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Review and Assessment of the Georges Bank and Gulf of Maine Haddock Fishery

Stephen H. Clark, William J. Overholtz and Richard C. Hennemuth
National Marine Fisheries Service, Northeast Fisheries Center
Woods Hole, Massachusetts 02543, USA

Abstract

The Georges Bank and Gulf of Maine haddock resource and fishery is reviewed. Nominal catches for Georges Bank averaged 46,000 metric tons annually during 1935-60 and then increased to a peak of 150,000 tons in 1965 as Canadian and distant water (European) fleets entered the fishery. Catches subsequently declined to an average of 5,000 tons during 1974-76 under quota and incidental catch limitations and then increased rapidly to an average of 21,000 tons in 1978-79. Nominal catches for the Gulf of Maine averaged 5,000 tons during 1935-66, declined to less than 1,000 tons during 1972-74 and increased to an average of 5,000 tons in 1978-79. Minor recreational catches have also been reported from the western Gulf of Maine in recent years.

Total stock size (age 2 and older haddock) for Georges Bank, determined from virtual population analysis, averaged 140 million fish (153,000 tons) during 1935-60, increased to 530 million fish (427,000 tons) in 1965 and declined precipitously to 8 million fish (22,000 tons) in 1972. Subsequently, there was a substantial increase in stock size due to recruitment of the 1975 year-class. The 1978 year-class appears to be comparable in size to that of 1975. Instantaneous fishing mortality (F) for age 3 and older fish averaged 0.44 during 1935-60, increased to a peak of 0.79 in 1966 and subsequently declined as abundance decreased and fishing effort was diverted to other species. Trends in abundance and mortality evidenced by data from research vessel surveys since 1963 have been generally consistent with those indicated by virtual population analysis. Variability in growth of Georges Bank haddock during 1931-65 and pronounced changes in the late 1960's and early 1970's appear primarily attributable to changes in abundance. Reduction in spawning stock biomass during the late 1960's and early 1970's was associated with low recruitment and increased variability in year-class size. Trends in abundance for the Gulf of Maine were similar to those observed for Georges Bank, although discrepancies were evident in relative strengths of recent year-classes.

Introduction

The haddock, *Melanogrammus aeglefinus* (L.), has supported the groundfish fishery of the New England area of the United States of America (USA) for many decades. Prior to 1900, this species was of minor importance commercially, being inferior to Atlantic cod, *Gadus morhua*, for salting purposes. Nominal catches (live weight equivalent of landings) were relatively constant during the 1880-1903 period, averaging about 24,500 (metric) tons annually (Power, 1958). In the early days of the fishery, the catch was taken primarily by hand-lines and line-trawls, but the Vigneron-Dahl trawl was introduced in 1905 and became the more prominant gear by 1920. Initially, haddock were usually marketed fresh, and until the 1920's catch trends were determined primarily by market demand for fresh fish. During that decade, however, increased demand for haddock, associated with introduction of filleting and quick-freezing techniques at dockside (Schuck, 1951; Power 1958), expansion of ice-making facilities, use of trawls, and introduction of diesel engines (Smith and Olsen, MS 1976), resulted in rapid expansion of the fishery, and the total USA catch of haddock in the Northwest Atlantic increased rapidly from 41,200 tons in 1921 to a peak of 132,200 tons in 1929. During this period, the bulk of the catch was taken on Georges Bank and in the Gulf of Maine (NAFO Subarea 5), although substantial quantities were also taken on Browns Bank (NAFO Division 4X) and areas farther eastward (Fig. 1). Subsequently, the

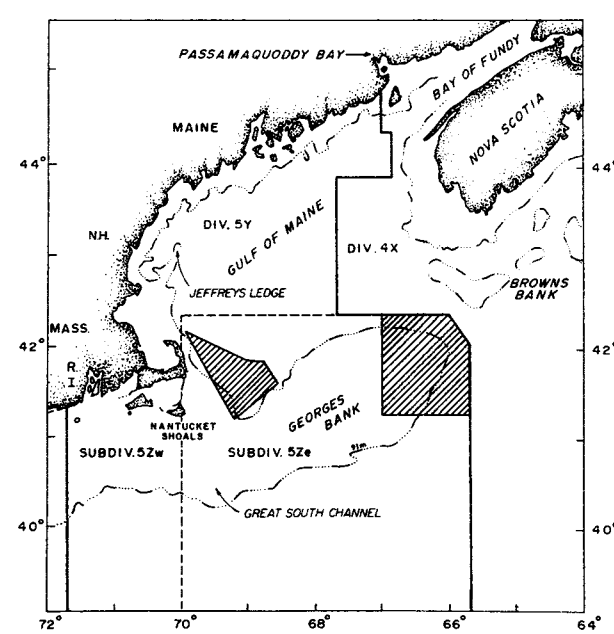

Fig. 1. Georges Bank and Gulf of Maine areas with place names and boundaries of divisions mentioned in the text. (Cross-hatched areas are subject to seasonal closure.)

USA catch declined sharply to an average of 75,400 tons annually during 1932-34 and stabilized at an average level of 70,300 tons during 1935-60. Over this period, USA catches from the Georges Bank-Gulf of Maine area averaged about 52,000 tons.

The entrance of distant-water fleets to the Georges Bank (Div. 5Z) fishery in the 1960's resulted in pronounced changes in haddock abundance and productivity. Catches on Georges Bank peaked at 150,400 tons in 1965 and subsequently declined to only 4,300 tons in 1974 due to poor recruitment and redirection of fishing effort to other species. In recent years, recruitment has improved and catches have increased, but abundance, age structure and other biological features have remained very different from the situation in 1935-60. Similar changes occurred in the Gulf of Maine (Div. 5Y), although catches by distant-water fleets appear to have been minimal.

The objectives of this paper are to review available biological and fishery-related data for Georges Bank and Gulf of Maine haddock, to provide an analytical assessment of the Georges Bank stock together with available assessment information for the Gulf of Maine, and to evaluate the implications of recent changes in abundance with respect to recruitment and growth.

History of Research

Georges Bank haddock have received intensive study, and a large volume of biological and statistical data has been assembled and published for this fishery. Organized research began in 1930, when funding was made available to the U.S. Bureau of Fisheries for haddock research in response to industry concern over rapidly declining landings and abundance (Schuck, 1951). Beginning in 1931, haddock landings were intensively sampled at major ports (Boston and Gloucester, Massachusetts, and Portland, Maine); data were collected on quantities landed by area (Rounsefell, 1948), size and age compositions, and other biological features, e.g. length-weight relationships. Much of the information for 1931-56 has been summarized by Schuck (1951), Clark and Dreyer (1961), and McCann and Dreyer (1963). Later material was published in the Sampling Yearbook series of the International Commission for the Northwest Atlantic Fisheries (ICNAF) and was also incorporated into assessment papers and other documents. Catch and effort data were collected and used for evaluation of trends in abundance (Schuck, 1949; Rounsefell, 1957) and for predictive purposes (Royce and Schuck, 1954). Considerable attention was also focused on discarding of small haddock (Herrington, 1935, 1936; Prematz, 1953). Other earlier contributions include studies on migration and stock identification (Needler, 1930; Schroeder, 1942; Schuck and Arnold, 1951), stock-recruitment (Herrington, 1948), and the influence of currents on larval distribution and survival (Walford, 1938).

During the 1950's, interest focused on gear selectivity (Graham, 1952; Clark, 1952) and evaluation of mesh regulations (Graham and Prematz, 1955; Clark, 1963). Colton (1955) studied seasonal distribution of haddock, Chase (1955) and Colton and Temple (1961) examined environmental influences on year-class size, and Clark and Vladykov (1960) and Grosslein (1962) provided further information on stock boundaries.

More recent work has been oriented largely toward stock assessment. Hennemuth (MS 1968, MS 1969) assessed the status of the Georges Bank stock and examined trends in abundance, mortality and recruitment; this work was subsequently updated by Clark and Overholtz (MS 1979) and Clark and Essig (MS 1980). Grosslein and Hennemuth (1973) reviewed factors affecting recruitment, and Grosslein (MS 1969) devised young-of-year indices based on bottom-trawl survey data. Hennemuth (1965) analyzed commercial age-length data to evaluate sampling and reporting requirements, Brown and Hennemuth (1971) provided length-weight equations and conversion factors for commercial landings, and Stern and Hennemuth (1975) applied Robson's two-factor analysis-of-variance approach to catch-effort data. Papers by Colton (1965) on distribution of eggs, larvae and juveniles and by Marak and Livingstone (1970) on spawning should also be noted.

Management

Prior to 1951, there was no legal basis for fishery management in international waters of the Northwest Atlantic. However, the need for management of the Georges Bank haddock fishery, to increase yield for a given level of fishing effort, was clearly demonstrated by extensive discarding of small haddock in the 1930's and 1940's (Herrington, 1936; Prematz, 1953; Graham and Prematz, 1955) which resulted from the use of trawl codends with stretched mesh sizes averaging 2.9 inches (73 mm). Establishment of ICNAF in 1951 provided an authority for management, and in June 1953 a regulation specifying a minimum mesh size of 4.5 inches (114 mm) in the trawl body and codend became effective for Subarea 5 (ICNAF, 1952). This regulation persisted with minor modifications until 1974, when the minimum codend mesh size was increased to 130 mm (5.1 inches). The regulation substantially increased harvesting efficiency (Graham and Prematz, 1955) and also appears to have reduced the quantities of haddock discarded from an average of 10-15% to

about 1-5% of the nominal catch (Grosslein and Hennemuth, 1973). Attempts have been made to evaluate the actual effect of this regulation on yield per recruit and total yield, but this has been difficult to quantify due to improved recruitment following its implementation.

Events during the 1960's substantially changed the status of the haddock resource in Subarea 5 and resulted in more intensive conservation measures. The documented severe reduction in abundance of Georges Bank haddock by 1969 led to the establishment under ICNAF of a total allowable catch (TAC) of 12,000 tons for 1970 and 1971 (ICNAF, 1969). The TAC was reduced to 6,000 tons for 1972 and 1973 and to zero (except for incidental by-catch) for 1974. The TAC was set at 6,000 tons for 1975 and 1976, as it was considered that a TAC would be more effective in controlling fishing mortality. These conservation measures were supplemented by closure of major haddock spawning areas to demersal trawling during March-April since 1970 (ICNAF, 1969), with subsequent minor modifications in boundary lines, duration of closure and gear restrictions (Fig. 1).

In 1977, the New England Regional Fishery Management Council assumed exclusive responsibility for management of the Georges Bank and Gulf of Maine haddock stock under the USA Fishery Conservation and Management Act of 1976. The Council adopted a fishery management plan which in effect continued previous management measures for haddock implemented under ICNAF. The objective of the resulting management system was to set an optimum yield (OY)[1] so as to achieve the greatest possible economic and social net benefits from the groundfish resource while ensuring that, by the end of the period covered by the plan, relevant stocks would be at levels which would produce enhanced and relatively stable yields. An OY of 6,200 tons (6,000 tons commercial, 200 tons recreational) was established for 1977 to be taken as incidental by-catch. Recruitment of the large 1975 year-class in 1977, together with a rapid increase in USA harvesting capacity and fishing effort, led to a series of increases in the OY and modifications in allocation schemes during 1977-78, culminating in removal of incidental catch limitations and an increase in the OY to 20,000 tons in July 1978, of which 16,900 tons were allocated for USA interests and 3,100 tons for Canada.

Management on a "fishing year" (October-September) rather than on a calendar year basis was implemented in October 1978. This permitted more timely use of autumn bottom-trawl survey data in determining the annual OY, i.e. autumn survey data could be used in winter or spring assessments and also as the basis for establishing the OY for the succeeding fishing year. Consequently, an assessment in January 1979, which indicated a substantial increase in spawning stock size and improved recruitment prospects (Clark and Overholtz, MS 1979), led to an OY for Subarea 5 of 28,254 tons for the 1978/79 fishing year and 32,500 tons for the 1979/80 fishing year, corresponding to an instantaneous fishing mortality (F) equal to the $F_{0.1}$ level (Gulland and Boerema, 1973). USA and Canadian allocations were 25,154 and 3,100 tons respectively for 1978/79 and 27,250 and 5,250 tons for 1979/80. In both fishing years, the USA allocations provided for an anticipated recreational harvest of 2,000 tons.

Biology

The most important spawning grounds in the Georges Bank-Gulf of Maine area are on eastern Georges Bank, although in some years significant spawning has also occurred in the Nantucket Shoals-Great South Channel region (Walford, 1938; Bigelow and Schroeder, 1953; Posgay and Marak, 1970; Colton and St. Onge, 1974). Some spawning is also known to occur northward along the Maine coast (Bigelow and Schroeder, 1953; Grosslein, 1962). Depth of spawning, based on collections of spawning adults, varies from 28 to 110 m (R. Livingstone, Northeast Fisheries Center, pers. comm., March 1980).

Georges Bank haddock spawn between January and June, with peak activity usually during late March-April (Bigelow and Schroeder, 1953), although bottom temperatures may delay or advance this peak by a month or more (Marak and Livingstone, 1970). Individual females may produce up to 3 million eggs depending upon size (Livingstone, pers. comm., March 1980). Eggs are planktonic, ranging from 1.2 to 1.7 mm in diameter, and hatch in about 13 days at 5°C; absorption of the yolk sac requires 10 days at this temperature (Bigelow and Schroeder, 1953). Survival prior to hatching appears to be highest when the temperature range is 4° *to 10°*C (Laurence and Rogers, 1976). That study indicated that haddock embryos are less tolerant of temperature and salinity extremes than cod embryos. Laurence *et al.* (1981) observed that, in direct feeding competition studies, growth and survival rates of cod larvae were superior to those of haddock. Laurence (1974) also found that haddock larvae may have a critical period after hatching when mortality may be great depending on the availability of planktonic prey.

Juveniles are pelagic in habit for several months (Colton and Temple, 1961; Colton, 1965), the phase

[1] "Optimum yield" of a fishery is defined as the amount of fish (a) that will provide the greatest overall benefit to the nation (USA) with particular reference to food production and recreational opportunities, and (b) which is prescribed as such on the basis of the maximum sustainable yield from such fishery, as modified by any relevant economic, social or ecological factors. (Fishery Conservation and Management Act of 1976; US Public Law 94-265; 94th Congress, H. R. 200, April 13, 1976).

possibly extending into winter, as they do not appear to be fully available to capture by bottom-trawl survey gear until the following spring. Little is known about the pelagic phase of the life cycle, although Colton and Temple (1961) reported a close association between juvenile haddock and the common red jellyfish, *Cyanea* sp., and Bigelow and Schroeder (1953) indicated that they feed on planktonic crustaceans. Subsequently, juveniles settle to the bottom, where they remain for the rest of their lives. Small invertebrates, especially echinoderms, crustaceans and annelid worms constitute the bulk of the diet during the demersal phase of the life span (Wigley, 1956; Wigley and Theroux, 1965; Maurer and Bowman, MS 1975).

