). From 1961 to 1979, 27% of the catch (by weight) on Georges Bank came from the month of September and 14% of the catch came in October. From 1967 to 1979 20% of the catch (by weight) in the western Gulf of Maine was made in the month of September and 13% of the catch was made in October. While some of the fish caught in September might have spawned, we assume that October 1 would be the best compromise of a time to represent annual spawning biomass.

Estimates of Mortality and Abundance for the Georges Bank and Western Gulf of Maine Adult Herring Fisheries.

In order to calculate the abundance of herring at the beginning of October 1, annual catches for the calendar years beginning on that date were analyzed. In previous herring assessments, catch at age was sometimes estimated quarterly based on incomplete catch and sample information. However, since the

bulk of the catch occurs in September and October, we felt that careful calculation of catch at age by month using all the data available in the ICNAF sampling year books and in the Northeast Fisheries Center data files was required. The data were then combined over months for the period of October 1 in one year to September 20 of the next year and a virtual population analysis was applied separately for the Georges Bank and the western Gulf of Maine areas (Table 4 and Table 5). Mean weights for September were applied to the data to determine potential spawning biomass on October 1. Natural mortality was assumed to be 0.20.

The Georges Bank Fishery

The terminal fishing mortality rates used in the virtual population analysis in 1977 were chosen to be slightly less than those in 1976 because of additional fishing restrictions in 1977 over those in existence in 1976. Fishing was restricted to a "window" area (Figure 2) for the first time in 1977. Directed fishing by large trawlers was allowed only in the window area from August 15 to September 30. In addition, the total allowable catch was reduced from 60,000 metric tons in 1976 to 33,000 metric tons in 1977. It should be noted that those were annual quotas for the year beginning January 1. The catch for 1976-1977 according to this analysis (October 1, 1976 - September 30, 1977) was, therefore, taken under a 1976 annual quota restriction of 60,000 metric tons from October 1, 1976, to January 1, 1977. and thereafter under an existing quota of 33,000 metric tons until September 20, 1977.

The Northwest Atlantic herring fishery was developed rapidly during the 1960's. It was not regulated until the early 1970's. The abundance of fully recruited herring in 1973 was, therefore, only 21% of the abundance during the 1965-1968 period. Even with catch quota management, the average fishing mortality rate for ages 6 and older was calculated to be 1.42 - 1.48 during 1973 to 1975 using a range of high and low starting fishing mortality rates in the VPA procedure in 1977. All indications, therefore, suggest that fishing mortality rates were excessive in both 1976 and 1977 for older age groups.

After 1972, the herring fishery on Georges Bank was heavily dependent on the 1970 year class. This year class accounted for about 80% of the total herring population on Georges Bank from 1974-1977. Estimates of abundance of the other year classes for these years, therefore, is not as critical to the estimate of total biomass. Fishing mortality rates increased rapidly on

all year classes after 1973 due to the decline in overall abundance of herring and the high level of fishing effort (Figure 3) which occurred even with quota restrictions. With the virtual population analysis technique, fishing mortality rates are estimated most reliably when the fishing mortality is increasing rapidly with age. The virtual population analysis, therefore, produced reliable estimates of fishing mortality as late as 1974 and 1975 (assuming that the catch at age data are correct) when the VPA procedure starts in 1977. Under these circumstances a wide range in assumed F's in the terminal year of the analysis will produce similar estimates of fishing mortality only two to three years earlier. Nevertheless, considerable thought was given to the terminal fishing mortality rates chosen in both 1977 and 1976.

For the 1967 year class a range of starting fishing mortalities of 0.6 to 1.1 were used for 1977. Estimates of fishing mortality varied by only 4% in 1974 and by 10% in 1975 over this range of starting fishing mortality rates. All fishing mortality rates from 1972 to 1976 were greater than 0.73 and averaged 1.08, 1.27, 0.89, 0.78, and 1.11 during 1972 to 1976. It is likely, therefore, that in 1977 if fishing had not been further restricted F would have been greater than 1.0. Allowing for some decrease in 1977 a starting F of 0.9 was assumed for 1977. This produced an estimate of fishing mortality in 1976 of 1.14 (Table 4) as compared to 0.96 if the starting F in 1977 had only been 0.6 and 1.22 if the starting F in 1977 had been as high as 1.1. It is obvious, therefore, that the starting F in 1977 is not very critical and that the fishing mortality rate was high in 1976 regardless of the approach used.

For the 1968 year class, terminal fishing mortality rates in 1977 from 0.6 to 1.1 produced estimated fishing mortality rates which steadily increased from 1974 to 1976 and which were greater than 1.1 in 1976 in all cases. For the 1969 year class starting fishing mortality rates in 1977 of 0.3 to 1.1 were tried. These calculations produced estimates of fishing mortality rates in 1975 and 1976 in excess of 1.0 and as great as 2.08. The fishing mortality rates of 1.1 were therefore chosen as proper starting fishing mortality rates in the virtual population analysis for both the 1968 and 1969 year classes in 1977.

There were no fish caught in 1977 of the 1965 and 1966 year classes, therefore the starting fishing mortality rates in the virtual population analysis were applied to 1976 catches. Fishing mortality rates were very high for neighboring

year classes in 1976. For the 1967 year class starting fishing mortality rates in 1977 of 0.9 or greater produced estimates of fishing mortality greater than 1.1 in 1976. For the 1968 year class starting fishing mortality rates in 1977 of 0.6 or more produced estimates of fishing mortality greater than 1.1 in 1976. For the 1969 year class starting fishing mortality rates in 1977 of 0.3 or more also produced estimates of fishing mortality rates greater than 1.1 in 1976. It appeared, therefore, that a starting F of 1.1 in 1976 for both year classes 1965 and 1966 was realistic.

The estimation of the size of the 1970 year class is critical to the determination of the total spawning biomass after 1972. The range of starting fishing mortality rates in 1977 of 0.3 to 0.9 indicated that F increased greatly from 0.27-0.28 at age 3 to 0.43-0.47 at age 4 to 0.67-0.80 at age 5 and to 0.96-1.54 at age 6. Fishing mortality increased from 1975 to 1976 by 80% for the 1969 year class, by 74% for the 1968 year class and by 45% for the 1967 year class. A range of starting fishing mortality rates for the 1971 year class in 1977 of 0.2 to 1.1 also provided a range of percentage increases in the calculated fishing mortality rates from 1975-1976 of from 53% to 142%. It is very likely, therefore, that the fishing mortality rate for the 1970 year class in 1976 increased by about 75% over that existing in 1975. A starting fishing mortality rate in 1977 of 0.7 was therefore assumed for the 1970 year class which produced fishing mortality rates of 0.28, 0.47, 0.78, and 1.42 for ages 3-6. The value of fishing mortality rate chosen for 1977 is really only critical for 1976 and 1977 as most estimates converge to the same number in 1975.

As with the 1970 year class the fishing mortality rate for the 1971 year class increased greatly from 1973 to 1976 and then declined. This again was obvious regardless of the starting fishing mortality rates chosen for 1977. The fishing mortality rate for 1975 was at least 0.66 and for 1976 at least 1.0 if the starting fishing mortality rate in 1977 was 0.2 or more. A starting fishing mortality rate of 0.5 was therefore assumed which produced a fishing mortality rate in 1976 of 1.57 and a low abundance of 1,700 metric tons in 1977 for the 1971 year-class.

Research vessel survey data have indicated that the 1971, 1972, and 1973 year classes were all low in abundance with the 1973 year class the largest of

the three (Anthony 1976). The catches, however, suggest that the 1973 year class was poorer than the 1971 year class and about equal to that of the 1972 year class. In fact the fishing mortality rate in 1977 would have to be as low as 0.07 for the 1973 year class and as high as 0.5 for the 1971 year class for the two year classes to be of the same order of magnitude at age 3. This low fishing mortality on the 1973 year class would in turn provide an abundance of 24,000 metric tons of 4 year old fish in 1977 which seems excessive in view of the lack of fish in the Georges Bank area after 1976. The catches of the 1972 year class were so poor that even with a fishing mortality rate as low as 0.05 in 1977 the recruitment at age 3 could not have been larger than 11,000 metric tons. Fishing mortality rates of 0.1 were, therefore, assumed for year classes 1972, 1973, 1974, in 1977. This assumption indicates a low abundance of 5,000, 12,000, and 300 tons for year classes 1972, 1973, 1974, respectively, in 1977. In view of the limited catch in 1977 even this amount of fish may be an overestimate. The estimation of fishing mortality, abundance and catches are given in Table 4.

The Western Gulf of Maine Adult Herring Fishery

Catch data for this fishery were available for the most recent year; October 1978 to September 30, 1979. A range of starting fishing mortality rates in the virtual population analysis were used for year classes 1973 to 1969 to investigate the effect of starting fishing mortality rates in the VPA on estimates of fishing mortality in years immediately prior to 1979. Two things were obvious; (1) the fishing mortality rates for the Gulf of Maine adult fishery were far less than those in the Georges Bank fishery, and (2) the fishing mortality rateds generally increased after 1973. For the 1969 year class the fishing mortality in 1978 was clearly less than 0.60 regardless of the starting fishing mortality rate in 1979 and for the 1970 year class in 1978 it was clearly less than 0.8 but close to 0.7. Starting fishing mortality rates of 0.9 to 0.8 were therefore chosen for the 1969 and 1970 year classes, respectively, in 1979.

The fishing mortality rate for the 1971 year class in 1978 was between 0.5-0.6 and 0.7 was, therefore, used as a starting fishing mortality rate in 1979 since mortality was generally increasing. For the 1972 and 1973 year classes fishing mortality rates in the last few years were increasing but were less than 0.6 for the 1972 year class in 1978 and less than 0.5 for the 1973 year class in 1978. Therefore, starting F's of 0.7 and 0.6 respectively were used for starting

fishing mortality rates in the virtual population analysis for the 1972 and 1973 year classes.

Catches of the 1974 year classes and younger accounted for over 73% of the total 1979 catch and the determination of the stock sizes for these year classes is critical in determining the total stock size.

The 1974 year class was the poorest year class to appear in Canadian catches (ICNAF Div. 4WXa) since 1965 when catch at age data were first available (Sinclair et al. 1979). The catch of this year class off Nova Scotia in 1976 at age 2 was only 20 million fish compared to an average catch of age 2 herring of 220 million fish from 1965 to 1975. In 1977 and 1978, catches at age 3 and 4 off the 1974 year class were also very poor. In the Maine coastal fishery in 1974 year class provided surprisingly good catches at ages 1, 2, and 3 but not at ages 4 and 5 in comparison with other year classes of the same age. In the Gulf of Maine adult herring fishery the catches of the 1974 year class were the poorest in recent years. During the first quarter of 1980 the 1974 year class accounted for only 1.1% of the total catch. A fishing mortality rate was, therefore, chosen for 1978 which produced a recruiting year class in 1977 equal to the poorest observed in the history of the fishery (the 1969 year class). The terminal F so chosen for 1978 was 0.68 which appears to be quite high in relation to other fishing mortality rates in 1978 or of the same age. The catches, however, suggest that this mortality rate may be too low.

The 1975 year class was also very poor in the catches off Canada but produced the largest catch at age 2 in the Maine juvenile herring fishery since the 1966 year class in 1968. Catches of this year class in the Gulf of Maine adult herring fishery in 1978 accounted for 28% of the total catch and it was not obvious from these catch data that this was a poor year class. During the first quarter of 1980, however, this year class produced only 4% of the total catch. The starting F of 0.6 was assumed for 1978 for the 1975 year class which produced a recruiting year class in 1978 equal to that of the 1971 year class and about half of the 1966 year class. This is a "fair" year class and given the uncertainties as to its abundance, seems to be a proper estimate.

The 1976 year class is a good year class and this is shown not only in the catches in Canada, in the Maine coastal fishery but in the Gulf of Maine adult fishery as well. In terms of catch this year class ranks second to the 1970 year class off Nova Scotia and in the Gulf of Maine and very close to

the catches of the 1966 year class in the Maine coastal fishery at age 2. This year class was assigned the value of a "good" recruiting year class or equal to the size of the 1966 year class in 1969 of about 278 million fish. This in turn required a terminal F in 1978 of 0.195.

These fishing mortality rates and stock sizes along with the catch at age are shown in Table 5.

Estimates of Maturity

Data were not available to estimate maturity ogives for the Georges Bank and Gulf of Maine herring fisheries. Table 6 presents maturity data for the Georges Bank fishery collected by the Federal Republic of Germany (Dornheim 1980). The criterion for mature herring is maturity stages 3 through 8 using the 8-grade maturity scale adopted by ICNAF in 1964 (ICES 1963; ICNAF 1964). Table 7 presents data from Boyar (1968) and Boyar (1980). The numbers sampled in most cases were not known but were at least 100 in each sample. These data were taken almost entirely from research vessel surveys. Table 8 presents maturity data from the commercial fishery in the western Gulf of Maine and Table 9 from the central and western area (Figure 1) of the Maine fishery in 1978 and 1979. There were no maturity information available for 1977 from the Maine fishery.

The data indicate for both the Georges Bank and Gulf of Maine areas that most of the age 4 fish are mature while the maturity of age 3 fish varies considerably. After 1970, Dornheim's data (Table 6) indicate that 100% of age 4 herring on Georges Bank were mature. Boyar's data (Table 7) for Georges Bank indicate that 83% of age 4 fish were mature after 1970. Prior to 1971 Dornheim's data indicate that 97% of the age 4 herring on Georges Bank were mature while Boyar's data suggest 92% maturity.

Data are very limited in the Gulf of Maine after 1970. Tables 7 and 8 indicate a maturity of 98% for age 4 herring in 1978 and 1979 whereas Boyar's data suggest that age 4 herring were 95% mature in 1977. The interesting point is that only 75% of age 4 fish were mature (on the average) from 1960-1971 (Table 7) in the western Gulf of Maine. For purposes of this paper we assume that age 4 fish are fully mature for all years on Georges Bank and after 1970 for the Gulf of Maine. For 1960-1970, 75% maturity is assumed for the Gulf of Maine.

No age 2 fish were found to be mature. The maturity of age 3 herring varied considerably, however, by both area and time. On Georges Bank an average of 94% were mature from 1971-1976 (Table 6) according to Dornheim and 79% for Boyar's data (Table 7). From 1967 to 1970, these data sets indicate 59% and 48% were mature, respectively. From 1960 to 1966 (Table 7), 25% were mature.

In the Gulf of Maine, age 3 herring were 46% mature in 1977 but only 9% mature over the period 1960-1970 (Table 7). No information exists for 1971-1976 for age 3 herring. Tables 8 and 9 provide information for 1978 and 1979 for the western Gulf of Maine area and the Maine coastal area. For the western Gulf of Maine area 14% of the age 3 herring were mature in 1978 and 21% were mature in 1979. Along the Maine coast, 21% of the age 3 herring were mature in 1978 and only 10% in 1979. An average for 1977-1979 of the 5 estimates is 22%.

The estimates of maturity vary greatly from year to year probably because of small sample sizes. Because of this it is necessary to average the maturity over a series of years wherever possible. For both age 3 and age 4 herring the maturity appears to increase after 1970. Herring on Georges Bank are much more mature at a given age than herring in the Gulf of Maine. This is expected as the fishery on Georges Bank was more concentrated on the spawning areas than the fishery in the Gulf of Maine.

We assume that for the Georges Bank area, 25% of the age 3 herring were mature from years 1960 through 1966. From 1967 through 1970, we averaged data from Tables 6 and 7 arriving at 57% maturity for age 3. After 1970 an average of 93% was estimated for age 3 herring for Georges Bank.

In the Gulf of Maine from 1960 to 1970, 9% were assumed to be mature. After 1970 an average of 22% is assumed. Although no data on maturity exist from 1971-1976 in the Gulf of Maine the mean lengths and weights of herring are more nearly like those in 1977-1979 than during the 1960's. Assuming that maturity is related to length, therefore, 22% rather than 9% is assumed for age 3 maturity from 1971-1976.

These maturity percentages were applied to the estimates of abundance in Tables 3 and 4 to estimate the numbers and biomass of the spawning population for both Georges Bank and the Gulf of Maine. These values are given in Table 16.

Changes in Length and Weight at Age

Both fecundity and maturity change with size of fish. Since 1960 there have been significant changes in growth which have affected both maturity and fecundity. The mean lengths of herring by age and year from the Georges Bank and western Gulf of Maine fisheries are given in Tables 10 and 11. Length at age has increased in recent years as the herring abundance has declined. While this increase in length at age has not been fully analyzed, it has been noted before (Anthony and Waring, 1980). A table from that paper is included here as Table 12 to show the increase in length which seemed to accelerate beginning with the 1968 year class in 1969. The calculated value of K in the Von Bertalanffy growth equation increased from 0.350 (year classes 1960-1963) to 0.357 (year classes 1964-1967) to 0.510 (year classes 1968-1971) for Georges Bank. For the western Gulf of Maine fishery the Ks for the same year classes were 0.250, 0.303, and 0.400. The change in growth is especially evident in the Maine juvenile fishery (Table 12) where age 2 fish were suddenly the size of the age 3 fish of the year before. This change in growth was also noted by Paciorkowski (1975) on Georges Bank. The increase in growth coincides with decreases in total stock abundance and apparently has caused the increase in maturity that seems to have occurred in the 1970's.

The change in growth is more dramatic in terms of weight rather than length in older fish and Figure 4 shows the increase beginning with the 1968 year class for the western Gulf of Maine fishery. The mean weights for years 1977-79 are shown for ages 3-6 for September only. With abundance at very low levels in 1977-1980, very large herring were observed. In past assessments, mean weights for ages 5-8 were 0.22, 0.24, 0.275, and 0.30 kg for the month of August. For 1977-79, the September mean weights were .270, 0.302, 0.324, and 0.346 for ages 5-8. In 1980 a herring was sampled from the Maine herring fishery that weighed 0.64 kg (Jean Chenoweth 1980). This is much larger than we have ever noted before. Such changes in growth can have profound effects on fecundity as well as yield production and maturity rates and this is discussed below.

Earlier work (Anthony 1971) demonstrated that growth at age 2 was related to the catch at age 2 in the Maine herring fishery. The catch at that time apparently was directly proportional to abundance (Anthony 1972). Figure 5 taken from Anthony (1972) shows the density-dependence. Straight lines were drawn through the modes of age-length frequencies calculated on a 2-week basis.

Herring of the very good 1960 year class were much smaller at age 2 than were herring of the very poor 1959 year class, for example. We conclude, therefore, that herring growth of a particular year class in the Gulf of Maine and Georges Bank area is a function of both total abundance and individual year-class abundance. The dependence on each taken separately and together remains to be discussed. When the overall stock abundance is high, density dependence will be obvious (especially in the younger ages). When the overall abundance declines, all year classes regardless of their individual abundance will exhibit increased growth to varying degrees. We further conclude that a decrease in stock abundance produces an increase in maturity of age 3 herring, and must have profound effects on the fecundity of the spawning population.

Fecundity

Fecundity information for the Georges Bank fishery is available from Yudanov (1966) for 1962, from Perkins and Anthony (1969) for 1963 and 1964, from Noskov and Zinkevich (1967) for 1964, 1965, and 1966, from Draganik and Rast (1970) for 1968 and from Schultz (1974) for 1971 (Table 13). Fecundity information is only available for the Gulf of Maine area from Perkins and Anthony (1969). The number of eggs per female increased from about 20,000 eggs for age 3 herring in both areas to 140,000 eggs for age 8 herring from Georges Bank and to 160,000 eggs for age 8 herring from the Gulf of Maine. Schultz (1974) found that the fecundity rates varied inversely with population abundance. His Figure 2 is reproduced here as Figure 6 with the regression line from Perkins and Anthony (1969) added. The data by Noskov and Zinkevich (1967) were not added to the figure as they did not describe the length measurement used. The data by Perkins and Anthony (1969) suffers from the fact that data were limited and were combined over two years. The fecundity line for 1963-64 in Figure 6 is not parallel to the other three lines and is probably due to the very slow growing and very abundant 1960 year class. The 1960 year class provided 50% of the fecundity information for this line at an average length of 27 cm. The fecundity information from the older herring (29-30 cm) came from the same year classes that provided the information contained in the "1962" line and Figure 6 shows a very good agreement between the two lines for the older fish. Since we only have fecundity data from 3 periods, the relationship may be fallacious, but we assume that an inverse relationship between abundance and fecundity exists.

Fecundity may be a function of overall abundance or abundance of its own year class or appears to be the case with the 1960 year class. We assume, however, at this point in time, that fecundity for all year classes within a given year is inversely related to overall abundance in the preceding year. This relationship is plotted in Figure 7. Each data point represents the number of eggs for a given total length category. The data point 28 above the year 1970 for example, means that a herring of 28 cm in total length carried 53,000 eggs in 1971 when the abundance (age 4 and older) in the previous year was 1.8 billion fish. Free hand lines were drawn through the data points for each centimeter group.

Recruitment

Examination of the estimates of exploitation indicates that herring are not fully recruited at age 3 and 4 in either the Georges Bank or western Gulf of Maine fisheries. Recruitment selection factors were calculated for both fisheries from estimates of the exploitation rates calculated on a calendar year basis (January 1 to December 31). Selection factors calculated from the data in Tables 4 and 5 might not be appropriate for the fishery since the majority of catch is taken from July through October (66%) for Georges Bank and from July through December (69%) for the western Gulf of Maine fishery (Tables 1 and 2). Tables 4 and 5 are based on catches from October 1 through September 30 of the next year.

Summary

In both the Georges Bank and western Gulf of Maine fisheries "ripe and running" herring were found as early as mid-September, with the peak spawning occurring in either late September to mid-October. Likewise the spawning sites have varied over time.