In maturation studies of Georges Bank haddock, Clark (1959) found that 21% of age 2 and 88% of age 3 fish were sexually mature, based on limited sampling during 1949-50. In more recent studies, Livingstone (pers. comm., March 1980) found that 46% of all age 2 haddock (64% male, 28% female) and 83% of all age 3 fish (90% male, 76% female) examined during 1968-72 were sexually mature and that the percentages subsequently increased to 54% for age 2 fish (74% male, 34% female) and to 95% for age 3 fish (98% male, 92% female) based on sampling during 1973-75.

Stock Structure

The Georges Bank haddock population (east of the Great South Channel, Fig. 1) appears to be relatively isolated from other areas. Early tagging studies (Needler, 1930; Schroeder, 1942; Grosslein, 1962), age composition and growth data (Needler, 1930; Schuck and Arnold, 1951), and meristic (vertebral) data (Clark and Vladykov, 1960) indicated practically no interchange between Georges Bank and areas to the east. Needler (1930) concluded that "the deep water of the Fundian Channel and of the central basin of the Gulf of Maine forms an effective barrier separating the haddock of the New England region from those of the Nova Scotian region", which might be expected in that haddock are uncommon at depths exceeding 100 fathoms (183 m) (Bigelow and Schroeder, 1953). Later tagging studies (Halliday and McCracken, 1970) also indicated little interchange of haddock between Georges Bank and Gulf of Maine areas and western Nova Scotia waters, and USA bottom-trawl surveys for 1975-77 likewise indicate a more or less discontinuous distribution (Fig. 2). Previous tagging studies also indicated little interchange between Georges Bank and the Nantucket Shoals and Gulf of Maine areas (Schroeder, 1942; McCracken, 1960; Grosslein, 1962).

Stock structure in the Nantucket Shoals-Gulf of Maine region is less clear. Tagging data from early studies suggested haddock movements in these areas to be limited (Schroeder, 1942; Bigelow and Schroeder, 1953). However, McCracken (1960), from tagging studies in Passamaquoddy Bay, found evidence for seasonal northward movement in the western Gulf of Maine in spring, followed by a reverse migration in early winter, and also evidence for some movement across the Bay of Fundy to western Nova Scotia. Small numbers of tagged haddock were also recaptured on Georges Bank. Grosslein (1962) hypothesized the existence of two somewhat distinct stocks in the western Gulf of Maine: a seasonally-migratory group (evidenced by McCracken's (1960) studies) ranging primarily from Jeffreys Ledge to the Bay of Fundy, and a relatively non-migratory group extending from Jeffreys Ledge to Nantucket Shoals. Grosslein also reported the existence of separate egg concentrations in the Great South Channel-Nantucket Shoals area and the western Gulf of Maine, although later ichthyoplankton data indicated a more or less continuous distribution (Colton and St. Onge, 1974). Early age composition and growth studies indicated a fairly close relationship between haddock of the Nantucket Shoals and Gulf of Maine areas (Needler, 1930). Bottom-trawl survey data for 1975-77 (Fig. 2) reveal only minor seasonal differences in distribution, indicating that haddock in these areas are relatively non-migratory.

In summary, previous studies have indicated the existence of two or possibly three groups of haddock in the Georges Bank-Gulf of Maine region, a Georges Bank group and one or two groups in the Nantucket Shoals-western Gulf of Maine area. Available data do not permit evaluation of the degree of intermixing among these groups, but interchange between these areas and Georges Bank does not appear to be extensive. It is possible that some interrelationships exist between these groups, as Grosslein and Hennemuth (1973) found generally good agreement between year-class size in the Georges Bank, Gulf of Maine and Browns Bank areas, i.e. the same year-classes have historically tended to be relatively strong or weak throughout the region, but discrepancies have been noted (e.g. the 1978 year-class was estimated to be strong on Georges Bank and weak in other areas). Although the apparent consistency may be attributable in part to uniform environmental conditions favoring or inhibiting larval survival, a more direct association (e.g. larval drift between areas) may also be involved. Trends in nominal catches and abundance indices for Georges Bank and the Gulf of Maine (discussed below) have also closely paralleled each other. In the absence of more definitive data, haddock in the Gulf of Maine (Div. 5Y) and in the area from Nantucket Shoals to eastern Georges Bank (Div. 5Z) have been considered separately in this paper. These have been the traditional areas used for statistical reporting and sampling since the early 1930's, thereby facilitating use of the existing data base.

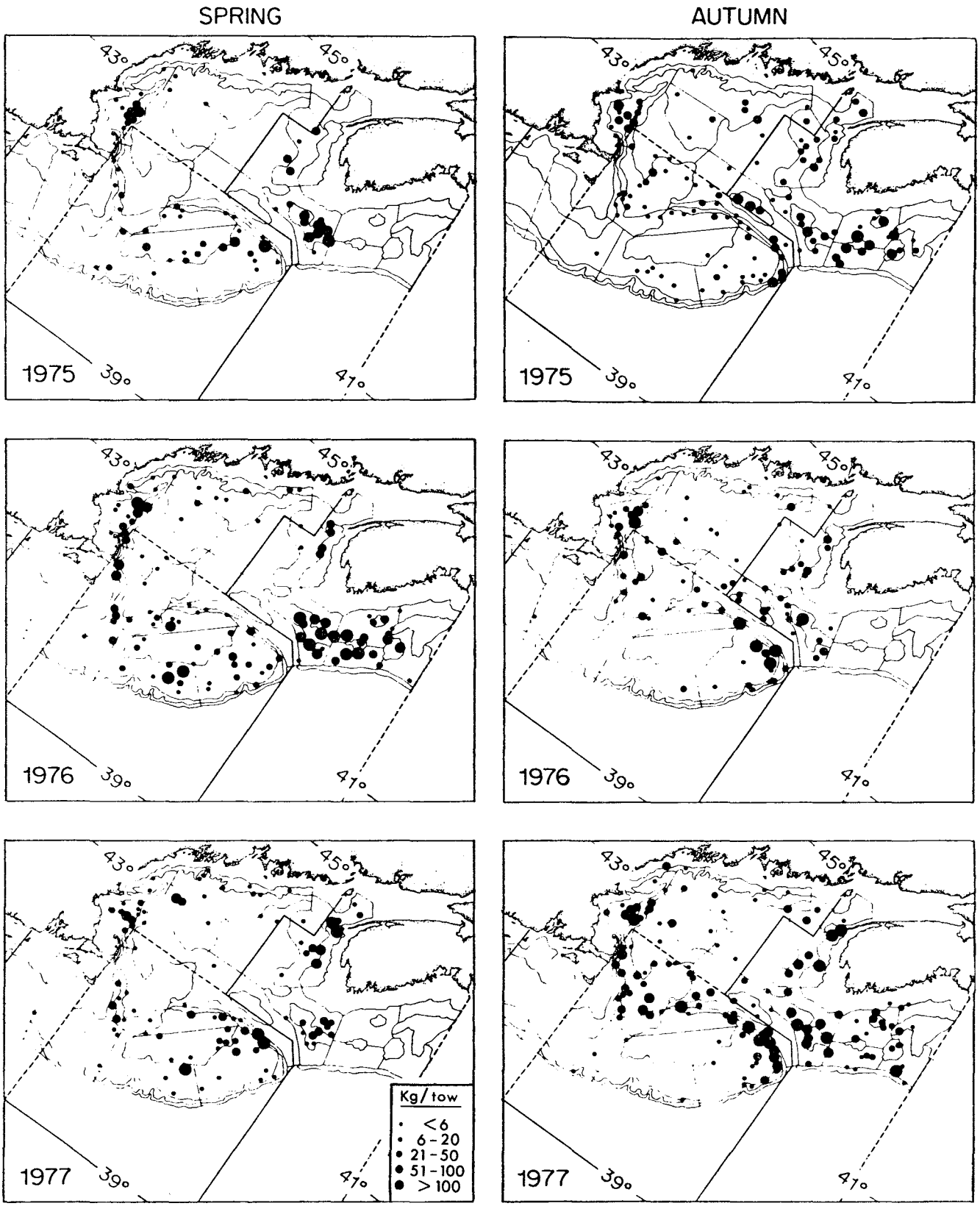

Fig. 2. Distribution of haddock (kg per tow) observed during USA spring and autumn bottom trawl surveys in Div. 4X and Subarea 5, 1975-77.

Commercial Fishery

Nominal catches

Hennemuth (MS 1969) recognized three periods in the history of the Georges Bank haddock fishery. The first of these, from the early 1900's to the early 1930's, constituted a "developmental period" during which nominal catches increased rapidly in response to technological improvements in the industry and changes in consumer preference. Consequently, the Georges Bank catch increased to a peak of 115,500 tons in 1929 but subsequently decreased to about 26,000 tons in 1934 as declining catch rates led to a diversion of fishing effort to other areas and species. The fishery then entered a period of stability during 1935–60, when fishing effort was relatively constant and catches averaged about 46,000 tons annually (Fig. 3). During these periods, the stock was exploited almost entirely by USA vessels.

The third period was marked by a rapid increase in fishing effort by distant-water (European) fleets and Canadian vessels, with a corresponding increase in haddock catches, followed by pronounced declines in abundance and productivity. The first catches by distant-water fleets were reported by Union of Soviet Socialist Republics (USSR) in 1962 (Table 1). In succeeding years of good recruitment and high abundance, the USSR catch increased to a peak of 81,900 tons in 1965, declined to 48,400 tons in 1966 and dropped sharply thereafter as fishing effort was diverted towards herring, *Clupea harengus*, and mackerel, *Scomber scombrus*. The Canadian catch also increased rapidly in the early 1960's to 18,300 tons in 1966, and the USA catch increased from 40,800 tons in 1960 to an average of 52,900 tons in 1965–66. Other

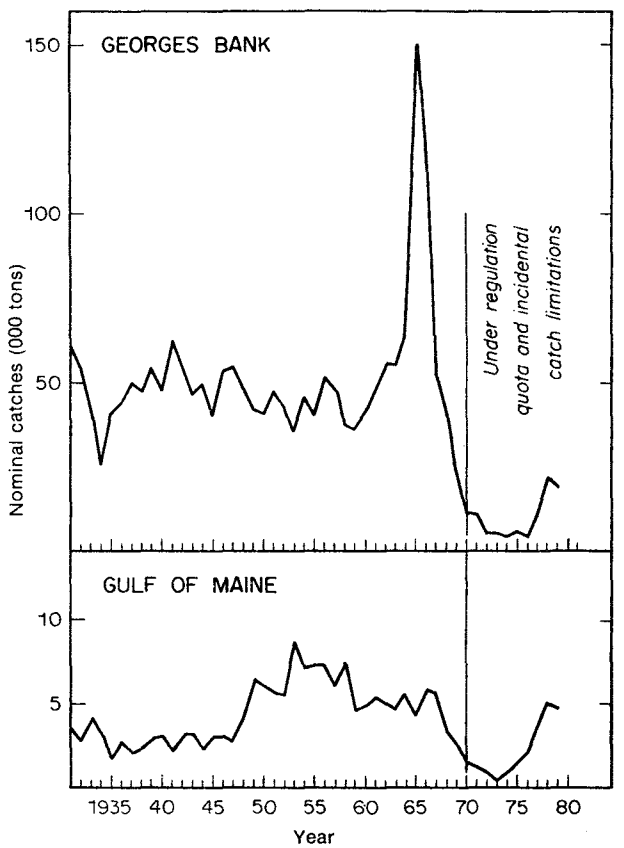

Fig. 3. Trends in nominal catches of haddock from Georges Bank and Gulf of Maine areas, 1931–79.

TABLE 1. Nominal catches (metric tons) of haddock from the Georges Bank and Gulf of Maine areas, 1956–79.[a]

Year	USA	Canada	USSR	Spain	Others[b]	Total
Georges Bank						
1956	51,144	—	—	—	—	51,144
1957	48,561	—	—	—	—	48,561
1958	37,322	—	—	—	—	37,322
1959	36,051	—	—	—	—	36,051
1960	40,800	77	—	—	—	40,877
1961	46,384	266	—	—	—	46,650
1962	49,409	3,461	1,134	—	—	54,004
1963	44,150	8,379	2,317	—	—	54,846
1964	46,512	11,625	5,483	2	464	64,086
1965	52,823	14,889	81,682	10	758	150,362
1966	52,918	18,292	48,409	1,111	544	121,274
1967	34,728	13,040	2,316	1,355	30	51,469
1968	25,469	9,323	1,397	3,014	1,720	40,923
1969	16,456	3,990	65	1,201	540	22,252
1970	8,415	1,978	103	782	22	11,300
1971	7,306	1,630	374	1,310	242	10,862
1972	3,869	609	137	1,098	20	5,733
1973	2,777	1,563	602	386	3	5,331
1974	2,396	462	109	764	559	4,290
1975	3,989	1,358	8	61	4	5,420
1976	2,904	1,361	4	46	9	4,324
1977	7,934	2,909	—	—	—	10,843
1978	12,160	10,179	—	—	—	22,339
1979	14,279	5,182	—	—	—	19,461
Gulf of Maine						
1956	7,278	29	—	—	—	7,307
1957	6,141	25	—	—	—	6,166
1958	7,082	285	—	—	—	7,367
1959	4,497	163	—	—	—	4,660
1960	4,541	383	—	—	—	4,924
1961	5,297	112	—	—	—	5,409
1962	5,003	107	—	—	—	5,110
1963	4,742	3	44	—	—	4,789
1964	5,383	70	—	—	—	5,453
1965	4,204	159	—	—	—	4,363
1966	4,579	1,125	—	—	—	5,704
1967	4,907	589	—	—	—	5,496
1968	3,437	120	—	—	—	3,557
1969	2,423	59	—	230	1	2,713
1970	1,457	38	—	63	4	1,562
1971	1,194	85	—	26	1	1,306
1972	909	23	4	—	—	936
1973	509	49	—	—	—	558
1974	622	198	—	—	9	829
1975	1,180	79	—	4	—	1,263
1976	1,865	91	—	—	—	1,956
1977	3,296	26	—	—	—	3,322
1978	4,538	641	—	—	—	5,179
1979	4,622	257	—	—	—	4,879

[a] Data source: ICNAF (1958–80) and NAFO (1981).

[b] Bulgaria, Cuba, Federal Republic of Germany, France, German Democratic Republic, Ireland, Japan, Poland, Romania and United Kingdom.

countries reporting catches of haddock from Georges Bank during the 1960's and 1970's, in addition to Spain (Table 1), were Bulgaria, Cuba, Federal Republic of Germany, France, German Democratic Republic, Ireland, Japan, Poland, Romania and United Kingdom. The Canadian and USA fisheries were directed towards haddock prior to 1974, and the USSR also directed substantial effort towards haddock in the mid-1960's, but catches by other countries appear to have been primarily incidental. Spanish catches resulted from demersal pair-trawling operations directed towards cod, and catches by Poland, Romania and USSR after 1966 resulted mainly from trawling operations directed towards herring, mackerel and silver hake, *Merluccius bilinearis*. The total nominal catch of Georges Bank haddock peaked at 150,400 tons in 1965 and then declined to 22,300 tons in 1969 (Fig. 3, Table 1) due to poor recruitment and declining abundance. The total catch averaged 11,100 tons in 1970–71 under a TAC of 12,000 tons, 5,500 tons in 1972–73 under a TAC of 6,000 tons and 4,700 tons in 1974–76 under incidental catch limitations. The catch subsequently increased to 22,300 tons in 1978 and 19,500 tons in 1979, due primarily to recruitment and growth of the 1975 year-class. Only Canada and USA have reported catches of haddock from Georges Bank since 1976.