The September - October catches during the course of these two fisheries has accounted for over 30% of the yearly catches. This, in conjunction with the above, justified using 1 October for the beginning of the year in the new VPA analysis. The starting F's used in each of the terminal years for the two fisheries were carefully analyzed; and the stock size estimates obtained on recruiting year-classes (age 3) are generally consistent with age 2 catches from the Maine coastal fishery.

For both the Georges Bank and western Gulf of Maine region the stock size (age 3+) declined rapidly after 1966 and 1968, respectively. This decline was halted for one year in 1973 when the good 1970 year-class (age 3) recruited

to both regions. In the Gulf of Maine the 1976 year-class (age 3) in 1979 has resulted in an increase above the 1977 and 1978 levels. The lack of a commercial fishery on Georges Bank since March 1977 precludes any determination of stock size (in 1978-79) for this region using VPA analysis.

The declines in stock size and generally low levels of recruitment have resulted in increased growth rates for herring. For Georges Bank available data also reveal that fecundity is inversely proportional to total stock size and thus has increased in recent years. The estimates of egg production in the Georges Bank region, adjusted for stock abundance, were highest in 1969 and 1973, respectively. These peaks reflect the affect of the good 1966 and 1970 year-classes. Thus errors in estimating the proportion of age 3 fish mature will be critical when good year-classes recruit to the fishery. Under constant egg production, the peaks occurred in 1966 and 1970, the years in which the two previously mentioned good year-classes were spawned.

In the Gulf of Maine region egg production estimates were highest in 1968 and excepting 1970 have steadily declined through 1978. The 1979 estimate increased as a result of recruitment from the good 1976 year-class. Again, the affect of mature three year-olds is evident.

It is evident that additional studies on herring growth, maturity, and fecundity especially for age 3 fish are required to better estimate spawning stock size and potential egg production.

References

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, NEFC, Lab. Ref. No. 78-07.

Anthony, V.C. 1971. The density dependence of growth of the Atlantic herring in Maine. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 1960: 197-205.

_____. 1972. Population dynamics of the Atlantic herring in the Gulf of Maine. Ph.D. Thesis, University of Washington, 266 pp.

For both the Georges Bank and western Gulf of Maine region herring abundance declined rapidly after 1966 and 1968, respectively. This decline was temporarily halted when the good 1970 year-class recruited to both regions in 1973. This year class was so rapidly overfished on Georges Bank that the fishery ended in 1977. In the Gulf of Maine the herring abundance has begun to recover due to the 1976 year class.

The declines in stock size and recruitment have apparently resulted in increased growth rates for herring. This, in turn, has resulted in an increase in percent maturity for age 3 adult herring. For Georges Bank, the data although limited, also suggest that fecundity at length is inversely proportional to total stock size and thus has increased in recent years. Changes in growth were profound. The rate of growth of a recruiting year class appeared to be related to its own abundance and to the total stock abundance as well. Above a threshhold stock abundance, density dependent growth was obvious; below that stock abundance, all year classes, regardless of abundance, grew quite well. The maturity of age 3 and age 4 herring increased greatly after 1970 when the stock abundance underwent its sharpest decline. The rate of recruitment appeared to increase for age 3 and age 4 herring at this time as well (especially for Georges Bank). The fecundity data were insufficient for the Gulf of Maine to allow examination of a possible fecundity-density dependent relationship. Data for Georges Bank were sufficient to strongly suggest such a relationship but additional data are required to confirm the relationship.

The multiplicative efforts of increased growth, maturity, recruitment, and fecundity at lenth on egg production demonstrated a surprising ability of herring to compensate for declining abundance. For example, age 3 herring from Georges Bank from the mid 1960's to the mid 1970's increased in length by 9% (the weight increase was greater), increased in maturity by 63%, increased in recruitment by 181% and increased in fecundity at length by 129%. From 1965 to 1975 the spawning stock on Georges Bank (age 4+) declined by 88% (by number) while the egg production only declined by 67% if one assumes the density dependent fecundity relationship given in Figure 7. - From the period 1965-1969, egg production only declined 45% to the period 1970-1974 for Georges Bank, assuming a change in fecundity with abundance (Table 16).

If the compensation as roughly estimated here is, indeed, correct, and if such compensation occurs in other species, then it is not surprising that spawning stock levels and recruitment are seldom found to be closely related.

References

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, NEFC, Lab. Ref. No. 78-07.

Anthony, V.C. 1971. The density dependence of growth of the Atlantic herring in Maine. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 1960: 197-205.

_____. 1972. Population dynamics of the Atlantic herring in the Gulf of Maine. Ph.D. Thesis, University of Washington, 266 pp.

_____ 1976. The effect on stock size from various assumptions of year class strengths for the Div. 5Z and Statistical Area 6 herring stock. ICNAF Res. Doc. 76/6/122, Ser. No. 3979, 7 pp.

Anthony, V.C., V.I. Sauskan, and J.K. Sigaev. 1970. Cooperative herring egg survey-Georges Bank, 1969. Int. Comm. Northw. Atlant. Fish., Res. Doc. 70/70, Ser. No. 2415 (mimeo): 9 p.

Anthony, V.C., and G.T. Waring. 1978. Assessment and management of the Georges Bank herring fishery. Rapp. P.-v. Reun. Cons. Int. Explor. Mer, 177: 72-116.

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

_____. 1976. The effect on stock size from various assumptions of year-class strengths for the Division 5Z and Statistical Aaea 6 herring stock. Int. Comm. Northw. Atl. Fish., Res. Doc. 76/122, Ser. No. 3979: 6 p.

_____. 1980. Personal communication. Northeast Fisheries Center, National Marine Fisheries Service, Woods Hole, Massachusetts 01543.

Chenoweth, J. 1980. Personal communication. Maine Department of Marine Resources. West Boothbay Harbor, Maine 04575.

Dornheim, H. 1980. Personal communication. Bundesforschungsanstalt fur Fisherei, Institut fur Seefischerei, Palmaille 9, 2 Hamburg 50, Germany, Federal Republic.

Draganik, B., and B. Rast. 1970. The fecundity of Georges Bank herring. ICNAF Redbook 1970 (Part III), pp. 117-122.

ICES. 1963. Report of Herring Committee. App. I. Recommendations adopted by the Herring Committee concerning routine methods and the reporting of herring biological data in the ICES area. Cons. Int. Explor. Mer Proc. Verb. Reunion, 1962.

ICNAF. 1964. Report of Standing Committee on Research and Statistics, App. I. Report of ad hoc Group on Herring and Other Pelagic Fish. ICNAF Redbook 1964, Part I.

_____. 1971. Report of Standing Committee on Research and Statistics, January 1971. App. I. Report of Assessment Subcommittee. Int. Comm. Northw. Atlant. Fish., Redbook 1971, Part 1: 43-54.

Lough, R.G., G.R. Bolz, M.D. Grosslein, and D. Potter. 1979. Abundance and survival of sea herring (Clupea harengus L.) larvae in relation to environmental factors, spawning stock size, and recruitment for the Georges Bank area, 1969-1977 seasons. ICES/ELH Symp./DS:7.

Noskov, A.S., and V.N. Zinkevich. 1967. Abundance and mortality of herring (Clupea harengus L.) on Georges Bank according to the results of egg calculation in spawning areas in 1964-66. Int. Comm. Northw. Atlant. Fish., Res. Doc. 67/98, Ser. No. 1897: 16 p.

Paciorkowski, A.J. 1975. Unpublished data. Sea Fisheries Institute, Skr. Paczt. 184, 81-345 Gdynia, Poland.

_____, and M. Gudy. 1975. Polish observations on the course of Georges Bank herring spawning in relation to catch per tow, 1972-1974. Inst. Comm. Northw. Atlant. Fish., Res. Doc. 75/37, Ser. AG 3516: 5 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.

Schultz, H. 1974. The fecundity of Georges Bank herring in 1971. ICNAF Res. Doc. 74/119, Ser. No. 3372, 8 pp.

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

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

Yudanov, I.G. 1966. Fecundity and efficiency of spawning of Atlantic herring in the Gulf of Maine. Trudy PINRO 17: 249-262

Table 1. Catch in tons by month and year for the Georges Bank herring fishery**.

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1961					11	1	2980	12611	16375	15719	15318	4535	67550
1962	41	5798	2132	7116	19853	24669	26142	22636	28079	11182	3211	1282	152141
1963	15	126	179	334	281	3059	28551	24540	29630	9160	512	1276	97646
1964	719	27	169	1549	9753	14948	19554	25566	47650	8721	1725	567	130949
1965	496	11	1015	5681	8426	7068	1253	1276	11496	1859	716	2395	41691
1966	959	698	2516	1025	6222	28456	36443	20286	31127	7148	402	3114	138396
1967	--	118	4305	13940	26836	27165	33790	26268	33983	23222	12447	15458	217532
1968	138	9517	27838	37738	24356	17376	33006	54543	108996	38075	14281	6976	372840
1969	6038	12624	9105	27470	20824	23944	30433	42960	71343	39299	15725	7315	307080
1970	6652	10656	16033	10936	9846	14887	13858	18023	74056	39591	14729	16016	245283
1971	3765	9939	7726	10209	15918	19159	22130	29669	68999	54908	13331	7799	263552
1972	582	3667	4265	5675	5601	10434	9597	23940	56588	37931	6325	6803	171408
1973	4368	8691	7784	12347	12700	11033	9413	31098	58063	38288	2468	1455	197708
1974	872	1273	2362	4184	16139	12689	10372	19840	37887	32474	7137	911	146140
1975	211	782	1900	4880	5802	5270	7310	15836	52902	31046	6988	8587	141514
1976	192	146	183	1053	778	1031	78	5755	24248	7238	1926	135	42763
1977#	512	958	306	14	--	--	--	-	--	--	--	--	1790
TOTAL	25560	65031	87810	144141	183346	221189	284910	374847	751422	395861	117241	84624	2735982
%	0.94	2.38	3.21	5.27	6.70	8.08	10.41	13.70	27.46	14.47	4.29	3.09	100.0

THERE WAS NO DISTANT WATER FLEET FISHERY FOR HERRING AFTER APR 1977
THE USA HERRING CATCHES IN 5Z-5A6 HAVE BEEN REMOVED AND ADDED TO THE GULF OF MAINE LANDINGS
THIS IS BASED ON TAGGING STUDIES AND AGE COMPOSITION DATA FROM RESEARCH AND COMM. VESSELS
E

Table 2. Catch in tons by month and year for the Gulf of Maine adult herring fishery.*

	Years															
Month	67	68	69	70	71	72	73	74	75	76	77	78	79	80	%**	Total
Jan	123	49	2360	1259	1197	1025	983	1025	2371	1068	2717	2896	2538	546	6.13	20157
Feb	81	195	519	155	418	596	1623	10779	2223	985	3584	5764	1499	3842	8.88	32263
Mar	564	212	363	391	360	869	1975	1386	3754	2965	3128	3664	3455	5497	7.22	28583
Apr	95	180	1444	159	612	969	1158	2819	1428	3746	2789	280	129	106	4.94	15914
May	424	356	808	1349	605	361	672	17	136	645	1094	477	6	132	2.17	7082
Jun	170	1594	88	421	1668	59	14	44	71	3	4	510	32	3172	1.46	7850
Jul	91	6780	1301	2306	2706	4279	580	311	639	1297	146	41	1603	5732	6.90	27812
Aug	100	6410	6162	5000	8403	7351	1611	86	913	1930	1808	46	8204		15.01	48024
Sep	3156	8296	11722	5838	16696	3676	320	576	1068	3817	1285	2106	7094		20.52	65650
Oct	2093	5529	5334	13970	5232	1144	332	1403	3138	2335	671	1462	50		13.34	42693
Nov	1755	2765	1513	6310	1481	866	438	1512	3617	1957	654	2419	1		7.90	25288
Dec	205	227	4460	5040	2020	297	121	2117	1629	117	392	1005	37		5.53	17667
Total	8857	32593	36074	42198	41398	21492	9827	22075	20987	20865	18272	20670	24648	19027		333983

*Includes USA catches taken in 5Z+6.

**Calculated for 1967-79 only.

Table 3. Spawning condition (percent) of herring from Georges Bank according to observations made by the Federal Republic of Germany (Dornheim 1980).

Year	month	total number sampled	prespawning (Stage 5)	ripe (Stage 6)	spent (Stage 7+8)
1967	Sept	96	91	3	0
	Oct	39	0	0	100
1968	Aug	413	66	1	6
1969	Aug	485	62	0	1
	Sept	441	28	58	5
	Oct	550	0	13	74
1970	Aug	1069	19	0	0
	Sept	512	46	45	2
1971	Aug	366	41	0	0
	Sept	502	4	95	0
	Oct	289	0	100	0
1972	Aug	236	75	0	0
	Sept	1015	62	19	4
	Oct	868	11	64	13
1973	Aug	464	27	0	0
	Sept	939	51	21	3
	Oct	144	76	10	8
1974	Sept	1684	74	14	8
1975	Aug	593	56	0	0
	Sept	395	93	0	0
1976	Aug	614	77	0	1
	Sept	145	46	40	11

Table 4. Fishing mortality, spawning stock size, and catch at age for the Georges Bank herring fishery (ICNAF Div. 5Z and Statistical Area 6) for annual periods of October 1 to September 30

FISHING MORTALITY

YEAR	AGES 1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	MEAN F-AGE 3/4+
1961-62	.000	.000	.069	.540	2.226	2.857	2.851	3.582	.000	.000	.000	1.087
1962-63	.005	.056	.123	.429	.489	.564	2.046	1.937	1.100	.000	.000	.669
1963-64	.008	.083	.106	.204	.532	.685	3.882	1.100	1.100	.000	.000	.182
1964-65	.000	.009	.036	.050	.146	.130	.004	1.100	.000	.000	.000	.086
1965-66	.000	.005	.031	.118	.202	.284	.271	.046	.000	.000	.000	.134
1966-67	.001	.001	.021	.096	.191	.322	.730	3.057	.247	.000	.000	.214
1967-68	.014	.038	.090	.351	.447	.491	.810	.237	1.100	1.100	.000	.384
1968-69	.000	.029	.202	.492	.526	.817	.866	.644	.880	.000	.000	.486
1969-70	.044	.140	.313	.389	.419	.463	.777	.716	1.293	2.783	.000	.432
1970-71	.035	.499	.388	.690	.626	.719	.853	.811	.801	2.627	1.100	.600
1971-72	.012	.030	.679	1.082	1.021	1.095	1.003	1.121	.827	1.153	1.100	.911
1972-73	.001	.281	.921	1.178	1.274	1.879	2.007	2.687	3.560	1.100	1.100	1.223
1973-74	.021	.195	.467	.600	.691	.900	.813	1.237	1.100	1.100	.000	.492
1974-75	.001	.128	.777	.781	1.155	.835	.787	.971	1.937	.000	.000	.731
1975-76	.038	.085	.249	1.569	1.416	2.075	1.449	1.141	1.100	1.100	.000	1.357
1976-77	.001	.100	.100	.100	.500	.700	1.100	1.100	.900	.000	.000	.402

STOCK SIZE (MILLIONS)

	1	2	3	4	5	6	7	8	9	10	11	TOTAL STOCK-AGE 3+ NUMBERS	BIOMASS
1961	4419.1	1003.7	768.0	303.0	467.5	195.7	29.1	7.1	.0	.0	.0	1770.4	333.5
1962	3638.4	3983.4	877.2	586.8	144.6	41.3	9.2	1.4	.2	.0	.0	1660.7	285.9
1963	2204.7	2957.8	3085.6	635.4	312.7	72.6	19.3	1.0	.2	.0	.0	4126.8	684.5
1964	1981.0	1791.2	2229.6	2271.3	424.1	150.3	30.0	.3	.0	.0	.0	5105.6	892.1
1965	1698.4	1592.1	1454.3	1762.0	1769.1	300.1	108.1	24.4	.0	.0	.0	5418.0	1040.9
1966	1913.5	1460.9	1298.5	1154.2	1281.6	1183.4	185.0	67.5	19.1	.0	.0	5189.3	1073.8
1967	1981.7	1520.2	1206.4	1041.9	858.6	866.5	702.5	73.0	2.6	12.2	.0	4763.7	931.4
1968	1346.0	1600.1	1198.1	902.4	600.4	449.4	434.3	255.8	47.2	.0	.0	3887.6	799.4
1969	1185.4	1122.6	1272.6	802.7	451.6	290.6	162.5	149.6	109.9	16.0	.0	3255.5	641.0
1970	931.7	891.5	799.0	762.2	446.9	243.2	149.8	61.1	59.9	24.7	.8	2547.6	505.1
1971	4100.2	736.6	443.1	444.0	312.9	196.8	97.0	52.3	22.2	22.0	1.5	1791.8	322.2
1972	200.7	3316.8	585.2	184.0	123.2	92.3	54.3	29.1	13.9	8.0	5.7	1095.7	172.8
1973	59.6	167.2	2051.2	190.8	46.4	28.2	11.5	5.9	1.6	.3	.0	2335.9	364.6
1974	108.2	47.8	112.7	1052.3	85.7	19.0	9.4	4.2	1.4	.0	.0	1284.7	234.6
1975	2.9	89.3	34.4	42.4	394.7	22.1	6.8	3.5	1.3	.2	.0	505.4	108.0
1976	110.4	2.3	67.1	22.0	7.2	78.4	2.3	1.3	.9	.0	.0	179.2	35.1

CATCH AT AGE (MILLIONS)

	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	TOTAL-AGE 3-4+ NUMBERS	WEIGHT
1961-62	.2	.1	46.6	115.6	391.0	174.3	25.9	6.6	.0	.0	.0	760.0	171.6
1962-63	17.4	195.2	91.9	187.0	51.1	16.3	7.5	1.1	.1	.0	.0	355.0	73.4
1963-64	16.4	212.9	282.9	106.8	118.0	33.0	18.0	.6	.1	.0	.0	559.4	105.2
1964-65	.7	14.0	70.6	100.5	52.2	16.6	.1	.2	.0	.0	.0	240.2	39.9
1965-66	.2	7.7	40.6	178.7	294.4	67.5	23.4	1.0	.0	.0	.0	613.3	132.4
1966-67	1.2	.9	23.9	95.9	176.1	296.5	87.9	60.9	3.8	.0	.0	771.9	203.0
1967-68	25.1	51.4	94.6	281.3	282.8	307.1	358.3	14.0	1.6	7.5	.0	1347.2	303.0
1968-69	.5	41.6	197.0	320.6	224.5	230.5	231.3	111.3	25.4	.0	.0	1340.6	231.4
1969-70	44.8	133.3	311.3	232.4	141.0	98.3	80.6	70.1	73.8	14.2	.0	1021.7	212.5
1970-71	29.2	320.1	234.2	348.4	186.9	114.4	79.0	31.2	30.3	21.6	.5	1046.5	212.4
1971-72	44.3	19.8	200.1	270.7	184.4	118.0	56.6	32.5	11.5	13.9	.9	868.5	190.5
1972-73	.1	738.9	324.1	117.7	82.1	73.0	42.6	25.6	12.9	4.9	3.5	686.4	117.9
1973-74	1.1	26.9	699.6	78.8	21.2	15.4	5.9	3.8	1.0	.2	.0	825.9	144.3
1974-75	.1	5.2	55.9	523.5	54.2	9.9	4.7	2.4	1.1	.0	.0	651.7	134.6
1975-76	.1	6.8	6.9	31.2	277.1	18.1	4.8	2.2	.8	.1	.0	341.8	79.2
1976-77	.1	.2	5.8	1.9	2.6	30.2	1.4	.8	.5	.0	.0	49.2	10.3

Table 5. Fishing mortality, spawning stock size and catch at age for the Western Gulf of Maine adult fishery (Jeffreys Ledge) for annual periods of October 1 to September 30.

FISHING MORTALITY

YEAR	AGES 1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	MEAN F-AGE 3/4
67-69	.001	.062	.085	.164	.192	.239	.260	.170	.544	.287	1.100	.180
68-69	.004	.033	.063	.126	.267	.300	.379	.549	.567	1.100	1.100	.238
69-70	.010	.029	.195	.125	.142	.230	.248	.234	.328	.373	.000	.191
70-71	.006	.205	.242	.345	.568	.912	1.595	.986	2.333	2.428	1.100	.750
71-72	.017	.189	.655	.659	.853	.830	.521	.660	.240	1.100	1.100	.594
72-73	.001	.052	.193	.787	1.095	1.483	1.775	1.763	1.710	1.100	.000	.949
73-74	.089	.090	.169	.200	.393	.357	.497	.441	.320	.971	.000	.185
74-75	.002	.243	.234	.268	.226	.911	.490	.792	.704	1.568	1.100	.279
75-76	.002	.124	.309	.328	.434	.772	.930	1.050	.551	.971	1.100	.422
76-77	.015	.132	.302	.643	.496	.609	.817	1.100	1.100	1.100	1.100	.476
77-78	.005	.168	.226	.403	.519	.451	.671	.550	.000	.000	.000	.430
78-79	.050	.195	.600	.680	.600	.700	.700	.800	.900	.000	.000	.641

STOCK SIZE (MILLIONS)