For the Gulf of Maine, nominal catches averaged over 10,000 tons annually during 1928–30, declined to a relatively constant level of about 3,000 tons during 1931–47 and increased to an average of 7,300 tons annually during 1953–58 (Fig. 3, Table 1). The catch varied between 4,400 tons and 5,700 tons during 1959–67, declined to less than 600 tons by 1973, and subsequently increased to about 5,000 tons during 1978–79. Gulf of Maine haddock were exploited exclusively by USA vessels until the mid-1950's when Canada began to report small catches from the area. Occasional catches by other countries have also been small.

Age composition of catches

Length frequencies and age-length keys were available for the USA haddock fishery on Georges Bank for 1931–79. Methods of sampling, ageing and analysis of such data were described by Hennemuth *et al.* (1964). Estimates of age compositions for 1931–55 were calculated on the basis of a biological year (February to January), and those for 1956–79 were derived by calendar year (Table 2).

For 1931–59, when the fishery was conducted entirely by USA vessels, monthly length frequencies were adjusted to provide length compositions of the corresponding nominal catches. These were then combined for 3-month periods (quarters) and the appropriate age-length keys applied to give quarterly catch-at-age compositions which were combined further to provide the estimated annual age composition of the catch. For later years, length frequencies and age-length keys were often unavailable for catches by Canada and distant-water fleets, and different procedures were used to estimate annual age compositions depending on whether catches were made with regulation-mesh groundfish trawls (i.e. Canada, Spain, United Kingdom and Ireland) or with small-mesh trawls (e.g. USSR). For the former group, USA quarterly catch-at-age compositions, obtained as described above, were adjusted upward using the appropriate nominal catches and then combined to provide the overall annual age composition of the catch for all countries involved. This procedure is not believed to have resulted in appreciable error, as catches by these countries were taken in essentially the same area as USA catches with trawls of similar (regulation) mesh-size. Available Canadian length-frequency data were generally similar to USA data, corroborating the validity of the procedure. For 1975 and 1976, when USA length-frequency data were limited in the last two quarters of the year, Canadian data (if available) were utilized together with USA data to calculate quarterly age compositions prior to their combination on an annual basis.

Nominal catches by the remaining countries (primarily USSR, Romania and Poland) appear to have been taken almost exclusively by small-mesh gear (i.e. trawls with 40-mm mesh codend liners), which necessitated a somewhat different aproach for years and seasons when sampling data were unavailable. USSR length frequencies, USA surveillance reports, information provided by USA fishermen, and USA research vessel survey data (Hennemuth, MS 1968) indicated that a large proportion of distant-water fleet catches during 1965 and 1966 consisted of ages 2 and 3 haddock. The basis for the method used was provided by USSR length frequencies of catches in the spring of 1973 and USA bottom-trawl survey data for April of that year, which were utilized to calculate a retention curve (Pope *et al.*, 1975) for USSR trawls relative to the USA survey trawl. This curve was applied to length frequencies from USA spring, summer and autumn surveys, as appropriate, to estimate length frequencies of catches by USSR and "other" countries (Table 1) for 1963–76. Catch-at-age compositions were then estimated by applying these frequencies and USA age-length keys to the reported catches by quarter, and combining over quarters, as before. Exceptions to this procedure included the use of USA commercial sampling data (in the absence of USA survey data) to estimate the age composition of USSR catches in 1962, and the use of available USSR length frequencies for 1966 and 1973 with the application of USA age-length keys to obtain the age compositions of distant-water fleet catches in those years.

TABLE 2. Estimated age composition of haddock in commercial landings (all countries) from Georges Bank (Div. 5Z), 1931-79.

Year	Number of fish caught (thousands)										Nominal catch (tons)	Calculated weight[b] (tons)	Ratio Nom./ Calc.
	1	2	3	4	5	6	7	8	9+	Total			
1931[a]	1,755	8,801	2,041	5,785	9,100	6,045	3,380	1,794	559	39,260	59,486	59,739	1.00
1932	118	2,084	25,871	2,421	3,676	2,894	1,320	664	391	39,439	54,512	54,552	1.00
1933	244	8,476	6,023	10.046	2,092	1.579	1,210	538	647	30.855	42,215	42,161	1.00
1934	341	4,454	5,414	3,734	3,149	1,051	619	250	168	19,180	25,795	25,590	1.01
1935	1,197	11,872	8,819	3,706	2,944	2,458	499	442	109	32,046	40.944	40,588	1.01
1936	880	12,327	11,486	5,431	2,141	1,377	1,362	259	124	35,387	43,445	43,428	1.00
1937	1,288	11,034	10.910	5,629	4,143	1,875	952	481	222	36,534	49,359	49,402	1.00
1938	1,030	20.199	7,755	3,755	2,113	1,600	945	327	173	37,897	47,773	47,691	1.00
1939	607	13,937	19,617	5,163	2,152	967	837	326	239	43,845	54,054	54,058	1.00
1940	2,040	7,254	12,317	8,253	2,510	1,479	752	222	136	34,963	47,906	47,913	1.00
1941	780	23,464	9,808	8,033	5,764	1,781	941	307	384	51,262	62,944	62,980	1.00
1942	310	14,307	16,348	6,531	3,996	2,331	1,036	227	176	45,262	55,376	55,409	1.00
1943	19	4,191	17,738	8,364	3,102	2,693	790	354	178	37,429	46,323	46,376	1.00
1944	64	761	8,437	14,843	5,689	2,281	497	469	108	33,149	49,637	49,667	1.00
1945	121	8,522	2,029	6,386	5,795	2,315	914	265	205	26,552	40,473	40,443	1.00
1946	209	7,466	15,213	2738	5,785	3,840	1,827	272	23	37,373	53,719	53,683	1.00
1947	90	16,621	10.334	7,181	2,127	2,739	1,501	745	457	41,795	54,431	54,376	1.00
1948	80	11,227	19,237	5,116	2,744	1.157	780	450	369	41,160	48,360	48,303	1.00
1949	328	6,472	12,479	9,608	2,347	1.061	624	409	353	33,681	42,254	42,500	0.99
1950	88	28,971	4,107	4,272	3,315	1,131	520	225	250	42,879	41,273	41,255	1.00
1951	645	8,266	26,472	2,177	2,448	2,138	740	297	215	43,398	47,318	47,422	1.00
1952	—	25,120	8,892	8,485	1,361	944	530	182	107	45,621	43,252	43,349	1.00
1953	1,083	1,807	17,588	5,726	3,757	1,012	542	337	152	32,004	35,926	35,930	1.00
1954	108	31,858	5,107	5,611	2,315	2,131	720	353	98	48,301	46,388	46,401	1.00
1955	90	3,941	19,251	3,316	3,278	1,649	1,068	320	173	33,086	40,851	40,881	1.00
1956	52	11,948	6,698	12,066	3,405	3,378	1,348	563	201	39,659	51,144	52,284	0.98
1957	35	6,594	14,046	4,523	5,822	2,357	1,630	473	366	35,846	48,561	48,847	0.99
1958	125	5,571	7,088	6,665	3,784	2,366	903	442	142	27,086	37,322	37,761	0.99
1959	94	5,716	7,994	5,169	3,934	1,758	1,172	424	334	26,595	36,051	37,994	0.95
1960	258	16,010	6,122	4,562	3,067	1,792	787	406	348	33,352	40,877	42,930	0.95
1961	62	10,689	14,927	4,198	2,917	1,856	1,266	496	674	37,085	46,650	48,522	0.96
1962	74	4,455	16,245	10,440	3,448	2,089	1,566	1,185	898	40,400	54,004	56,430	0.96
1963	2,910	4,047	7,418	11,152	8,198	2,205	1,405	721	1,096	39,152	54,846	57,731	0.95
1964	10,101	15,935	4,554	4,776	8,722	5,794	2,082	1,028	1,332	54,324	64,086	67,823	0.94
1965	9,601	125,818	44,496	5,356	4,391	6,690	3,772	1,094	1,366	202,584	150,362	181,774	0.83
1966	114	6,843	100,810	19,167	2,768	2,591	2,332	1,268	867	136,760	121,274	140,715	0.86
1967	1,150	168	2,891	20,667	10,338	1,209	993	917	698	39,031	51,469	52,065	0.99
1968	8	2,994	709	1,921	14,519	3,499	677	453	842	25,622	40,923	41,018	1.00
1969	2	11	1,698	448	654	5,954	1,574	225	570	11,136	22,252	22,336	1.00
1970	46	158	16	570	186	214	2,308	746	464	4,708	11,300	12,376	0.91
1971	—	1,375	223	40	289	246	285	1,469	928	4,855	10,862	11,998	0.91
1972	156	2	450	81	32	120	78	66	1,236	2,221	5,733	6,464	0.89
1973	2,560	2,057	3	386	53	30	77	15	447	5,628	5,331	6,790	0.79
1974	46	1,820	657	2	70	2	2	53	249	2,901	4,290	4,647	0.92
1975	192	1,034	1,864	375	4	42	4	4	88	3,607	5,420	5,545	0.98
1976	144	473	550	880	216	—	23	4	112	2,402	4,324	4,287	1.01
1977	—	6,130	187	680	515	357	4	39	111	8,023	10,843	11,582	0.94
1978	—	761	11,315	305	567	517	139	14	67	13,685	22,339	22,403	1.00
1979	—	26	1,726	7,169	525	410	315	96	46	10,313	19,461	21,100	0.92

[a] Data for 1931-55 reported in terms of "biological year" (February-January); data for 1956-79 reported by calendar year.
[b] Obtained by multiplying numbers caught at age by corresponding mean weight-at-age data in Table 7.

The age compositions of catches assumed to have been taken by small-mesh trawls were combined with those taken by large-mesh (regulation) trawls to obtain the age compositions of total nominal catches by all countries for the 1931-79 period (Table 2, Fig. 4). Calculated catch weights, obtained by multiplying catch-at-age values in Table 2 by corresponding mean weight-at-age values (Table 7) and summing over age-groups, were generally within 5% of the observed weights, the largest discrepancies being related to years when sampling inadequacies existed (e.g. 1965 and 1966). No attempt was made to incorporate recreational catches into the data base for Georges Bank, as nearly all of these haddock were taken in the western Gulf of Maine.

About 80% of the haddock (numbers) landed from Georges Bank during 1935-60 consisted of age-groups 2, 3 and 4 (Table 2, Fig. 4), the relative proportions being 32, 31 and 17% respectively. Introduction of

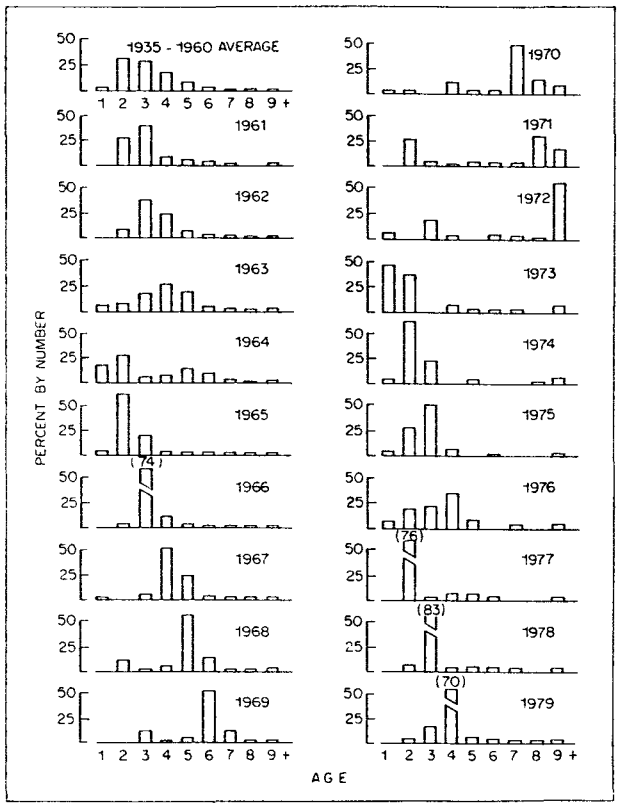

Fig. 4. Percentage age composition of haddock in commercial landings from Georges Bank, combined for 1935-60 and individually for 1961-1979.

the mesh regulation in 1953, specifying 4.5 inches (114 mm) as the minimum codend mesh size, markedly reduced the catching and discarding of unmarketable haddock (Graham and Premetz, 1955). However, because the 50% selection length for 114-mm mesh trawls (37.5 cm) closely approximated the average cull size (34-35 cm) in those years, there was little observable change in the age composition of commercial landings following the introduction of the mesh regulation, and short-term losses were minimal. Recruitment of the outstanding 1963 year-class in 1965, heavy exploitation during 1965-66, and poor recruitment in subsequent years resulted in a significant change in age composition; for example, the 1963 year-class accounted for 62 and 74% of the haddock catch (numbers) in 1965 and 1966 respectively. This year-class accounted for 65% of the total number and 54% of the total weight caught during 1965-69 and continued to support the fishery during the early 1970's in the absence of significant contributions from the relatively poor year-classes of 1965-71 (Table 2, Fig. 4). The 1972 year-class, although weak, was considerably larger than the 1965-71 year-class average and provided a relatively large catch (number) of age 1 fish in 1973 (Fig. 4), taken primarily by USSR vessels. Recruitment of the 1971 and 1972 year-classes had a depressing effect on the percentage of total catch by number accounted for by the 1963 year-class, but this year-class still accounted for over 25% of the nominal catch by weight during 1973-74. The strong 1975 year-class, which recruited to the fishery in 1977, accounted for 76% of the catch by number and 69% by weight during 1977-79 (Table 2, Fig. 4).

Age composition data for the Gulf of Maine commercial fishery are comparatively limited, but available information indicates that age-structure and recruitment patterns in recent years (not illustrated) were generally similar to those observed for Georges Bank. The 1963 year-class contributed the bulk of the catch by number and weight during 1966-70, and the 1975 year-class predominated during 1977-79. Intervening years were characterized by poor recruitment, as was the case for Georges Bank.

Recreational Fishery

Information on recreational catches of haddock in the New England area was collected in national saltwater angling surveys for 1960, 1965 and 1970 (Clark, 1962; Deuel and Clark, 1968; Deuel, 1973), in a regional survey of northeastern United States for 1974 (Ridgely and Deuel, MS 1976), and in a marine recreational fishery statistics survey of the Atlantic and Gulf coasts for 1979 (U.S. Dept. Commerce, 1980). Nicholson and Ruais (MS 1979) also derived estimates of recreational catches by party and charter boats in the Georges Bank-Gulf of Maine region for 1978 by analysis of logbook data, but reporting was incomplete and the catches appear to have been underestimated to an unknown degree. The first three surveys were conducted by household interviews soliciting data on number and average weight of each species caught over a recall period of one year. The 1974 survey collected similar information by telephone and by mail for a 2-month recall period. The 1979 survey included telephone interviews to obtain trip data over a 2-month recall period and on-site interviews during which catches were sampled to determine species and size composition. Differences in methodology and regional boundaries imply that results are comparable only in a general way. The 1-year recall period used in earlier surveys implies the potential for overestimation (U.S. Dept. Commerce, 1980).