	1	2	3	4	5	6	7	8	9	10	11	TOTAL STOCK-AGE 3+	
1967	342.3	250.1	184.8	177.6	167.3	148.7	89.4	19.7	5.5	1.3	.2	794.5	165.7
1968	204.2	278.8	192.4	138.9	123.5	113.0	95.9	56.4	13.6	2.6	.8	737.1	157.9
1969	162.8	166.3	220.9	148.0	100.3	77.4	68.6	53.7	26.7	6.3	.0	701.9	147.2
1970	104.4	132.1	132.3	148.8	106.9	71.2	50.3	43.8	34.8	15.7	3.6	607.4	132.6
1971	819.9	84.9	88.1	85.0	86.3	49.6	23.4	8.4	13.4	2.8	1.1	358.1	74.4
1972	160.0	660.0	57.6	37.5	36.0	30.1	17.7	11.4	3.5	8.6	.0	202.4	43.2
1973	110.8	131.2	512.9	38.9	13.8	9.9	5.6	2.5	1.6	.5	.0	585.7	84.1
1974	246.6	83.0	98.1	354.6	26.1	7.6	5.7	2.8	1.3	1.0	.2	497.4	87.0
1975	102.7	202.1	53.3	63.6	222.0	17.0	2.5	2.8	1.0	.5	.2	362.9	77.9
1976	182.2	84.0	146.2	32.0	37.5	117.8	6.4	.8	.8	.5	.2	342.2	65.0
1977	339.0	147.0	60.3	88.5	13.8	18.7	52.5	2.3	.0	.0	.0	236.1	53.1
1978	97.2	276.2	101.7	39.4	48.4	6.7	9.7	21.9	1.1	.0	.0	228.9	43.2

CATCH AT AGE (MILLIONS)

	1/2	2/3	3/4	4/5	5/6	6/7	7/8	8/9	9/10	10/11	11/12	TOTAL CATCH-AGE 3/4 NUMBERS	UEIGHT
67-68	.4	13.7	13.7	24.4	26.6	28.8	18.6	2.8	2.1	.3	.1	117.4	27.0
68-69	.7	8.2	10.6	14.9	26.3	26.7	27.6	21.8	5.4	1.6	.5	135.4	32.6
69-70	1.4	4.3	35.6	15.8	12.1	14.5	13.7	10.2	6.8	1.8	.0	110.5	27.8
70-71	.6	22.3	25.9	39.6	42.4	39.2	37.3	25.3	29.5	13.5	2.2	254.9	56.2
71-72	12.8	13.3	38.8	37.6	45.5	25.7	8.7	3.7	2.6	1.7	.7	165.0	26.3
72-73	.2	30.5	9.2	18.9	22.1	21.6	13.7	8.8	2.7	5.3	.0	102.3	17.2
73-74	8.6	10.3	72.5	6.4	4.1	2.7	2.0	.8	.4	.3	.0	89.2	16.4
74-75	.5	16.3	18.6	76.0	4.8	4.2	2.0	1.4	.6	.7	.1	108.4	15.9
75-76	.2	21.4	12.9	16.2	71.3	8.4	1.4	1.7	.4	.3	.1	112.7	22.8
76-77	2.4	9.4	34.7	13.9	13.4	49.2	3.3	.5	.5	.3	.1	115.9	20.8
77-78	1.6	20.7	11.1	26.8	5.1	6.2	23.5	.9	.0	.0	.0	73.6	15.5
78-79	4.3	44.6	42.8	17.8	20.0	3.1	4.5	11.1	.6	.0	.0	99.1	23.4

Table 6. Percent maturity and Number of Atlantic sea herring sampled from Georges Bank by the Federal Republic of Germany. (Dornheim, 1980)

Year	Month	Age 3		Age 4	
		n	% mature	n	% mature
1967	Sept.	1	100	9	100
1968	Aug.	28	43	46	89
1969	Aug.-Sept.-Oct.	213	56	405	93
1970	Aug.-Sept.	263	63	754	100
1971	Aug.-Sept.	529	92	314	100
1972	Aug.-Sept.-Oct.	163	96	604	100
1973	Aug.-Sept.-Oct.	1,315	96	84	100
1974	Sept.	58	67	1,478	100
1975	Aug.-Sept.	6	100	156	100
1976	Aug.-Sept.	59	77	22	100

Table 7. Number of Atlantic sea herring sampled by the U.S. from the Georges Bank and Gulf of Maine areas from August to October with percentage mature at ages 3 and 4.

Year	Georges Bank				Gulf of Maine			
	Age 3		Age 4		Age 3		Age 4	
	n	%	n	%	n	%	n	%
1960	100+	62	100+	97	100+	2	100+	79
1961	100+	6	100+	87	100+	0	100+	92
1962	100+	56	100+	95	100+	15	100+	66
1963	100+	33	100+	97	100+	27	100+	96
1964	100+	9	100+	93	100+	1	100+	92
1965	100+	10	100+	79	100+	7	100+	70
1966	100+	0	100+	90	100+	12	100+	60
1967	8	50	100+	91	100+	17	100+	74
1968	38	28	100+	96	100+	4	100+	65
1969	--	--	--	--	100+	7	100+	60
1970	60	61	100+	92	100+	4	100+	58
1971	--	--	--	--	--	--	--	--
1972	--	--	--	--	--	--	--	--
1973	--	--	71	96	--	--	--	--
1974	25	72	508	60	--	--	--	--
1975	--	--	--	--	--	--	--	--
1976	--	--	--	--	--	--	--	--
1977	8	100	78	99	13	46	67	95

Table 8. Percent maturity and number of Atlantic sea herring sampled from the Western Gulf of Maine by the United States.

Year	month	Age 3		Age 4	
		n	% mature	n	% mature
1978	August	147	18	55	96
	September	62	10	6	100
	October	54	7	4	100
	Total	263	14	65	97
1979	August	125	21	18	100
	September	130	13	19	95
	October	163	28	38	100
	Total	418	21	75	99

Table 9. Percent maturity and number of Atlantic sea herring sampled from the Western and Central sections of the Maine herring fishery.

Year	month	Age 3		Age 4	
		n	% mature	n	% mature
1978	August	141	29	62	97
	September	59	15	7	100
	October	48	3	7	100
	Total	248	21	76	98
1979	August	125	2	--	--
	September	158	5	4	100
	October	145	23	32	97
	Total	428	10	36	97

Table 10. Mean length at age for the month of September[1] from the Georges Bank herring fishery (numbers of fish in brackets).

YEAR	AGES 3	4	5	6	7	8	9	10	11
62	25.4 (32)	27.8 (411)	29.3 (179)	30.6 (47)	31.9 (7)	32.9 (2)	34.2 (1)		
63	24.4 (456)	27.8 (140)	29.2 (291)	30.3 (147)	31.4 (42)	32.6 (3)	33.1 (2)		
64	23.7 (24)	27.3 (345)	29.5 (45)	30.6 (68)	31.8 (39)	32.9 (7)	34.5 (1)	34.1 (36)	33.5 (2)
65	25.2 (80)	27.1 (87)	29.0 (122)	31.0 (12)	32.0 (13)	33.0 (4)	34.0 (4)		
66	25.8 (1)	28.0 (20)	29.4 (96)	30.6 (118)	32.1 (34)	33.0 (18)	34.2 (8)		
67	25.3 (10)	27.7 (35)	29.2 (35)	30.4 (155)	31.8 (73)	33.0 (23)	34.6 (13)	34.5 (1)	
68	25.5 (3)	27.1 (13)	29.1 (50)	30.3 (53)	31.7 (50)	32.9 (18)	33.5 (86)	34.5 (21)	35.3 (5)
69	25.4 (114)	28.2 (149)	30.1 (84)	31.3 (81)	32.2 (52)	33.0 (68)	33.4 (89)	33.6 (7)	34.4 (5)
70	24.5 (34)	27.1 (29)	28.9 (20)	30.5 (11)	31.9 (7)	32.9 (18)	33.9 (6)		
71	25.0 (303)	27.1 (145)	28.9 (116)	30.4 (58)	32.5 (13)	32.7 (20)	33.7 (6)		
72	25.8 (144)	28.5 (190)	30.1 (472)	31.6 (292)	32.6 (268)	33.6 (132)	34.5 (108)	35.1 (34)	35.6 (62)
73	26.1 (1229)	28.7 (97)	30.7 (57)	31.2 (47)	32.3 (25)	32.7 (14)	33.5 (6)	34.4 (11)	35.5 (1)
74	26.3 (127)	29.1 (1954)	32.7 (250)	33.9 (133)	34.9 (83)	35.4 (26)	34.9 (7)	36.0 (1)	
75	27.4 (141)	29.5 (369)	30.6 (1776)	32.6 (74)	33.4 (58)	34.1 (30)	35.4 (10)	36.0 (3)	
76	25.1 (39)	29.3 (66)	30.6 (182)	31.3 (1028)	33.5 (47)	35.3 (3)	34.9 (7)	35.0 (2)	35.5 (2)

[1]For years 1962-65, 1974-76 the September mean lengths at age were determined from 3rd quarter age/length keys.

Table 11. Mean lengths at age for the month of September[1] from the Western Gulf of Maine herring fishery (numbers of fish in brackets).

	AGES							
YEAR	3	4	5	6	7	8	9	10
68	25.0 (94)	26.5 (128)	28.4 (134)	30.1 (89)	31.3 (131)	32.3 (98)	33.7 (22)	34.6 (1)
69	24.4 (308)	26.3 (116)	28.8 (128)	30.2 (223)	31.6 (191)	32.4 (121)	33.5 (94)	34.6 (1)
70	24.3 (230)	26.7 (210)	28.2 (151)	29.9 (132)	31.4 (109)	32.4 (71)	33.7 (74)	34.6 (1)
71	24.8 (740)	26.9 (851)	28.9 (1262)	30.0 (139)	31.4 (222)	32.3 (478)	33.5 (606)	34.6 (1)
72	25.8 (40)	28.5 (86)	30.3 (73)	31.8 (34)	33.6 (16)	35.0 (4)	35.0 (1)	35.0 (1)
73	24.7 (43)	29.9 (13)	31.3 (9)	31.5 (11)	33.1 (31)	35.0 (6)	35.0 (1)	35.0 (1)
74	25.0 (1)	27.9 (37)	29.0 (1)	31.0 (1)	33.0 (5)	33.0 (8)	33.3 (4)	35.0 (2)
75	25.8 (12)	28.6 (2)	29.7 (35)	31.0 (2)	33.0 (2)	32.5 (2)	33.0 (2)	34.3 (1)
76	25.7 (63)	28.5 (26)	29.4 (28)	30.5 (69)	33.0 (6)	33.8 (5)	33.8 (5)	35.0 (1)
77	26.6 (7)	28.6 (36)	30.8 (4)	30.8 (4)	31.7 (36)	32.3 (3)	33.3 (1)	34.0 (1)
78	25.8 (90)	29.0 (63)	30.3 (112)	31.9 (12)	31.6 (8)	32.8 (65)	33.0 (3)	34.5 (2)
79	26.5 (99)	29.0 (76)	30.8 (32)	32.0 (22)	33.3 (4)	33.8 (4)	33.8 (7)	34.6 (1)

[1] 1968-72 mean lengths were determined from 3rd quarter age/length keys.

Table 12. Mean lengths (cm) of herring of recent year classes (1968 and later) compared with lengths of earlier year classes for two areas (length weighted over year classes by number sampled).

	GEORGES BANK					WESTERN MAINE			
	Year Classes					Year Classes		Year Classes	
	1960-1963	1964-1967	1968-1971			1957-1967		1968-1973	
AGE	LENGTH (cm)	LENGTH (cm)	LENGTH (cm)	AGE	MONTH	LENGTH (cm)	NUMBER	LENGTH (cm)	NUMBER
2.00	15.1		14.7	1	May	4.8	200		
2.25	16.5	15.5	16.5	1	June	4.7	200	5.8	100
2.50	21.3	20.6	21.7	1	July	5.6	131	6.2	100
2.75	20.1	20.9	21.5	1	Aug.	11.0	228		
3.00	20.2	21.6	22.8	1	Sept.	12.3	1217	14.3	4
3.25	21.7	22.2	21.5	1	Oct.	13.0	1054	14.5	53
3.50	24.5	24.3	25.0	1	Nov.	14.7	411	15.1	73
3.75	24.4	25.1	25.0						
4.00	23.9	25.9	27.0	2	Jan.	12.6	154		
4.25	26.1	26.4	27.7	2	Feb.	12.7	581	13.5	93
4.50	27.4	27.2	28.4	2	Mar.	13.2	853	15.3	40
4.75	27.1	27.2	29.1	2	Apr.	13.8	299		
5.00	26.7	27.5	29.8	2	May	15.8	1733	16.9	55
5.25	27.9	28.0	30.0	2	June	15.9	3830	17.4	220
5.50	29.0	28.9	30.3	2	July	16.7	3425	18.6	379
5.75	29.1	29.2	30.4	2	Aug.	16.8	3340	18.9	227
6.00	29.7	30.4	30.7	2	Sept.	18.5	2049	20.8	130
6.25	30.0	29.6		2	Oct.	19.0	1656	21.0	355
6.50	30.4	30.4		2	Nov.	18.9	219	20.1	158
6.75	30.6	30.6							
7.00	30.6	32.9		3	Jan.	16.8	19	20.9	14
7.25	31.3	29.8		3	Feb.	17.1	109	17.6	12
7.50	31.8	32.5		3	Mar.	17.3	238	18.0	10
7.75	31.8	32.0		3	Apr.	18.1	81		
8.00	31.5	33.8		3	May	17.5	117		
8.25	32.2			3	June	18.7	1222	22.7	64
8.50	32.8			3	July	19.9	735	22.3	61
8.75	32.6			3	Aug.	21.7	442	22.9	17
9.00	32.5			3	Sept.	22.6	513	25.9	64
9.25	32.4			3	Oct.	22.7	477	25.0	94
				3	Nov.	23.0	74	23.6	44
L_∞	34.1	34.5	33.3						
K	.350	.357	.510						
t_o	.228	.257	.803						

Table 13. Fecundity of Atlantic herring from Georges Bank and the Gulf of Maine areas (thousands of eggs).

Total Length (cm)	Georges Bank				Gulf of Maine
	Draganik and Rast (1970) Year 1968	Schultz (1974) Year 1971	Yudanov (1966) Year 1962	Perkins and Anthony (1969) Year 1963/64	Perkins and Anthony (1969) Year 1963/64
25.0	20	35	55	28	18
26.0	25	40	58	41	33
27.0	30	47	65	55	49
28.0	38	53	73	68	64
29.0	45	68	83	81	79
30.0	55	80	96	94	95
31.0	67	90	107	107	110
32.0	80	103	119	120	126
33.0	95	132	131	133	141
34.0	113	157	162		
35.0	123	127	167		

Table 14. Estimated egg production ($x10^{-9}$) for mature herring from the Georges Bank stock by year and age, based on scaled fecundity relationships.

	AGE									
YEAR	3	4	5	6	7	8	9	10	11	TOTAL
1961	781.4	4332.9	19405.4	9398.4	1547.6	404.6				35870.3
1962	487.1	6971.2	5784.0	1945.8	487.6	84.0				15759.7
1963	1712.6	7548.6	12512.0	3412.2	1028.2	60.0	14.7			26288.3
1964	1237.4	21987.2	13574.4	6392.0	1500.0	23.0				44714.0
1965	591.9	16668.6	44230.0	9456.3	4760.8	1207.8				76915.4
1966	576.5	6355.9	33321.6	37277.1	7030.0	3312.4	1094.4			89467.9
1967	1017.4	6870.6	17601.3	23831.5	23185.0	2920.0	124.8	628.3		76178.9
1968	1674.4	10323.5	21914.6	19099.5	21720.0	14708.5	2714.0			92154.5
1969	2147.2	9963.8	13999.6	12059.9	7804.8	8228.0	6875.0			61078.3
1970	1246.9	8048.8	13220.0	9728.0	7714.7	3151.8	3960.0			47070.2
1971	3496.5	13090.8	14867.5	14515.2	6062.5	3746.2	1720.5	1793.0	130.4	59422.6
1972	5129.0	6027.9	6468.0	5405.4	3550.5	1971.0	1071.0	668.0	501.7	30792.5
1973	17979.0	7422.8	3132.0	2213.7	986.0	507.5	136.0	36.0	513.0	32956.0
1974	1246.9	36631.6	4290.0	1187.5	686.2	331.8	118.3			44492.3
1975	301.6	1649.5	20924.0	1320.9	513.4	315.0	117.6	17.5		25159.5
1976	599.9	873.9	388.8	4821.6	192.0	119.0	85.0			7080.2

Table 15. Estimated egg production ($x10^{-9}$) for mature herring from the Gulf of Maine stock by year and age.

	AGE									
Year	3	4	5	6	7	8	9	10	11	Total
1967	5.2	795.1	2899.4	6020.6	4917.0	1395.9	394.8	109.2	15.6	16552.8
1968	0.6	621.9	2140.9	4572.1	5280.0	3553.2	958.8	202.8	62.4	17392.7
1969	1.5	662.2	1739.0	2604.2	3773.0	3389.4	1889.4	499.2		14557.9
1970	0.9	395.2	836.9	2717.0	2772.0	2759.4	2453.4	1113.9	280.8	13329.5
1971	13.0	1004.4	2234.3	2191.7	1649.7	722.4	1152.4	240.8	103.2	9311.9
1972	1.0	548.4	1077.9	1334.4	949.0	890.4	309.6	379.6		5490.3
1973	92.7	432.9	433.2	401.8	394.8	183.3	112.8	42.3		2093.8
1974	17.7	5141.2	554.2	319.4	408.9	176.4	98.7	70.5	15.6	6802.6
1975	9.9	922.1	5004.3	617.1	183.3	197.4	70.5	42.3	17.2	7064.1
1976	48.5	464.0	1019.2	4276.1	352.0	50.4	56.4	46.8	15.6	6329.0
1977	10.8	1585.7	433.1	790.2	2893.0	151.2				5430.9
1978	33.7	705.2	1311.9	327.4	690.9	1551.0	84.6			4704.7

Table 16. Estimates of the Georges Bank and Gulf of Maine stock (age 3+) in weight (MT) and two estimates of egg production.

	Georges Bank				Gulf of Maine		
Year	Stock Size Age 3+ (Fully Recruited) MT	Stock Size Age 3+ (fully recruited and mature) MT	Egg Production Scaled Fecundity no's $x10^{-9}$	Egg Production Constant Fecundity no's $x10^{-9}$	Stock Size Age 3+ (Fully recruited) MT	Stock Size (Fully Recruited and mature) MT	Egg Production no's $x10^{-9}$
1961	200	188	35870	33968			
1962	109	96	15760	15609			
1963	211	160	26288	34714			
1964	362	325	44714	55299			
1965	665	643	76915	120283			
1966	761	749	89468	137554			
1967	723	713	76179	131943	94	86	16553
1968	547	537	92155	132460	96	90	17393
1969	389	378	61078	144433	85	78	14558
1970	320	313	47070	57786	81	76	13330
1971	263	163	59423	56196	40	38	9312
1972	146	145	30793	26856	28	27	5490
1973	186	177	32956	27650	30	15	2094
1974	178	182	44492	38118	43	40	6803
1975	102	104	25160	21676	42	41	7064
1976	29	29	7080	5936	38	34	6329
1977					31	29	5431
1978					25	22	4705

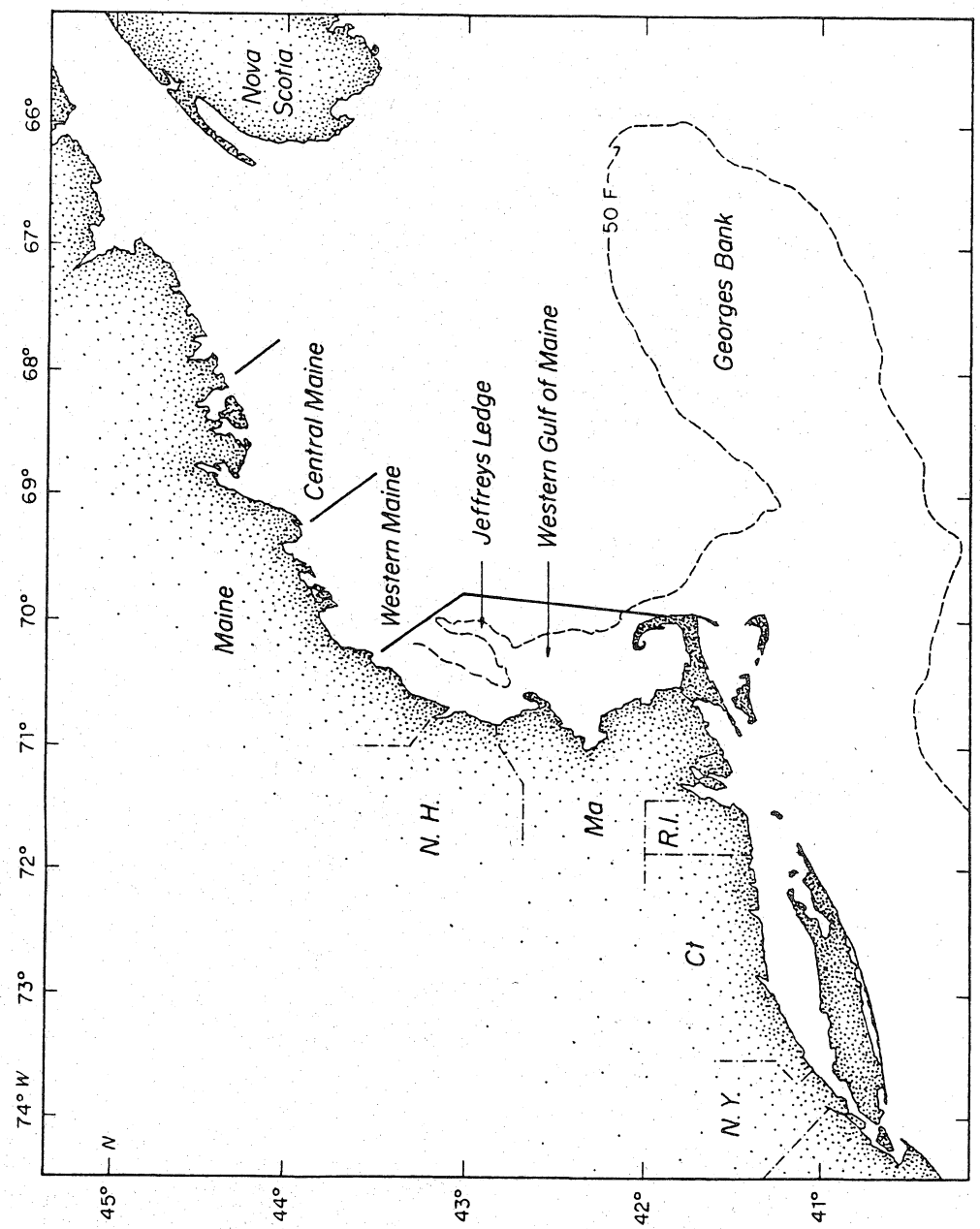

Figure 1. Description of areas mentioned in text.