The 1960, 1965 and 1970 surveys indicated recreational haddock catches of 767, 9,702 and 1,147 tons respectively, but the 1974 survey indicated a catch of only 199 tons. Party and charter-boat logbook data for 1978 indicated a catch of 279 tons, but, as that segment of the fishery accounted for only 70% of the total recreational catch of haddock in 1970 (Deuel, 1973), the total recreational catch in 1978 probably exceeded 400 tons. The bulk of the reported catch in 1978 was taken in late autumn and practically the entire amount

(278 tons) was taken in the western Gulf of Maine. Results of the 1979 survey indicated a total recreational haddock catch of 406 tons. Even in the western Gulf of Maine, however, haddock seems to be of relatively minor importance as a recreational species; cod and pollock accounted for 90% of Maine party-boat catches in 1977 (Nicholson and Ruais, MS 1979).

Research Vessel Surveys

Research vessels of the Northeast Fisheries Center, Woods Hole, have conducted bottom-trawl surveys of the Georges Bank-Gulf of Maine area in autumn since 1963 and in spring since 1968. A stratified-random sampling design has been used for these surveys based on geographical strata delineated by depth and historical fishing patterns (Fig. 5). A standard "36 Yankee" groundfish trawl with 1.25-cm mesh codend liner was used in all autumn surveys and in all spring surveys during 1968-72; a modified high-opening "41 Yankee" trawl was used in subsequent spring surveys, and consequently data for 1968-72 were adjusted by a factor of 1.7 to compensate for differences in surface area covered by the two different trawls. Details of survey procedures and application of resulting data to stock assessments have been published elsewhere (Grosslein, 1969; Clark, 1979). The data from these surveys have been used in this paper to derive indices of relative abundance and biomass (stratified mean catch per tow in numbers and weight) and to evaluate mortality, growth and recruiting year-class size.

Trends in abundance and biomass

The spring survey (weight) index for Georges Bank (Fig. 5, strata 13-25, 29 and 30) declined from 23.1 kg in 1968 to 5.4 kg in 1975 and subsequently increased to 35.7 kg in 1980, the highest value observed in this time series (Table 3). The corresponding autumn survey index declined from 64.1 kg in 1964 to 2.6 kg in 1974, increased to an average of 23.4 kg in 1976-77, and varied from 15.2 to 26.9 kg during 1978-80, the average being 20.2 kg. Trends in spring and autumn survey indices in terms of numbers have closely paralleled those observed in terms of weight (Table 3). These data indicate a decline in biomass of more than 90% during 1964-74, and spawning stock, as evidenced by catches of age 3 and older haddock in spring and age 2 and older haddock in autumn (Tables 4 and 5), declined to an apparent all-time low during the early 1970's. Increased abundance and biomass in

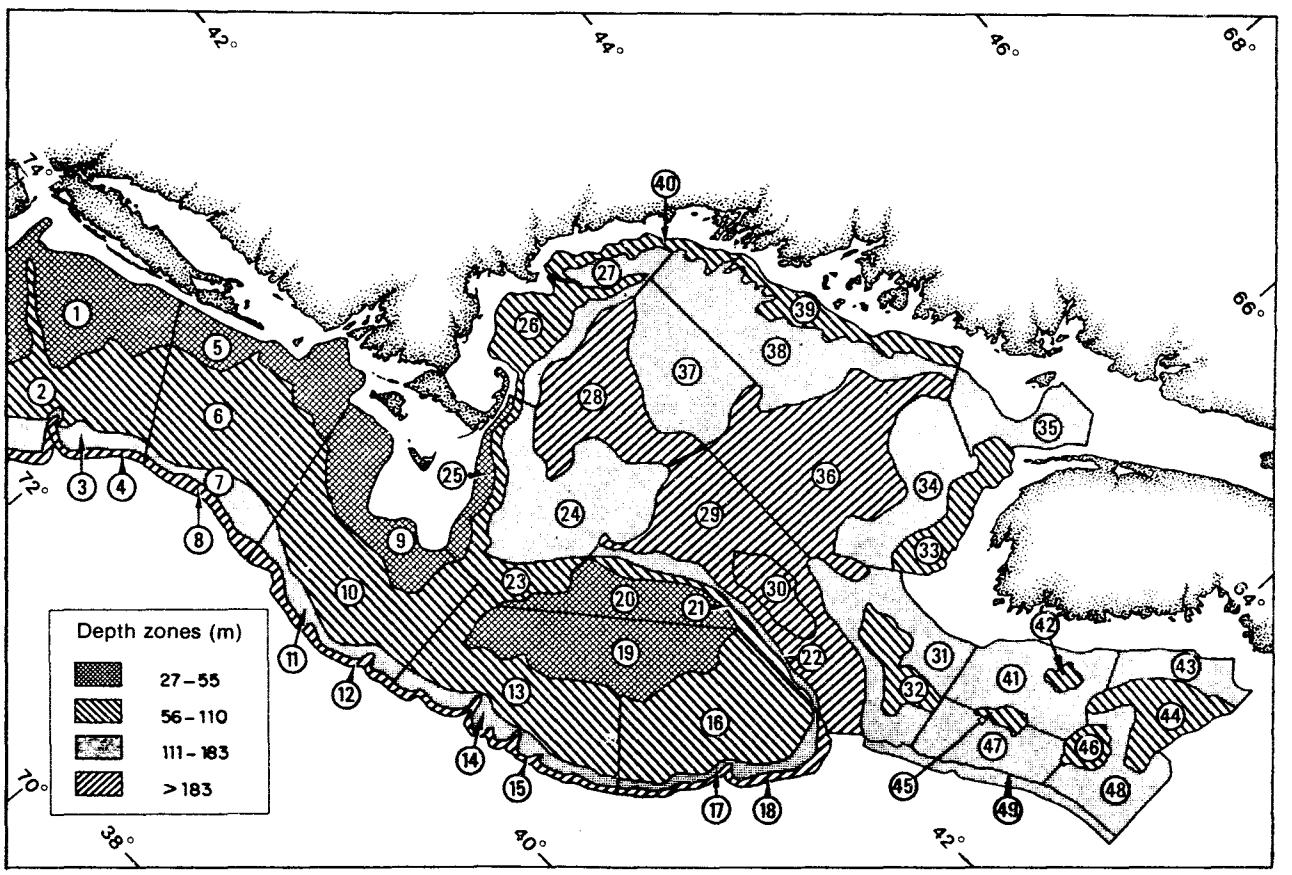

Fig. 5. Stratification scheme used for USA spring and autumn bottom-trawl surveys of Georges Bank and Gulf of Maine areas.

TABLE 3. Mean catch per tow in numbers and weight (kg) of haddock in spring and autumn stratified-random bottom-trawl surveys on Georges Bank and in the Gulf of Maine, 1963-80.

	Georges Bank[a]				Gulf of Maine[b]			
	Spring		Autumn		Spring		Autumn	
Year	Number	Weight	Number	Weight	Number	Weight	Number	Weight
1963	—	—	97.34	52.83	—	—	46.68	33.57
1964	—	—	129.70	64.07	—	—	9.51	12.47
1965	—	—	68.26	48.20	—	—	11.70	11.72
1966	—	—	22.32	19.78	—	—	7.82	9.18
1967	—	—	11.88	16.87	—	—	8.18	11.16
1968	15.56	23.13	5.06	10.20	6.99	9.71	5.75	11.42
1969	8.26	19.05	2.28	5.59	4.32	8.30	3.66	8.51
1970	6.84	19.28	5.17	8.94	1.03	1.94	1.96	4.87
1971	3.18	5.62	2.83	3.70	1.00	2.84	1.93	5.39
1972	7.26	8.30	7.62	5.61	0.98	0.98	1.33	2.01
1973	25.23	10.18	9.98	6.48	0.88	1.06	2.80	5.68
1974	12.77	11.72	2.71	2.64	0.96	0.70	1.80	2.21
1975	4.18	5.44	20.78	10.00	1.86	2.30	3.71	5.71
1976	55.83	10.41	47.68	23.68	5.59	4.21	4.05	5.32
1977	24.74	17.60	19.02	23.13	4.56	4.45	6.79	7.34
1978	13.03	20.71	20.70	15.18	0.91	0.95	8.00	18.16
1979	30.53	13.09	42.74	26.87	2.32	3.17	4.52	11.50
1980	40.32	35.71	24.98	18.47	1.81	2.24	5.85	8.24

[a] Strata 13–25 and 29–30 of Fig. 5.
[b] Strata 26–28 and 36–40 of Fig. 5.

TABLE 4. Age composition of haddock caught per tow in spring bottom-trawl surveys on Georges Bank and in the Gulf of Maine, 1968-80.

	Mean catch per tow at age (numbers)												Totals		
Year	1	2	3	4	5	6	7	8	9	10	11	12+	Age 1+	Age 2+	Age 3+
Georges Bank															
1968	0.27	3.23	0.53	0.80	7.62	1.92	0.29	0.51	0.37	—	—	—	15.54[a]	15.27	12.04
1969	0.02	0.05	0.66	0.17	0.48	4.83	1.17	0.32	0.15	0.17	0.10	0.10	8.22	8.20	8.15
1970	0.77	0.29	—	0.37	0.53	0.53	2.28	1.12	0.54	0.14	0.22	0.07	6.86	6.09	5.80
1971	—	1.33	0.29	—	0.14	0.14	0.10	0.94	0.20	0.03	—	0.03	3.20	3.20	1.87
1972	4.61	0.10	0.70	0.14	0.03	0.05	0.15	0.03	0.97	0.29	0.10	0.12	7.29	2.68	2.58
1973	20.59	3.25	—	0.36	0.06	—	0.12	0.01	—	0.66	0.05	0.15	25.25	4.66	1.41
1974	1.43	8.92	1.92	—	0.16	—	0.01	0.07	—	—	0.16	0.09	12.76	11.33	2.41
1975	0.63	0.65	2.23	0.42	—	0.09	0.06	0.01	—	—	0.01	0.09	4.19	3.56	2.91
1976	54.22	0.20	0.40	0.62	0.29	—	0.03	—	—	—	0.01	0.06	55.83	1.61	1.41
1977	0.41	22.42	0.28	0.82	0.40	0.30	—	0.03	—	—	—	0.08	24.74	24.33	1.91
1978	0.05	0.65	10.69	0.24	0.63	0.55	0.11	0.04	0.02	0.02	—	0.03	13.03	12.98	12.33
1979	24.24	1.06	0.76	3.83	0.22	0.11	0.25	0.04	0.02	—	—	0.01	30.54	6.30	5.24
1980	3.49	31.34	0.34	0.70	3.27	0.45	0.25	0.31	0.10	0.06	—	—	40.31	36.82	5.48
Gulf of Maine															
1968	—	—	—	0.39	5.15	1.09	0.09	0.03	0.24	—	—	—	6.99[a]	6.99	6.99
1969	—	—	0.09	0.02	0.22	3.04	0.80	0.05	0.09	—	—	—	4.31	4.31	4.31
1970	—	—	—	—	—	0.17	0.70	0.10	0.05	0.02	—	—	1.04	1.04	1.04
1971	—	—	—	—	—	0.03	0.03	0.73	0.05	0.05	0.05	0.05	0.99	0.99	0.99
1972	0.66	—	—	—	—	—	—	—	0.24	0.03	0.02	0.02	0.97	0.31	0.31
1973	0.09	0.53	—	0.04	—	—	—	—	0.01	0.21	0.01	—	0.89	0.80	0.27
1974	0.60	0.06	0.22	—	—	—	—	—	0.01	0.01	0.01	0.06	0.97	0.37	0.31
1975	0.01	1.32	0.10	0.25	—	0.01	—	—	—	—	0.01	0.16	1.86	1.85	0.53
1976	3.46	0.05	1.24	0.12	0.61	—	0.02	—	—	—	—	0.09	5.59	2.13	2.08
1977	0.59	2.39	0.02	0.90	0.27	0.39	—	—	—	—	—	—	4.56	3.97	1.58
1978	0.06	0.47	0.21	0.04	0.10	0.03	—	—	—	—	—	—	0.91	0.85	0.38
1979	0.25	—	1.08	0.80	0.06	0.08	0.06	—	—	—	—	—	2.33	2.08	2.08
1980	0.87	0.12	0.14	0.36	0.28	0.02	—	—	—	—	—	0.03	1.82	0.95	0.83

[a] Differences between values in this column and data in Table 3 are due to rounding.

TABLE 5. Age composition of haddock caught per tow in autumn bottom-trawl surveys on Georges Bank and in the Gulf of Maine, 1963-80.