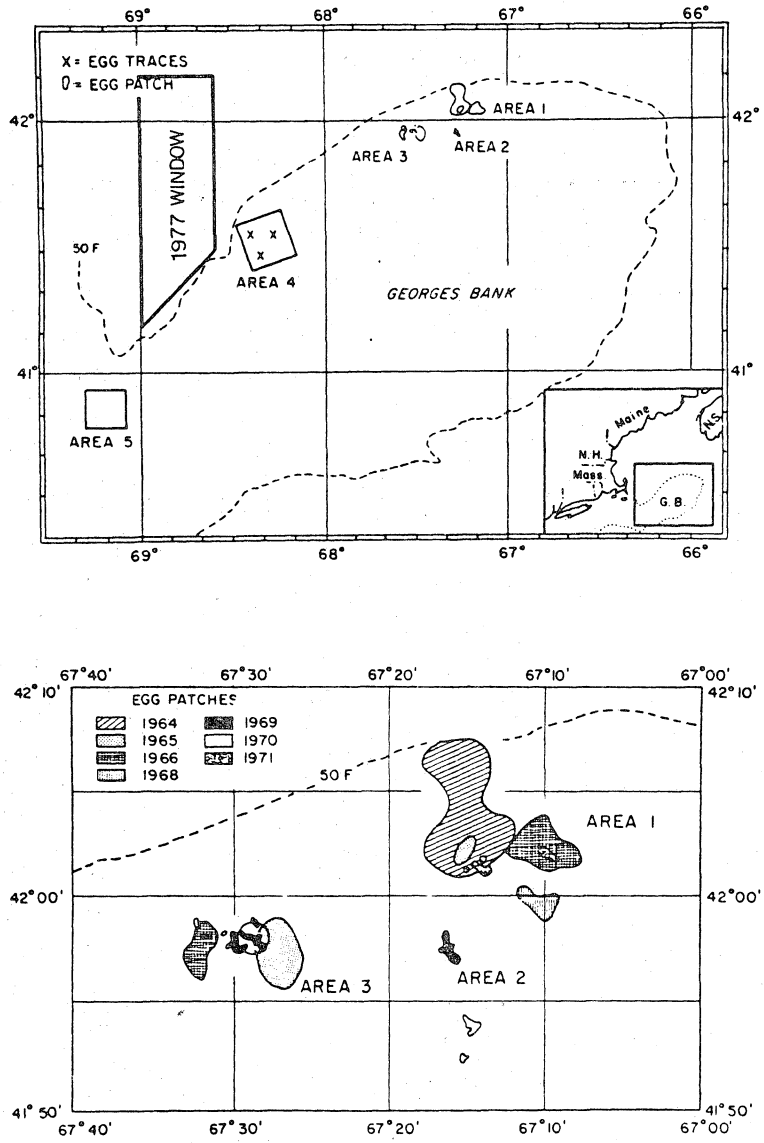

Figure 2. Herring spawning areas on Georges Bank and the "window" opened for fishing in 1977.

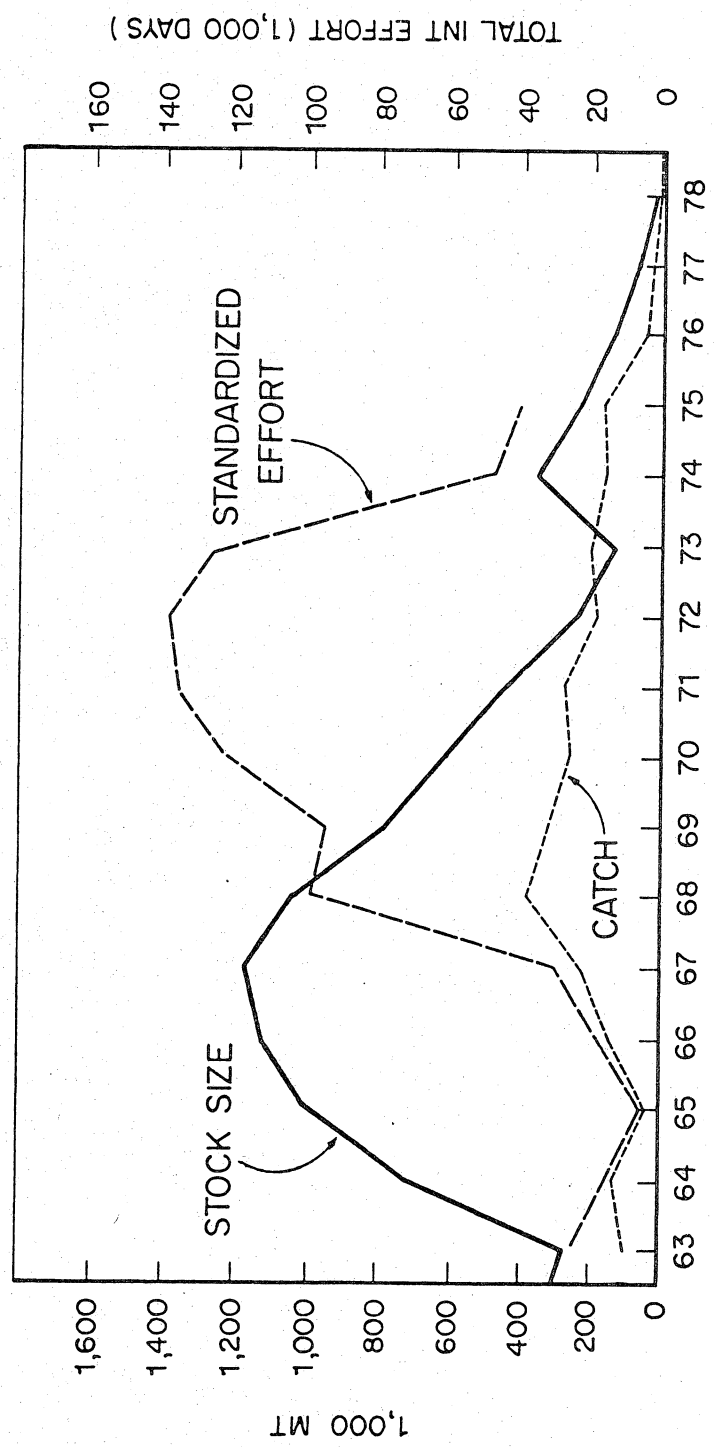

Figure 3. Herring stock size (age 4 and older) effort and catch (age 3 and older) for the Georges Bank herring fishery.

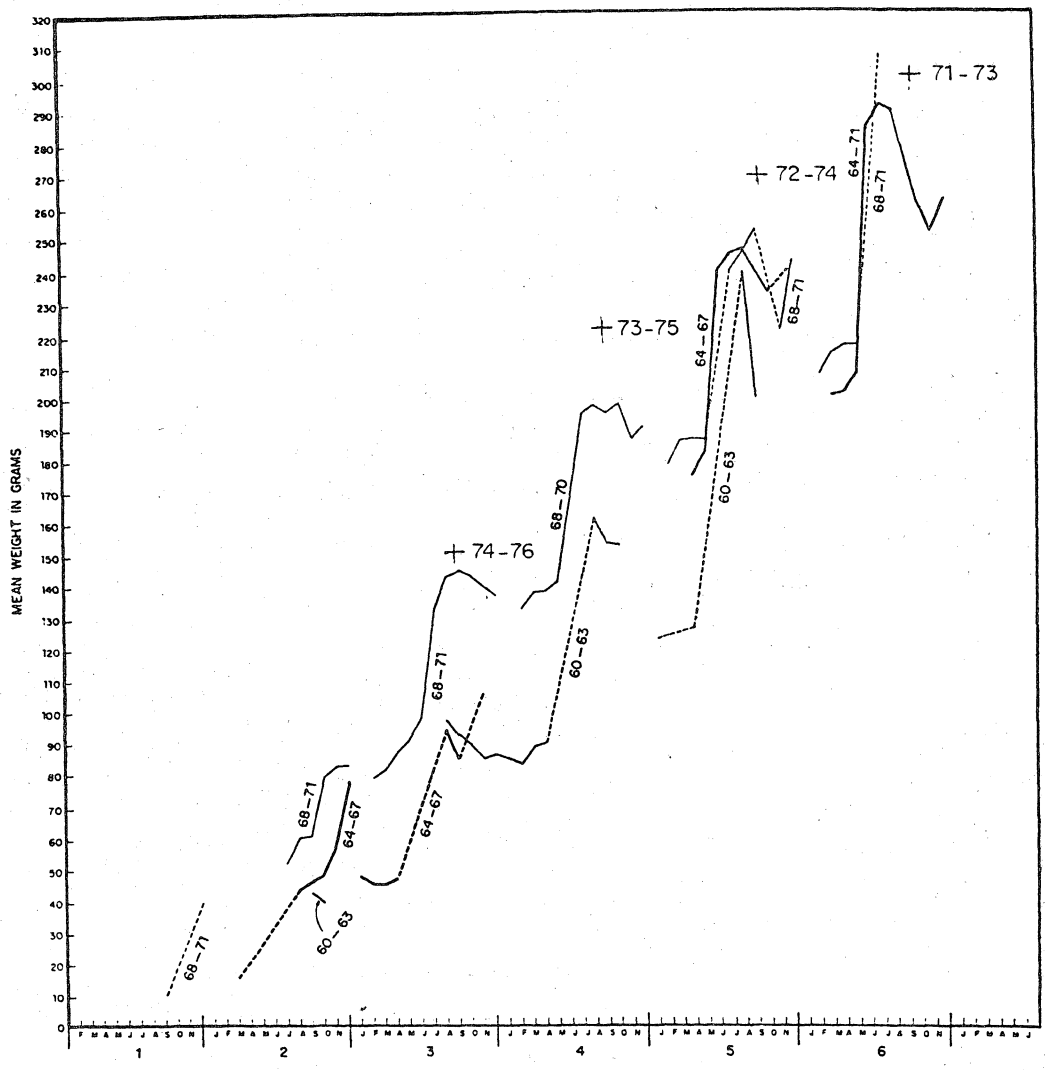

Figure 4. Mean weights of herring by month from the Jeffreys Ledge (western Gulf of Maine) fishery showing the increase in mean weight beginning with the 1968 year class. (Year classes given on each curve).