Year	Mean catch per tow at age (numbers)													Totals		
	0	1	2	3	4	5	6	7	8	9	10	11	12+	Age 0+	Age 1+	Age 2+
Georges Bank																
1963	56.33	17.04	6.19	4.57	5.60	3.99	1.37	1.13	0.79	0.22	0.05	0.01	0.03	97.32[a]	40.99	23.95
1964	1.59	75.75	42.78	3.91	1.20	2.56	1.05	0.46	0.17	0.22	—	—	—	29.69	28.10	52.35
1965	0.22	6.82	51.94	6.51	0.72	0.54	0.61	0.54	0.17	0.18	—	—	—	68.25	68.03	61.21
1966	4.12	0.64	1.94	12.34	2.25	0.35	0.33	0.22	0.08	0.05	—	—	—	22.32	18.20	17.56
1967	0.02	4.51	0.24	0.67	4.54	1.09	0.33	0.14	0.22	0.12	—	—	—	11.88	11.86	7.35
1968	0.06	0.04	0.64	0.09	0.22	2.59	0.85	0.18	0.11	0.26	—	—	—	5.04	4.98	4.94
1969	0.26	0.02	—	0.19	0.09	0.11	1.02	0.34	0.06	0.04	0.04	—	0.10	2.27	2.01	1.99
1970	0.03	2.77	0.14	0.01	0.19	0.18	0.34	0.92	0.32	0.18	0.02	0.04	0.03	5.17	5.14	2.37
1971	1.63	—	0.21	0.05	0.01	0.15	0.02	0.06	0.50	0.15	0.01	0.02	0.01	2.82	1.19	1.19
1972	4.53	1.69	—	0.35	0.06	—	0.06	0.04	0.02	0.51	0.26	0.05	0.05	7.62	3.09	1.40
1973	2.17	6.04	1.08	—	0.13	0.03	—	0.05	0.01	0.01	0.37	0.06	0.04	9.99	7.82	1.78
1974	0.50	1.19	0.66	0.21	—	0.01	—	—	—	0.02	—	0.09	0.04	2.72	2.22	1.03
1975	15.76	0.42	0.48	3.26	0.62	—	0.02	—	0.01	0.01	—	—	0.19	20.77	5.01	4.59
1976	2.90	43.07	0.35	0.36	0.55	0.20	—	0.03	0.07	0.03	—	—	0.14	47.70	44.80	1.73
1977	0.11	1.75	15.33	0.46	0.47	0.52	0.28	0.03	0.01	—	—	—	0.07	19.03	18.92	17.17
1978	10.82	0.69	0.85	7.59	0.15	0.21	0.37	0.01	—	0.01	—	—	—	20.70	9.88	9.19
1979	1.08	37.29	0.03	0.74	3.12	0.21	0.23	0.04	0.01	—	—	—	—	42.75	41.67	4.38
1980	9.56	2.22	10.41	0.37	0.15	1.39	0.39	0.38	0.07	0.05	—	—	—	24.99	15.43	13.21
Gulf of Maine																
1963	23.90	8.18	1.14	2.02	4.66	3.31	1.12	0.88	0.70	0.47	0.24	—	0.03	46.65[a]	22.75	14.57
1964	0.02	2.99	1.87	0.48	0.82	1.62	0.96	0.32	0.22	0.18	0.03	—	—	9.51	9.49	6.50
1965	0.04	0.25	5.39	3.40	0.17	0.98	0.77	0.44	0.21	0.04	—	—	—	11.69	11.65	11.40
1966	0.01	0.03	0.37	4.86	1.60	0.18	0.41	0.29	0.04	0.02	—	—	—	7.81	7.80	7.77
1967	—	—	0.20	0.83	5.37	1.21	0.33	0.08	0.12	0.03	—	—	—	8.17	8.17	8.17
1968	—	—	—	0.06	0.13	4.13	0.95	0.17	0.22	0.09	—	—	—	5.75	5.75	5.75
1969	—	—	—	0.02	0.02	0.02	2.78	0.57	0.09	0.01	0.06	—	0.07	3.64	3.64	3.64
1970	—	0.03	—	—	—	0.03	0.06	1.41	0.41	—	0.01	0.02	—	1.97	1.97	1.94
1971	0.18	—	0.04	—	0.01	—	0.07	0.11	1.34	0.07	0.06	—	0.06	1.94	1.76	1.76
1972	—	0.80	—	0.02	—	—	—	—	—	0.34	0.12	0.06	—	1.34	1.34	0.54
1973	0.76	0.01	0.64	—	0.24	0.02	0.01	0.03	0.01	0.09	0.78	0.12	0.09	2.80	2.04	2.03
1974	0.01	1.13	0.13	0.29	—	—	—	—	0.01	—	—	0.15	0.08	1.80	1.79	0.66
1975	0.60	0.15	1.29	0.37	0.93	—	0.03	0.03	—	—	0.02	0.06	0.24	3.72	3.12	2.97
1976	1.10	1.18	0.05	0.86	0.11	0.52	—	0.10	—	—	—	—	0.12	4.04	2.94	1.76
1977	0.03	2.74	2.65	0.10	0.85	0.13	0.21	—	—	—	—	0.01	0.06	6.78	6.75	4.01
1978	0.14	0.01	1.65	3.78	0.38	0.94	0.77	0.12	—	0.02	—	—	0.19	8.00	7.86	7.85
1979	0.59	0.30	0.01	0.79	1.97	0.41	0.30	0.09	0.05	0.01	—	0.01	—	4.53	3.94	3.64
1980	3.25	0.41	0.26	—	0.24	0.88	0.55	0.11	0.08	0.08	—	—	—	5.86	2.61	2.20

[a] Differences between values in this column and data in Table 3 are due to rounding.

the late 1970's primarily reflect recruitment and growth of the 1975 and 1978 year-classes (discussed below).

Trends in indices for the Gulf of Maine (Fig. 5, strata 26-28 and 36-40) are similar to those for Georges Bank (Table 3). The spring survey (weight) index declined from 9.2 kg in 1968 to 0.7 kg in 1974, increased to 4.5 kg in 1977 and then declined to an average of 2.7 kg in 1979-80. The corresponding autumn survey index declined from 33.6 kg in 1963 to low values of 2.0 kg in 1972 and 2.2 kg in 1974, increased to 18.2 kg in 1978 and then declined to an average of 9.9 kg in 1979-80. Again, trends in numbers per tow were similar (Table 3), and spawning stock size declined to minimal levels in the early 1970's (Tables 4 and 5).

Age distributions of haddock from these surveys indicate that the 1962 and 1963 year-classes dominated the Georges Bank and Gulf of Maine populations until the early 1970's (Tables 4 and 5). However, the 1975 and 1978 year-classes were the only strong year-classes to appear on Georges Bank since 1963. The 1975 year-class accounted for 85% by number of the survey catch of age 2 and older fish in 1977-79, while the 1978 year-class accounted for 85 and 79% by number in the 1980 spring and autumn surveys respectively. The 1978 year-class appears to have been comparable in size to the 1975 year-class on Georges Bank but was obviously much weaker in the Gulf of Maine.

The pronounced changes in stock abundance evidenced by research vessel survey data have been accompanied by other changes as well. Spatial density, reflected by changes in relative frequency of numbers caught per tow in autumn on Georges Bank (Fig. 6), has changed markedly, with declining percentages of large catch-per-tow values and a corresponding increase in percentages of small catches, as abundance declined in the late 1960's and early 1970's.

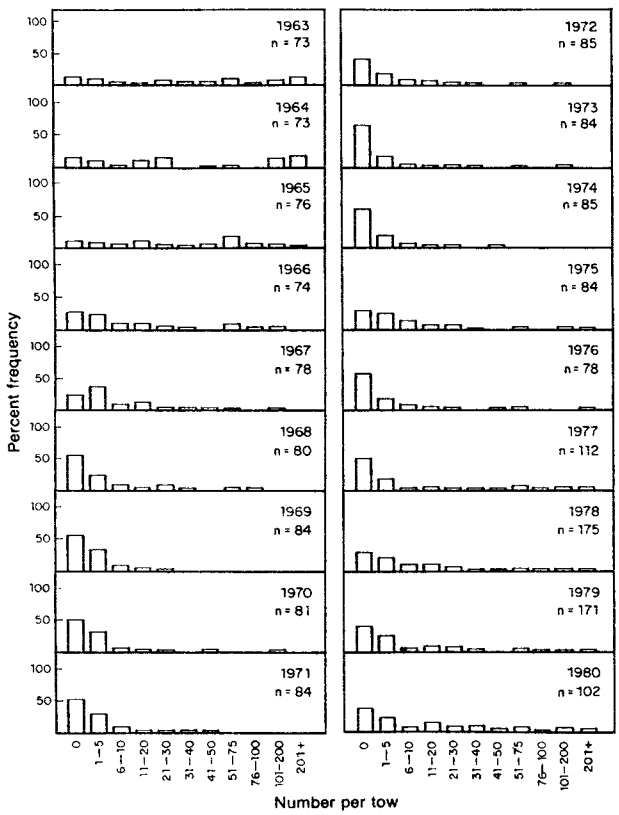

Fig. 6. Frequency distributions of catch per tow (numbers) for Georges Bank haddock, expressed as relative percentages of total numbers of tows, in USA autumn bottom-trawl surveys, 1963–80.

Also, variability in numbers caught per tow, measured by the coefficient of variation, increased from 0.17 for 1963–66 to 0.29 for 1967–75 and subsequently remained high at 0.36 for 1976–80. Trends were similar for catch per tow in weight, the corresponding values being 0.17, 0.30 and 0.33 respectively. Spatial patterns of abundance in the mid-1960's (not shown) indicated a tendency for haddock to be rather widely distributed over most of Georges Bank, whereas in recent years haddock tended to be concentrated along the northern edge and on the northeast peak of the bank (Fig. 2). These observations may indicate that the population distributes itself in different density patterns with changes in overall magnitude, resulting in changes in the underlying statistical distribution describing haddock observations in the survey data. This could well affect fishing success and the precision of survey estimates. Pennington and Grosslein (MS 1978) noted that the negative binomial distribution is most often appropriate for describing survey data, implying the use of a logarithmic transformation as a variance-stabilizing approach, but the resulting distribution may not be normal. For Georges Bank, trends for indices calculated from transformed data, (i.e. *ln* (x+1), agreed very closely with trends for indices calculated from linear data, although agreement with numbers and biomass estimates calculated from virtual population analysis (VPA) was not as good for transformed values ($r = 0.97$ and 0.89 in terms of numbers and $r = 0.98$ and 0.94 in terms of weight for linear and transformed values respectively).

Mortality

Spring and autumn survey data (Tables 4 and 5) were used to examine trends in instantaneous total mortality (Z). Estimates of Z were obtained by catch-curve analyses of data for the more successful year-classes, using fully-recruited portions of the curves (Fig. 7). Due to conspicuous differences in exploitation patterns during the 1960's, as reflected in curvilinearity of the plotted catch-per-tow values for several year-classes, analyses were performed separately for 1964–67 data and data for later years. Analyses for Georges Bank were based on autumn survey data for 1963–80 and spring survey data for 1968–72, as gear configuration was the same for these periods. However, apparent seasonal differences in catchability precluded the use of spring survey data for the Gulf of Maine.

Mortality on the 1958–61 year-classes was quite high during 1964–67, Z exceeding 0.8 in all cases, and was even higher on the 1962–64 year-classes, being 1.21, 0.99 and 1.16 respectively (Fig. 7). With instantaneous natural mortality (M) of 0.2, these high Z-values imply that instantaneous fishing mortality (F) exceeded levels providing maximum yield per recruit or F_{max} (discussed below). As noted above, the exceptionally large 1962 and 1963 year-classes attracted heavy fishing pressure by USSR vessels during the mid-1960's, and mortality on the relatively small 1964 year-class was also high, as that year-class was vulnerable to capture during this period by trawls with 40-mm mesh codend liners. With declining effort after 1967, the average value of Z for the 1961–64 year-classes declined from 1.05 during 1964–67 to 0.52 after 1967. However, mortality on more recent year-classes (1966, 1972 and 1975) was higher (Fig. 7).

Results for the Gulf of Maine differ somewhat from those obtained for Georges Bank (Fig. 7), although in general they appear to reflect observed distributions of fishing effort. Mortality on the 1958 year-class during 1964–67 was higher than on Georges Bank, estimates of Z for the 1959 year-class were similar, and those for subsequent year-classes were generally lower, as would be expected in view of the concentration of fishing effort by distant-water fleets on Georges Bank during the mid-1960's.

Estimates of Z were also calculated by pooling survey data for age 3 and older fish over three periods

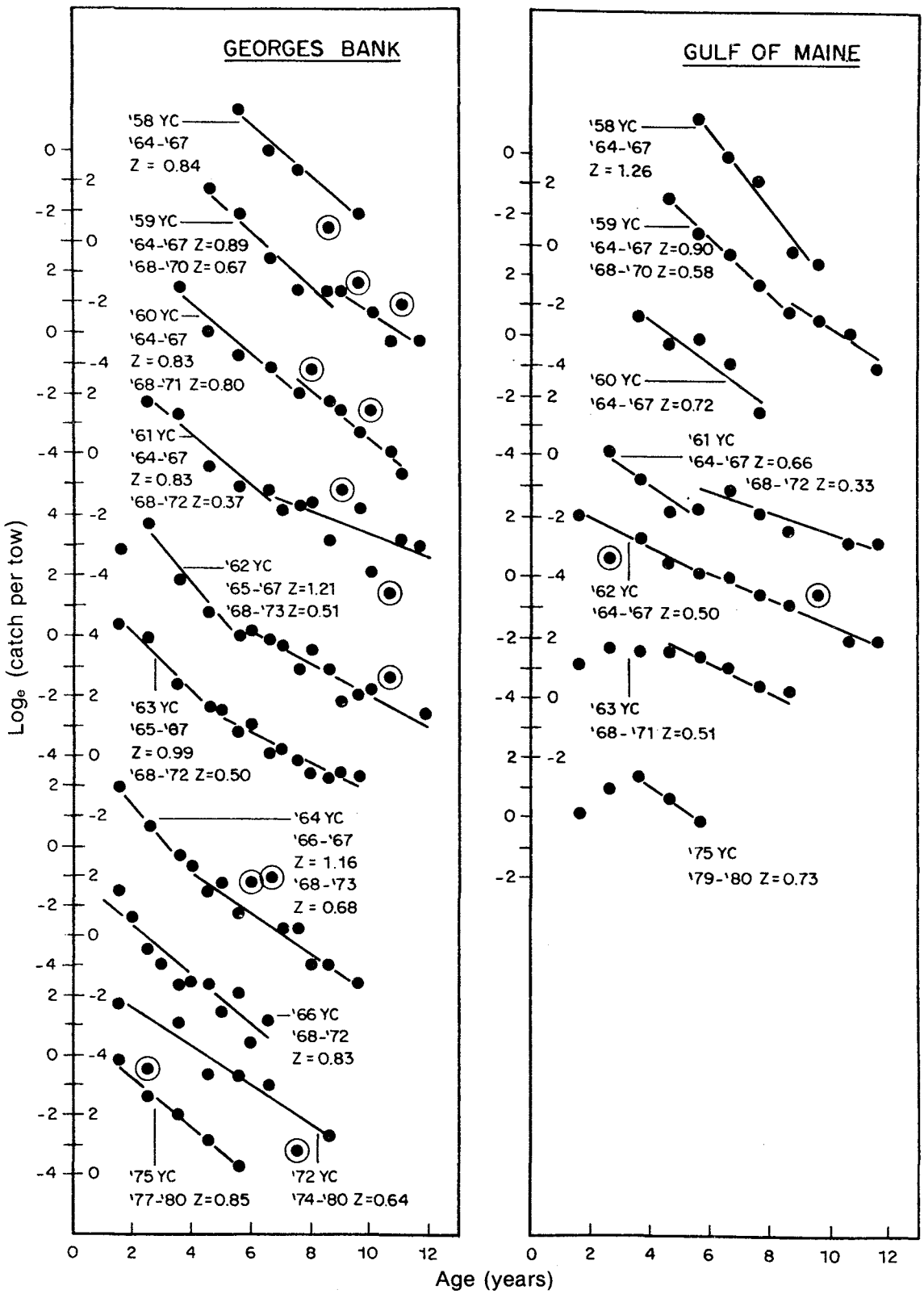

Fig. 7. Catch curves from selected year-classes of haddock in Georges Bank and Gulf of Maine areas, derived from analysis of USA spring and autumn bottom-trawl survey data. (Circled points not used in calculations.)

(1964-67, 1968-72 and 1973-80), e.g. the 1964-67 autumn value was derived from

$$ln\left[\frac{\Sigma \text{ (age 3 and older for 1963–66)}}{\Sigma \text{ (age 4 and older for 1964–67)}}\right]$$

and the 1968–72 spring value was derived from

$$ln\left[\frac{\Sigma \text{ (age 3 and older for 1968–71)}}{\Sigma \text{ (age 4 and older for 1969–72)}}\right]$$

Results for Georges Bank indicate a decline in Z from 1.06 in 1964-67, when fishing effort by distant-water fleets was high, to an average of 0.50 in 1968-72, as fishing effort declined due to reduced abundance. This was followed by an increase to an average of 0.67 in 1973-80 despite increasingly restrictive conservation measures (Table 6). For the Gulf of Maine, mortality in 1964-67 and 1973-80 was considerably lower than for Georges Bank, but results for 1968-72 were inconsistent (Z = 0.71 and 0.44 from spring and autumn surveys respectively).

The above trends in mortality are in general agreement with the observed distribution of fishing effort by area and time. However, the estimates given in Table 6 should be considered with caution. Considerable variability is evident in the data used to derive these estimates, as would be expected from sampling different age-groups in a contagiously distributed population, and resulting impacts would be expected to be greatest during periods of low abundance. Also, average estimates of this type are usually most reliable when fishing mortality is relatively constant in each period of averaging, but it is unlikely that this condition was met during the periods considered with the possible exception of 1968-72.

TABLE 6. Estimates of instantaneous total mortality (Z) based on spring and autumn bottom-trawl survey data for Georges Bank and the Gulf of Maine.

	Georges Bank		Gulf of Maine	
Period	Spring	Autumn	Spring	Autumn
1963-67	—	1.06	—	0.65
1968-72	0.51	0.49	0.71	0.44
1973-80	0.61	0.72	0.41	0.33

Growth

Growth rates for Georges Bank haddock have fluctuated considerably, particularly since 1960. During 1935-60, nominal catches, stock sizes and recruitment (discussed below) remained at relatively constant levels, and the average weights of age 3 and older haddock in USA commercial landings exhibited no clear trend (Fig. 8). With declining recruitment and stock abundance in subsequent years, however, average weights increased substantially to peak levels in the 1970's.

The variability evident in mean weight-at-age data for USA commercial landings (Table 7) appears to reflect the effect of recruitment of several strong year-classes. In particular, the outstanding 1963 year-class initially grew more slowly than others since the mid-1930's and, together with the strong 1962 year-class, appears to have exerted a depressing effect on the growth of succeeding year-classes (i.e. those of 1964 and 1965). Similar trends are evident throughout the time series for other strong year-classes (Fig. 9); in fact, there was a decline in mean weight for all age-groups following every period of very strong recruitment (one or more year-classes of over 100 million fish at age 2). Recruitment of the very strong 1939 and 1940 year-classes was associated with declining mean weights at age in the mid-1940's, and the appearance of the very strong 1948, 1950 and 1952 year-classes was associated with a similar response in the 1950's. In the early to mid-1960's, the stock size increased to peak levels due to recruitment of the very strong 1958, 1959 and 1962 year-classes and the outstanding 1963 year-class, and mean weights again declined (Fig. 9). The rapid increase in growth in the 1970's was associated

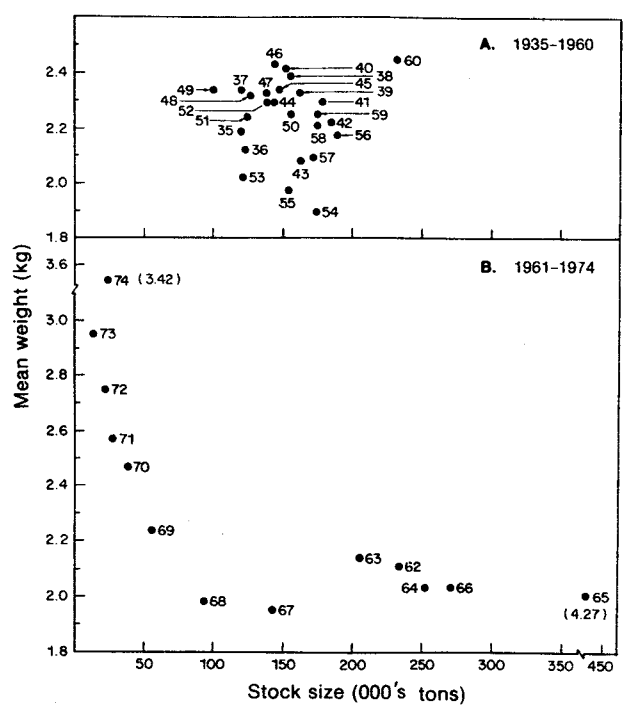

Fig. 8. Relation between mean weight of haddock (age 3 and older) in USA commercial landings from Georges Bank and stock size (age 2 and older) from virtual population analysis for (A) 1935-60 and (B) 1961-74.

TABLE 7. Mean weights (kg, whole) of haddock by age-group, as observed from samples of USA commercial landings from Georges Bank, 1931-79.

	Mean weight at age (kg)								
Year	1	2	3	4	5	6	7	8	9+
1931	0.75	0.78	1.18	1.37	1.65	2.01	2.31	2.54	3.03
1932	0.64	0.85	1.09	1.82	1.89	2.19	2.74	2.93	3.20
1933	0.54	0.73	1.35	1.42	1.73	2.39	2.46	2.59	2.60
1934	0.42	0.73	1.13	1.49	1.75	2.11	2.54	2.85	2.98
1935	0.46	0.87	1.22	1.60	1.79	1.98	2.56	2.79	3.42
1936	0.51	0.81	1.19	1.56	1.72	2.09	2.35	2.63	3.32
1937	0.48	0.87	1.24	1.52	1.94	2.19	2.82	3.08	3.56
1938	0.56	0.87	1.37	1.76	2.16	2.30	2.67	2.75	3.71
1939	0.57	0.82	1.18	1.64	1.98	2.48	2.66	2.96	3.42
1940	0.56	0.89	1.27	1.59	1.87	2.34	2.90	3.10	3.87
1941	0.52	0.79	1.20	1.57	1.87	2.31	2.67	2.93	3.52
1942	0.52	0.79	1.15	1.46	1.71	2.03	2.64	3.15	3.38
1943	0.52	0.73	0.99	1.43	1.69	1.89	2.34	2.84	3.37
1944	0.62	0.80	1.09	1.40	1.87	2.31	2.61	3.07	3.68
1945	0.58	0.84	1.24	1.57	1.93	2.37	2.69	3.23	3.35
1946	0.52	0.78	1.20	1.63	1.83	2.22	2.70	3.28	4.18
1947	0.58	0.73	1.15	1.61	2.02	2.36	2.79	3.06	3.32
1948	0.52	0.67	1.04	1.54	1.94	2.35	2.69	3.16	3.50
1949	0.54	0.73	0.99	1.44	1.94	2.40	2.72	3.20	3.69
1950	0.43	0.68	1.07	1.33	1.80	2.24	2.60	3.26	3.42
1951	0.53	0.70	0.95	1.40	1.79	2.34	2.81	3.11	3.30
1952	—	0.69	0.94	1.29	1.71	2.22	2.54	3.13	3.49
1953	0.55	0.64	0.94	1.19	1.62	2.02	2.37	2.71	3.31
1954	0.44	0.77	0.90	1.27	1.49	1.82	2.24	2.43	3.08
1955	0.58	0.83	1.08	1.29	1.67	1.95	2.32	2.53	2.96
1956	0.42	0.84	1.04	1.38	1.70	2.13	2.43	2.88	3.62
1957	0.54	0.80	1.11	1.41	1.77	2.08	2.41	2.77	3.11
1958	0.67	0.82	1.12	1.35	1.77	2.25	2.63	2.93	3.39
1959	0.56	0.85	1.15	1.45	1.80	2.18	2.57	3.05	3.52
1960	0.60	0.81	1.22	1.55	1.92	2.47	2.94	3.26	3.78
1961	0.52	0.84	1.11	1.54	1.87	2.26	2.54	2.88	3.24
1962	0.54	0.85	1.07	1.41	1.77	2.14	2.47	2.62	3.29
1963	0.57	0.87	1.18	1.47	1.68	2.15	2.35	3.04	3.10
1964	0.50	0.83	1.12	1.43	1.64	2.01	2.40	2.64	2.97
1965	0.58	0.69	1.03	1.35	1.67	1.99	2.26	2.66	3.11
1966	0.58	0.73	0.89	1.26	1.70	2.07	2.28	2.87	3.18
1967	0.66	0.70	0.95	1.18	1.42	2.05	2.31	2.66	3.10
1968	0.59	0.81	1.05	1.32	1.57	2.10	2.32	2.62	2.86
1969	0.52	0.78	1.10	1.69	1.75	1.99	2.52	2.99	3.63
1970	0.71	1.27	1.22	1.93	2.19	2.39	2.58	3.23	3.75
1971	—	1.03	1.31	1.74	2.39	2.81	2.92	3.10	3.72
1972	0.62	1.03	1.74	2.04	2.42	2.92	3.06	3.44	3.66
1973	0.60	1.03	1.58	2.13	2.41	3.29	3.42	3.86	3.94
1974	0.72	1.06	1.82	2.32	2.83	3.76	4.05	3.92	4.26
1975	0.62	0.98	1.63	2.21	2.20	2.94	4.00	4.05	4.33
1976	0.50	0.99	1.39	1.99	2.66	—	3.69	4.67	4.94
1977	—	1.07	1.44	2.17	2.73	3.21	4.15	4.00	4.99
1978	—	0.94	1.50	2.04	2.79	3.19	3.37	3.61	5.11
1979	—	1.00	1.28	2.02	2.51	3.14	3.78	3.79	4.87

with reductions in stock size in the late 1960's and early 1970's.

The rapid increase in growth of Georges Bank haddock evidenced in the late 1960's occurred in spite of generally declining temperatures (Davis, 1978), but temperature may have been a contributing factor in the early 1970's. The mean bottom temperature on Georges Bank increased from 4.4° C in 1971 to 6.3° C in 1974 (spring surveys) and from 10.5° C in 1970 to 12.7° C in 1973 (autumn surveys), although the latter values were not appreciably different from those in the mid-1960's (averaging 11.9° C) when growth rates were substantially lower. However, stock biomass declined by more than 95% during 1965-72. One obvious inference is that increased availability of food associated with declining recruitment and stock size in the late 1960's and early 1970's was responsible for the pronounced acceleration in growth during 1968-75.

Changes in haddock growth have been observed by several European researchers, notably Anderson (1938), Raitt (1939), Sonina (1965, 1969), Jones and Hislop (1978), and Jones (MS 1979). An apparent

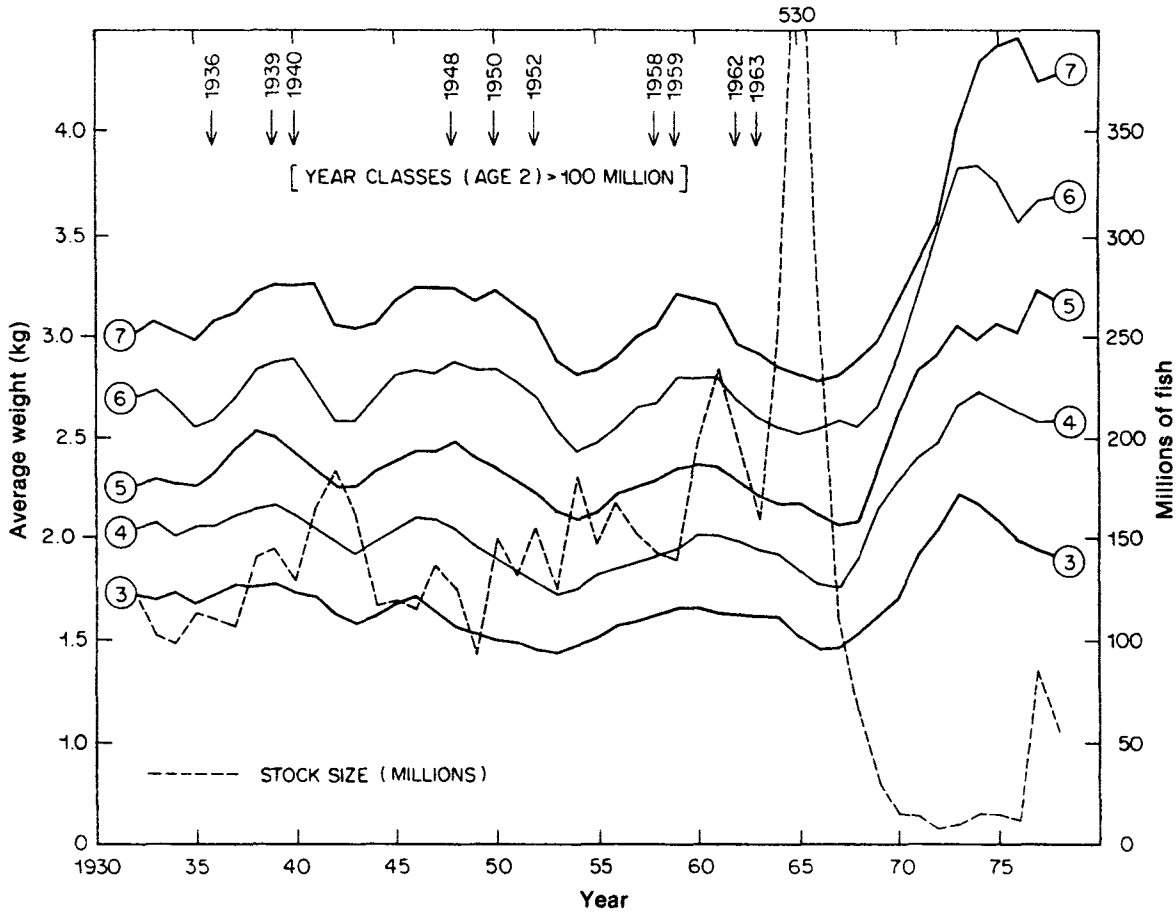

Fig. 9. Trends in mean weight at age and stock size (millions) for Georges Bank haddock, 1931-77.

inverse relationship between population abundance and growth was observed in all of these studies. Similarly, Templeman *et al.* (1978) and Templeman and Bishop (1979) observed inverse relationships between population abundance and growth for Grand Bank and St. Pierre Bank haddock (changes in abundance were determined to have been the major source of variation in growth for the Grand Bank population, but temperature may have contributed to the observed trends for the St. Pierre Bank population). For Grand Bank haddock, abundant year-classes appeared to have depressed growth of subsequent year-classes, as observed in the present study for Georges Bank haddock.

Commercial weight-at-age data for 1973-77 (Table 7) and length-at-age data from spring and autumn research vessel surveys during the same period do not reveal any consistent shifts in growth patterns and appear to be representative of recent conditions. Accordingly, survey data for 1973-77 were used to derive growth parameter estimates. Ages were determined from scales of 2,910 haddock from Georges Bank. By convention, 1 January was assumed to be the birthdate, and ages were coded such that a haddock hatched in a given year was assumed to be 0.3 years old during the spring survey (April) and 0.8 years old during the following autumn survey (October). The method of Tomlinson for unequal sample sizes (Abramson, 1971) was used to fit the von Bertalanffy growth equation.