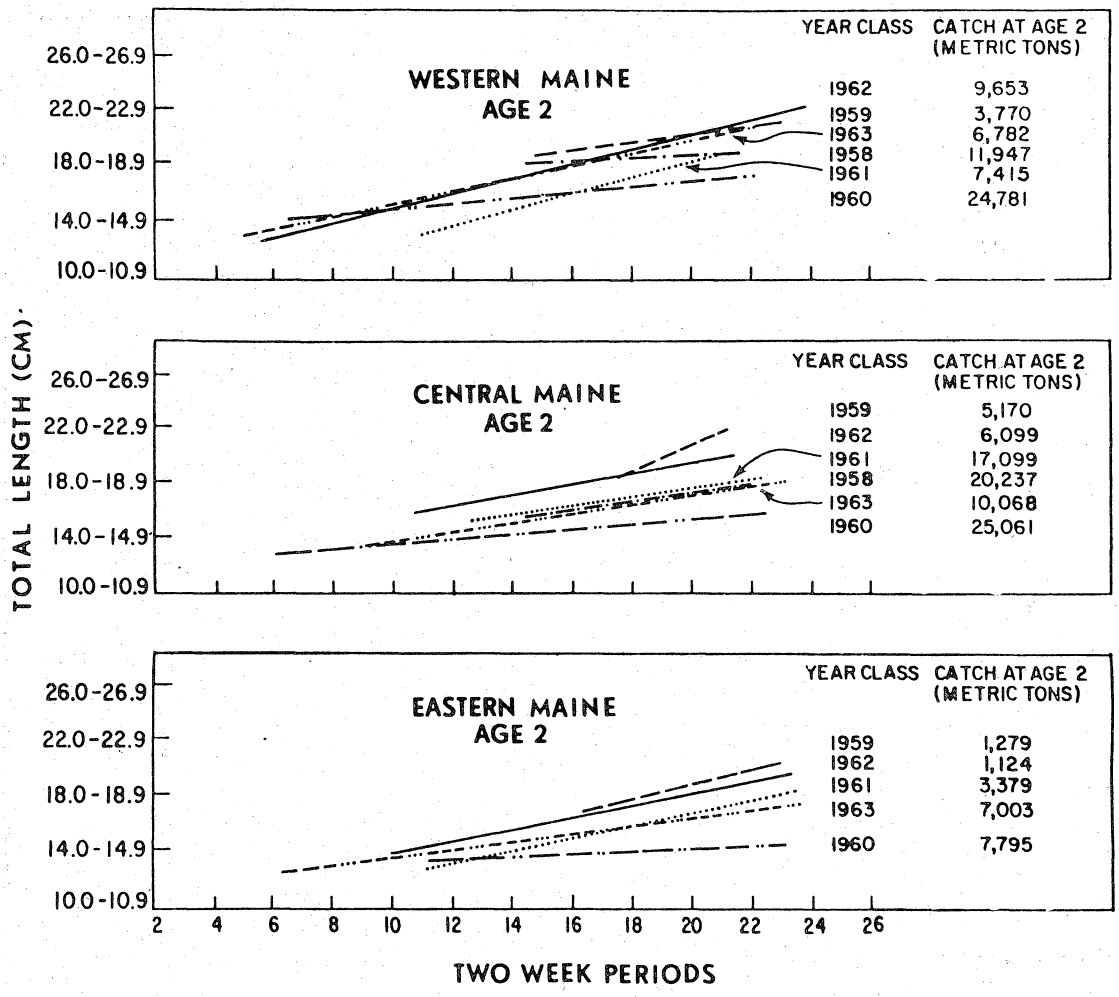

Figure 5. Plots of smoothed modal lengths at age 2 compared with the total herring catch at age 2 from the Maine juvenile fishery.

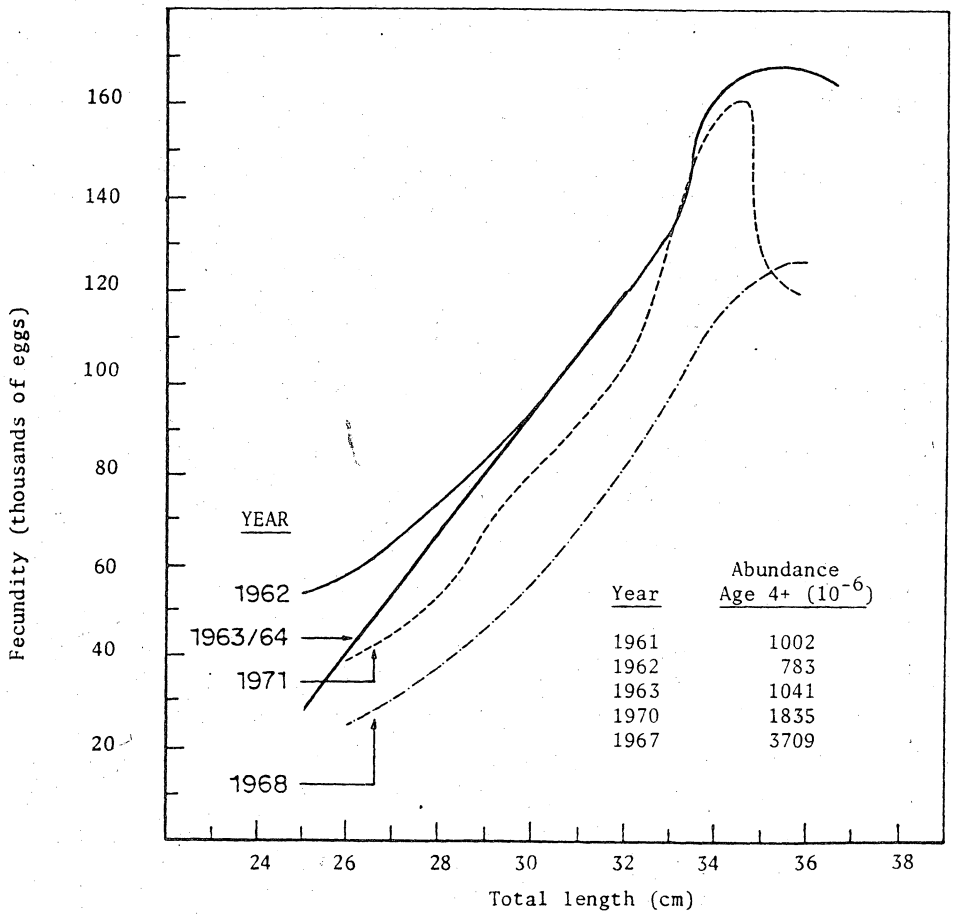

Figure 6. Mean fecundity of Georges Bank herring in relation to total length in years 1962, 1963/1964, 1968, and 1971. (From Schultz, 1974, except 1963/64 data from Perkins and Anthony 1969).

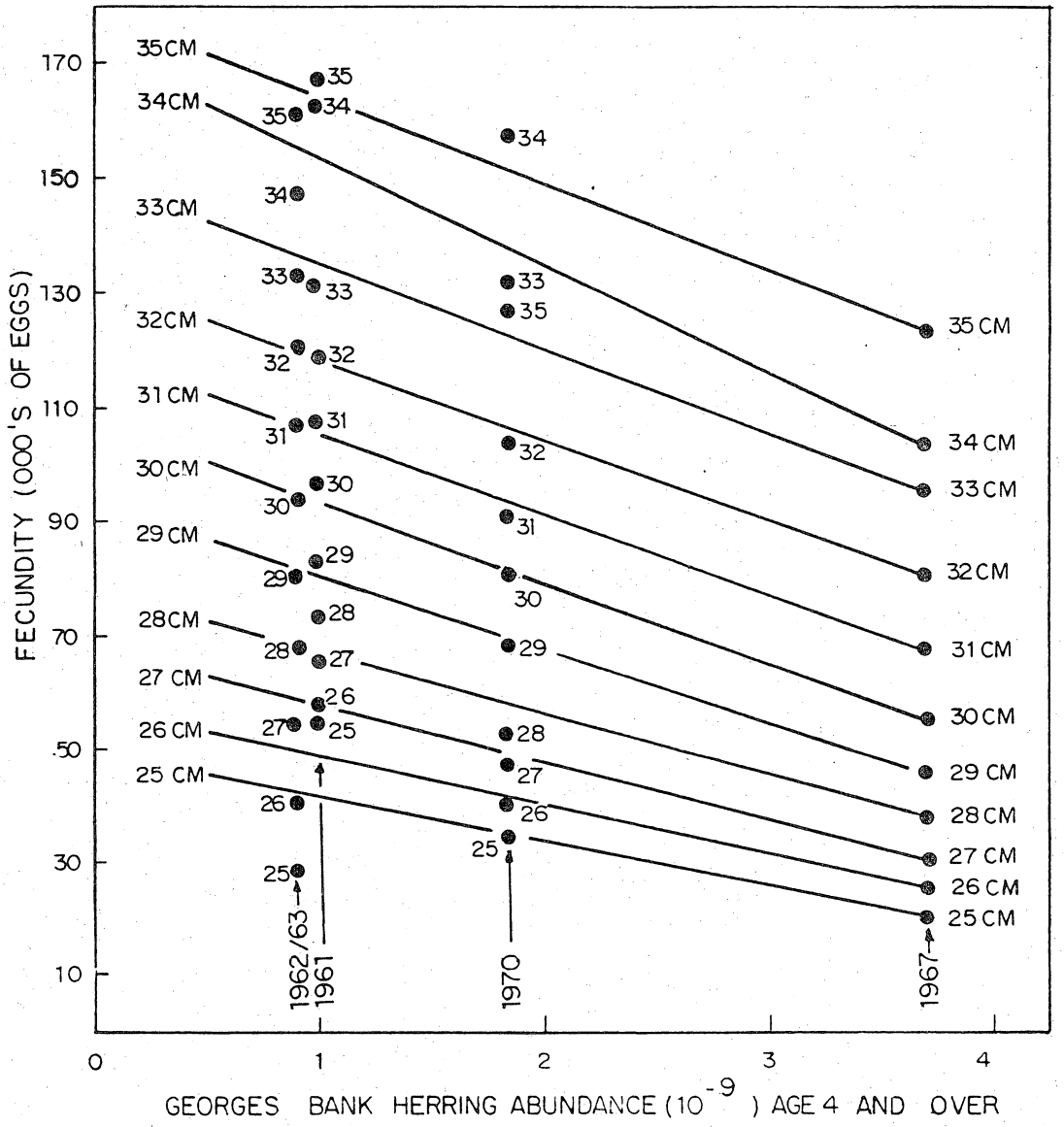

Figure 7. Change in fecundity by centimeter groups according to abundance in the previous year for the Georges Bank herring fishery.