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

where L_t is fork length (cm) at age t, L_∞ is the maximum calculated length, k is the Brody growth coefficient, and t_o is the hypothetical age at zero length. The resulting equation for Georges Bank haddock was

$$L_t = 73.80 \ (1 - e^{-0.3763(t-0.1649)})$$

A similar analysis of 1,249 specimens from the Gulf of Maine population provided the equation

$$L_t = 72.91 \ (1 - e^{-0.3524(t-0.2946)})$$

Predicted lengths at age indicate slightly slower growth for Gulf of Maine haddock (Fig. 10).

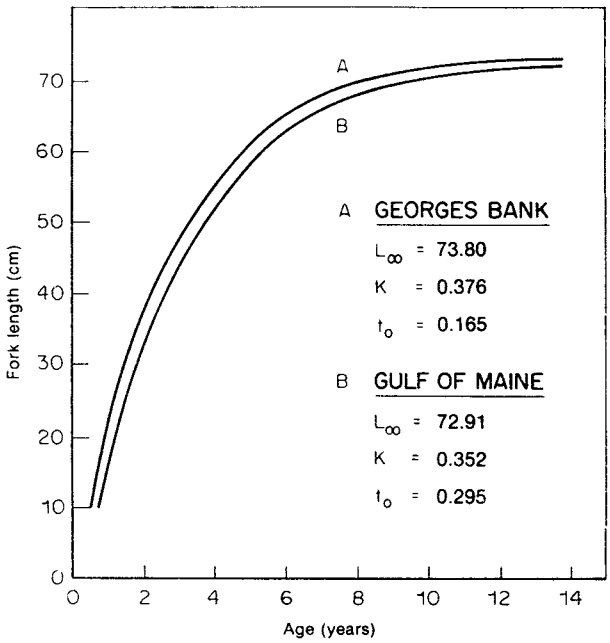

Fig. 10. Von Bertalanffy growth curves for Georges Bank and Gulf of Maine haddock, obtained from analysis of USA spring and autumn bottom-trawl survey data for 1973-77.

The calculated L_∞ value of 73.8 cm for Georges Bank haddock is similar to that reported by Beverton (1965) for this stock (73 cm) although the k value obtained in the present study is considerably higher (0.376 versus 0.28). The latter value was derived from analysis of commercial length-at-age data, implying a downward bias in k due to commercial gear selectivity (resulting in omission of data for the younger age-groups).

Yield per Recruit

Canadian and USA vessels, engaged in demersal trawling for haddock, cod and yellowtail flounder, *Limanda ferruginea*, in the Georges Bank-Gulf of Maine area, use gear fabricated of synthetic twine (usually polyamide fibres); current regulations for USA vessels require a stretched mesh size of at least 130 mm in the codend. Previous selectivity experiments with double braided polyamide trawls (Holden, 1971) indicated a selection factor of 3.4 for haddock. A similar value (3.5) was obtained by Smolowitz (MS 1978) during gear selectivity studies in the western Gulf of Maine. Use of data reported by Holden (1971) implies a mean selection length (l_c) of 44.2 cm, and application of the above growth equations implies a mean selection age (t_c) of 2.6 years for Georges Bank haddock and 2.9 years for haddock in the Gulf of Maine. However, alleged use of smaller-meshed codends in the USA fishery in recent years implies that t_c may actually be somewhat lower.

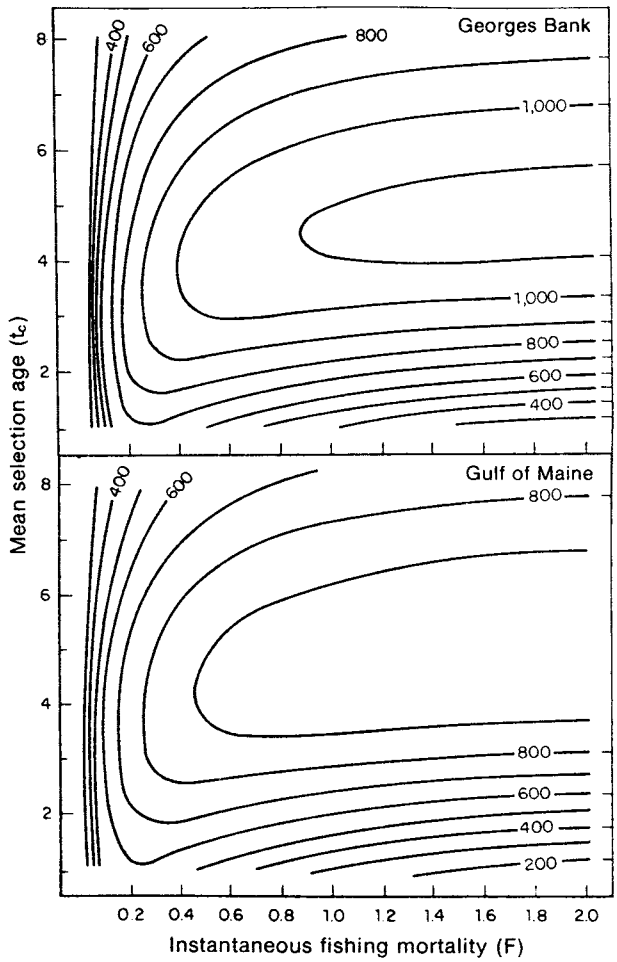

Fig. 11. Yield isopleths (g) for Georges Bank and Gulf of Maine haddock, based on parameter estimates given in Table 8.

TABLE 8. Parameters used in yield-per-recruit modeling for Georges Bank and Gulf of Maine haddock.

Parameter	Georges Bank	Gulf of Maine
Fishing mortality, F	0.1-2.0	0.1-2.0
Natural mortality, M	0.2	0.2
Asymptotic weight, W_∞ (gm)	4,374	4,214
Length-weight exponent, b	3.07[a]	3.07[a]
Brody growth coefficient, K	0.3763	0.3524
Hypothetical age at zero length, t_0 (yr)	0.1649	0.2946
Age at recruitment, t_r (yr)	1.0	1.0
Mean selection age, t_c (yr)	1.0-8.0	1.0-8.0
Hypothetical maximum age, t_λ (yr)	18	18

[a]M. D. Grosslein, Northeast Fisheries Center, Woods Hole, per. comm., 1980).

Yield isopleths were calculated for the Georges Bank and Gulf of Maine stocks (Fig. 11) using the Paulik and Gales (1964) modification of the Beverton and Holt (1957) model and the parameters listed in Table 8. Transverse isopleths for Georges Bank for t_c values of 2.0, 2.5 and 3.0 years indicate that yield per

recruit is maximized at F (F_{max}) values of 0.36, 0.47 and 0.63 respectively, the corresponding $F_{0.1}$ values (Gulland and Boerema, 1973) being 0.21, 0.23 and 0.26 (Table 9). For the Gulf of Maine, F_{max} values of 0.32, 0.41 and 0.54 and $F_{0.1}$ values of 0.19, 0.22 and 0.25 were

TABLE 9. F_{max} and $F_{0.1}$ values obtained for Georges Bank and Gulf of Maine haddock for three mean selection ages.

Selection age	Georges Bank		Gulf of Maine	
	F_{max}	$F_{0.1}$	F_{max}	$F_{0.1}$
2.0	0.36	0.21	0.32	0.19
2.5	0.47	0.23	0.41	0.22
3.0	0.63	0.26	0.54	0.25

obtained for the same t_c values. Calculations employing the unmodified Beverton and Holt yield model with the above growth parameter estimates for Georges Bank at the same t_c values gave F_{max} values of 0.42, 0.55 and 0.76 and $F_{0.1}$ values of 0.22, 0.26 and 0.33 respectively (Clark and Overholtz, MS 1979).

Stock Abundance and Recruitment

Georges Bank

A VPA of the catch-at-age data for Georges Bank haddock (Table 2) was performed to estimate fishing mortality (F) and stock size for 1931–77. As haddock recruit strongly to the fishery at age 2 (partial recruitment has averaged about 75% for most recent year-classes), total stock size estimates were calculated in terms of age 2 and older fish, and spawning stock size estimates were calculated as 50% of age 2 fish and 100% of age 3 and older fish. Natural mortality (M) was assumed to be 0.2 for all age groups, the value used in previous assessments of the Georges Bank stock.

The lack of directed fishing effort data for recent years (1974–77) due to incidental catch regulations precluded estimation of F for 1977 from relationships between F and fishing effort in preceding years. Accordingly, a special procedure was used to estimate a starting F-value for 1977. Stock size estimates (numbers, age 3 and older) from a preliminary VPA with a trial F-value of 0.30 for 1977 were regressed against numbers per tow (age 2 and older, lagged one year) from autumn research vessel surveys for the 1964–74 period (Fig. 12). Stock size for 1977 was then predicted and used with known catch-at-age in numbers for 1977 to estimate exploitation rate (u) and F for 1977. This value of F was then used as the starting F in another VPA to generate new stock size estimates, and the procedure was repeated until F for 1977 stabilized at 0.365, the starting value used in the final VPA.

There is some doubt relative to the actual catch of age 3 and older haddock in 1977 (Table 2), as incidental catch regulations were in effect during the summer and autumn of that year when the strong 1975 year-class was recruiting to the fishery. Under these regulations, fishermen were allowed to retain and land only a small portion of the total haddock catch, which according to industry sources resulted in the discarding of large quantities (precise estimates being unavailable). This situation appears to have been unprecedented for the Georges Bank stock and was different from that under ICNAF management when TACs and/or incidental catch limitations were in effect but were not severely limiting due to low abundance. In the absence of length or age composition data for these discards, it could be assumed that significant quantities of age 3 and older haddock were discarded, but ancillary information indicates that discarding was confined primarily to age 2 fish (the recruiting 1975 year-class). In the few cases where information on discarding was reported, small (age 2) haddock were primarily involved; also, it is logical to assume that, in situations where both small and large haddock were available, fishermen would discard the smaller, lower-priced fish. Accordingly, it is believed that any downward bias in the 1977 estimate of F (from lack of discard data for age 3 and older haddock) is not substantial. However, discarding of haddock and misreporting of haddock as other species occurred to a significant degree in 1978, and, because the 1975 year-class at age 3 was clearly involved, VPA was not applied to data for 1978–79. Results of this analysis are given in Tables 10 and 11 and Fig. 13.

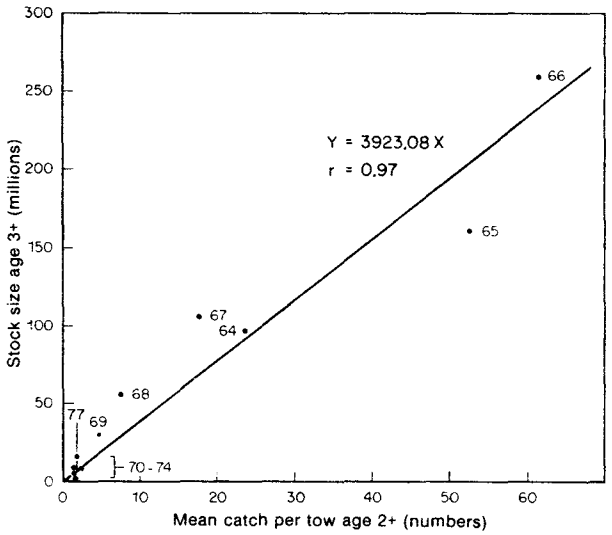

Fig. 12. Relation between stock size (age 3 and older) of Georges Bank haddock from virtual population analysis and mean catch per tow (age 2 and older) from USA autumn bottom-trawl surveys, 1964–74.

Weighted estimates of F (age 3+) declined from 0.62 in 1931 to 0.34 in 1934 (Table 10) as fishing effort declined following heavy exploitation in the late 1920's. Estimates subsequently averaged 0.44 during 1935–60, slightly lower than F_{max} which was about 0.5 for this

TABLE 10. Instantaneous fishing mortality (F), from virtual population analysis, with M = 0.20, for Georges Bank haddock, 1931–77.

Year	Fishing mortality by age-group									Mean F[a]
	1	2	3	4	5	6	7	8	9+	Age 3+
1931	0.048	0.128	0.172	0.425	0.836	0.956	1.060	0.618	0.618	0.618
1932	0.003	0.074	0.664	0.316	0.528	0.710	0.561	0.609	0.609	0.609
1933	0.005	0.287	0.315	0.593	0.497	0.455	0.751	0.470	0.470	0.470
1934	0.006	0.123	0.300	0.330	0.372	0.502	0.323	0.335	0.335	0.335
1935	0.023	0.308	0.377	0.346	0.470	0.560	0.475	0.404	0.404	0.404
1936	0.017	0.338	0.551	0.422	0.345	0.420	0.707	0.487	0.487	0.487
1937	0.013	0.296	0.568	0.580	0.667	0.577	0.580	0.588	0.588	0.588
1938	0.014	0.299	0.351	0.389	0.448	0.594	0.654	0.401	0.401	0.401
1939	0.011	0.273	0.530	0.418	0.405	0.380	0.728	0.494	0.494	0.494
1940	0.020	0.180	0.413	0.445	0.368	0.542	0.576	0.428	0.428	0.428
1941	0.008	0.338	0.393	0.523	0.648	0.487	0.813	0.492	0.492	0.492
1942	0.006	0.186	0.419	0.496	0.540	0.599	0.588	0.465	0.465	0.465
1943	0.001	0.097	0.369	0.393	0.466	0.881	0.416	0.408	0.408	0.408
1944	0.001	0.044	0.286	0.606	0.510	0.757	0.387	0.468	0.468	0.468
1945	0.003	0.193	0.159	0.365	0.507	0.402	0.806	0.368	0.368	0.368
1946	0.002	0.217	0.620	0.332	0.662	0.760	0.644	0.602	0.602	0.602
1947	0.002	0.274	0.525	0.683	0.467	0.782	0.783	0.599	0.599	0.599
1948	0.003	0.284	0.585	0.540	0.612	0.503	0.534	0.574	0.574	0.574
1949	0.003	0.302	0.586	0.662	0.514	0.510	0.562	0.601	0.601	0.601
1950	0.002	0.370	0.319	0.407	0.505	0.503	0.508	0.404	0.404	0.404
1951	0.007	0.208	0.687	0.279	0.433	0.725	0.734	0.617	0.617	0.617
1952	0.000	0.386	0.361	0.491	0.282	0.295	0.392	0.397	0.397	0.397
1953	0.009	0.057	0.514	0.419	0.420	0.350	0.276	0.466	0.466	0.466
1954	0.002	0.389	0.227	0.305	0.297	0.449	0.452	0.291	0.291	0.291
1955	0.001	0.106	0.432	0.226	0.294	0.358	0.426	0.372	0.372	0.372
1956	0.001	0.190	0.264	0.533	0.382	0.559	0.559	0.419	0.419	0.419
1957	0.001	0.157	0.355	0.286	0.535	0.499	0.582	0.389	0.389	0.389
1958	0.002	0.128	0.252	0.284	0.412	0.434	0.362	0.305	0.305	0.305
1959	0.001	0.139	0.272	0.294	0.271	0.342	0.399	0.288	0.288	0.288
1960	0.002	0.184	0.216	0.246	0.285	0.190	0.253	0.233	0.233	0.233
1961	0.001	0.124	0.261	0.225	0.246	0.279	0.199	0.250	0.250	0.250
1962	0.002	0.117	0.280	0.294	0.292	0.279	0.402	0.290	0.290	0.290
1963	0.017	0.151	0.291	0.316	0.397	0.308	0.307	0.327	0.327	0.327
1964	0.024	0.124	0.253	0.308	0.438	0.543	0.535	0.387	0.387	0.387
1965	0.392	0.468	0.593	0.531	0.517	0.718	0.846	0.605	0.605	0.605
1966	0.032	0.540	0.870	0.555	0.584	0.666	0.594	0.791	0.791	0.791
1967	0.113	0.060	0.462	0.430	0.670	0.550	0.587	0.495	0.495	0.495
1968	0.024	0.477	0.377	0.644	0.616	0.503	0.694	0.588	0.588	0.588
1969	0.002	0.042	0.549	0.436	0.473	0.557	0.445	0.524	0.524	0.524
1970	0.012	0.247	0.080	0.358	0.325	0.278	0.436	0.393	0.393	0.393
1971	0.000	0.559	0.652	0.292	0.311	0.955	0.727	0.552	0.552	0.552
1972	0.020	0.040	0.357	0.526	0.401	0.205	0.964	0.363	0.363	0.363
1973	0.221	0.386	0.077	0.594	0.799	0.823	0.196	0.484	0.484	0.484
1974	0.008	0.242	0.204	0.067	0.199	0.059	0.111	0.201	0.201	0.201
1975	0.122[b]	0.231	0.418	0.172	0.186	0.176	0.160	0.337	0.337	0.337
1976	0.001[b]	0.490	0.185	0.356	0.142	0.006	0.138	0.237	0.237	0.237
1977	...[c]	...[c]	0.365	0.365	0.365	0.365	0.365	0.365	0.365	0.365

[a]Weighted by stock size in numbers over age-groups 3 to 7; used as starting F for age-groups 8 and 9+.
[b]Predicted value.
[c]Cannot be estimated due to high discarding and misreporting in 1977.

period (Hennemuth, MS 1969). During the late 1950's and early 1960's, F declined somewhat and then steadily increased to 0.79 in 1966 as fishing effort by distant-water fleets intensified. Subsequently, F declined to relatively low levels in the 1970's coincident with low recruitment and redirection of fishing effort to other species. These trends are generally consistent with those evidenced by analysis of research vessel survey data, although the decline in average F from 1964–67 to 1968–72 based on survey data (0.86 to 0.30, assuming M = 0.2, Table 6) was greater than that indicated by VPA for the same periods (0.64 to 0.53, Table 10).

Total stock size (age 2 and older) increased from 100 million fish (113,000 tons) in 1933–34 to an average of 140 million fish (153,000 tons) in 1935–60 (Table 11, Fig. 13). During the late 1950's and early 1960's, however, stock size increased more or less continuously, particularly in the latter part of this period due to significant contributions by the very strong 1958 and 1959

TABLE 11. Stock sizes from virtual population analysis, with M = 0.2, for Georges Bank haddock, 1931-78. (Weights calculated by applying mean weight-at-age data for first quarter of each year.)

	Stock size by age-group (000s)									Total stock (age 2+)		Spawning stock[a]	
Year	1	2	3	4	5	6	7	8	9+	Number (000s)	Weight (tons)	Number (000s)	Weight (tons)
1931	41,183	80,780	14,217	18,310	17,482	10,670	5,608	4,249	1,324	152,640	180,209	112,250	151,533
1932	45,586	32,138	58,205	9,801	9,801	6,205	3,360	1,590	936	122,036	129,600	105,967	123,172
1933	52,103	37,314	24,435	24,539	5,849	4,733	2,496	1,570	1,889	102,825	117,599	84,168	105,286
1934	60,477	42,517	22,930	14,594	11,105	2,915	2,459	964	648	98,132	108,404	76,874	94,373
1935	58,872	49,226	30,795	13,907	8,594	6,265	1,445	1,457	359	112,048	120,207	87,435	104,208
1936	58,645	47,132	29,634	17,296	8,058	4,397	2,929	736	352	110,534	123,837	86,968	109,933
1937	106,346	47,215	27,515	13,981	9,289	4,674	2,365	1,182	546	106,767	120,143	83,160	105,743
1938	79,251	85,910	28,739	12,764	6,410	3,904	2,149	1,085	574	141,535	155,661	98,580	120,867
1939	59,750	63,993	52,183	16,565	7,080	3,354	1,765	915	671	146,526	161,572	114,530	140,134
1940	111,805	48,379	39,862	25,158	8,930	3,866	1,878	698	428	129,199	152,253	105,010	134,836
1941	114,103	89,700	33,077	21,586	13,197	5,058	1,841	864	1,081	166,404	179,284	121,554	152,374
1942	61,462	92,731	52,365	18,279	10,479	5,654	2,545	669	518	183,240	185,096	136,875	154,495
1943	23,566	50,122	63,038	28,207	9,114	5,002	2,544	1,157	582	159,766	163,552	134,705	151,021
1944	64,821	19,422	37,261	35,685	15,588	4,681	1,698	1,374	316	116,025	142,963	106,314	137,913
1945	51,611	53,281	15,216	22,921	15,942	7,667	1,798	944	730	118,499	147,149	91, 859	125,570
1946	93,096	42,009	35,950	10,630	13,033	7,861	4,200	657	56	114,396	144,026	93,392	131,423
1947	60,971	76,237	27,673	15,831	6,243	5,501	3,010	1,806	1,108	137,409	138,934	99,291	114,538
1948	33,352	49,872	47,472	13,402	6,547	3,205	2,062	1,126	923	124,609	126,777	99,673	111,317
1949	125,835	27,266	30,739	21,657	6,393	2,907	1,588	989	854	92,393	99,760	78,760	91,581
1950	58,894	102,756	16,506	14,003	9,146	3,132	1,429	741	824	148,537	156,023	97,159	111,838
1951	105,619	48,368	58,120	9,824	7,632	4,519	1,551	704	510	131,228	124,762	107,044	108,077
1952	43,589	85,981	32,160	23,941	6,086	4,053	1,791	609	358	154,979	139,367	111,989	110,994
1953	133,495	35,688	47,848	18,346	11,999	3,759	2,470	991	447	121,548	120,428	103,704	109,543
1954	52,552	108,354	27,590	23,421	9,884	6,454	2,169	1,535	426	179,833	174,869	125,656	131,528
1955	92,857	43,107	60,121	17,993	14,133	6,011	3,373	1,130	611	146,479	155,140	124,926	137,897
1956	61,067	76,081	31,741	31,957	11,747	8,624	3,441	1,804	643	166,038	188,771	127,998	157,958
1957	62,310	49,998	51,533	19,963	15,361	6,562	4,038	1,611	1,245	150,311	171,726	125,312	150,727
1958	59,260	51,137	34,995	29,579	12,278	7,363	3,261	1,847	593	141,053	175,513	115,485	151,990
1959	126,540	48,613	36,847	22,277	18,225	6,658	3,907	1,859	1,466	139,852	175,934	115,546	154,788
1960	123,370	104,753	34,651	22,979	13,592	11,384	3,872	2,147	1,840	195,218	232,377	142,842	187,334
1961	53,899	100,927	71,348	22,860	14,709	8,371	7,707	2,462	3,348	231,732	269,626	181,269	226,732
1962	38,736	44,363	72,995	44,990	14,938	9,418	5,185	5,170	3,917	200,976	233,529	178,795	218,002
1963	186,718	31,766	32,305	45,158	27,450	9,131	5,833	2,840	4,312	158,795	205,068	142,912	194,585
1964	460,854	150,289	22,361	19,781	26,951	15,117	5,494	3,513	4,550	248,056	252,423	172,912	202,827
1965	32,436	368,278	108,689	14,212	11,903	14,244	7,190	2,634	3,287	530,437	426,817	346,298	314,493
1966	4,040	17,940	188,745	49,185	6,840	5,813	5,690	2,526	1,728	278,467	271,349	269,497	267,313
1967	11,822	3,205	8,562	64,755	23,112	3,123	2,444	2,572	1,956	109,729	143,354	108,127	142,489
1968	366	8,643	2,473	4,418	34,481	9,687	1,475	1,113	2,070	64,360	93,321	60,039	89,604
1969	969	293	4,393	1,388	1,900	15,248	4,796	603	1,529	30,150	56,471	30,004	56,341
1970	4,337	794	230	2,076	735	970	7,155	2,516	1,565	16,041	39,342	15,644	38,977
1971	70[b]	3,511	508	174	1,188	435	601	3,788	2,392	12,597	28,016	10,842	26,629
1972	8,763	57	1,644	217	106	713	137	238	4,453	7,565	21,850	7,537	21,827
1973	14,172	7,035	45	942	105	58	476	43	1,275	9,979	14,432	6,462	11,548
1974	6,783	9,300	3,914	34	426	39	21	320	1,504	15,558	21,693	10,908	18,159
1975	1,844	5,513	5,977	2,613	26	285	30	15	338	14,797	22,588	12,041	20,245
1976	94,000[b]	1,337	3,583	3,221	1,801	18	196	21	583	10,760	21,594	10,092	20,939
1977	23,000[b]	77,000[c]	671	2,439	1,847	1,280	14	140	398	83,789	72,524	45,289	44,804
1978	4,000[b]	19,000[c]	32,000[c]	381[d]	1,386[d]	1,050[d]	728[d]	8[d]	306[d]	54,859	66,210	45,369	59,275

[a] Includes 50% of age 2 and 100% of age 3 and older fish. [b] Back-calculated assuming M = 0.20. [c] Predicted. [d] Calculated from $N_{i+1} = N_i e^{-Z_i}$

year-classes. Stock size subsequently peaked at 530 million fish (427,000 tons) in 1965 due to recruitment of the very strong 1962 and the outstanding 1963 year-classes, the latter being estimated to have consisted of 368 million fish at age 2, six times larger than the 1935-60 year-class average. Stock abundance declined precipitously in the late 1960's and early 1970's to an average level of 9 million fish (18,000 tons) in 1972-73 in response to over-exploitation and poor recruitment, and, after averaging 14 million fish (22,000 tons) during 1974-76, rose sharply in 1977 with recruitment of the 1975 year-class.

Trends in estimates of spawning stock size have paralleled those observed for total stock size, decreasing to a low of 77 million fish (94,000 tons) in 1934 and then increasing to an average of 109 million fish (131,000 tons) during 1935-60 (Table 11). Spawning stock size subsequently peaked at 346 million fish (314,000 tons) in 1965 before declining to an apparent all-time low of 6 million fish (12,000 tons) in 1973. Since then, it increased to an average of 11 million fish (20,000 tons) during 1974-76 and rose sharply in 1977-78 as the 1975 year-class matured.

Estimation of stock abundance for 1977 and subsequent years is obviously dependent on estimates of recruiting year-class size. For 1977, the 1975 year-

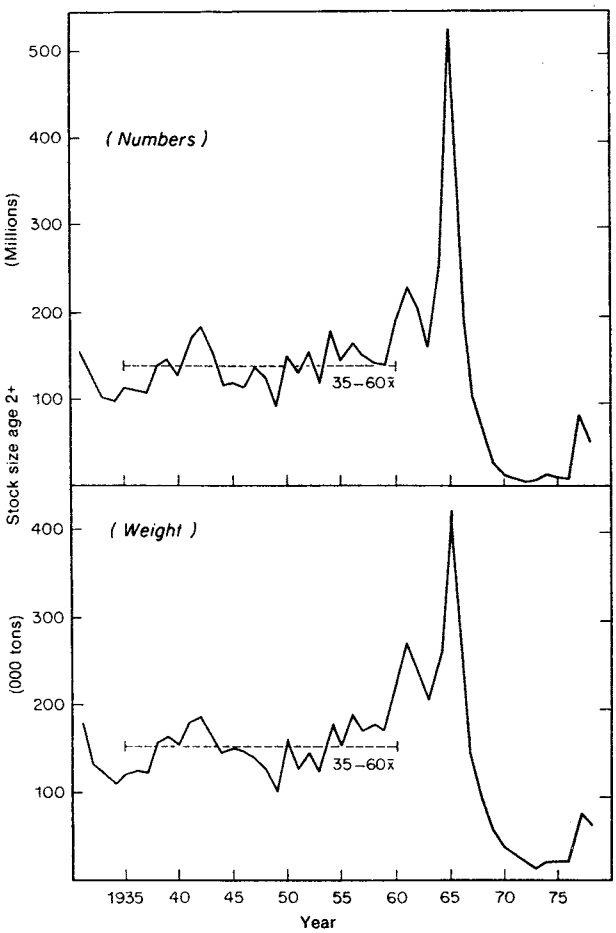

Fig. 13. Trends in stock size (number and weight) of age 2 and older haddock on Georges Bank, estimated from virtual population analysis, 1931-78.

class estimate is critical due to the apparent strength of this year-class and low abundance of older fish. This year-class dominated 1977-79 survey catches of age 2 and older fish on Georges Bank (Tables 4 and 5) and was also the strongest to appear in surveys conducted by Federal Republic of Germany and USSR research vessels in cooperation with USA during 1973-76, its size being estimated at more than 100 million fish at age 2 based on simple ratios of catch per tow of the 1972 and 1975 year-classes at age 1 (Clark and Overholtz, MS 1979).

Estimation of the sizes of the 1975 and subsequent year-classes has been complicated by uncertainty about nominal catch at age and variability in survey abundance indices. Variability in catch per tow has increased during the available time series (1968-80 for spring surveys and 1963-80 for autumn surveys) and was particularly high in 1976 and 1979 due primarily to anomalous catch-per-tow values for age 1 fish. Therefore, the potential exists for distortion of empirical relationships between VPA estimates of year-class size

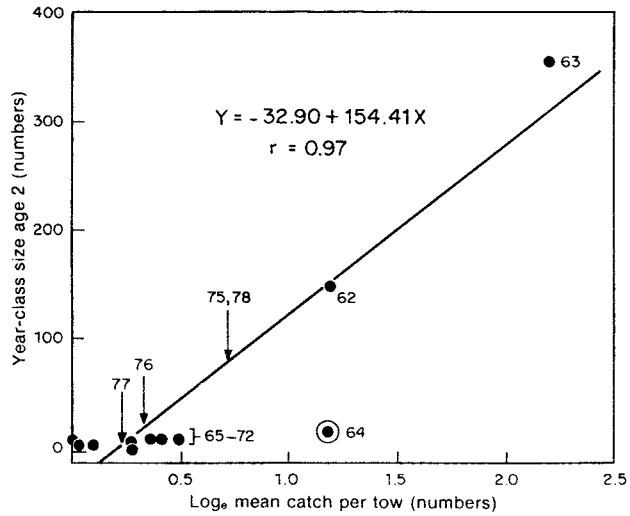

Fig. 14. Relation between year-class size of haddock (age 2) from virtual population analysis and mean catch per tow (based on *ln* x+1 values) from USA autumn bottom-trawl surveys on Georges Bank, 1962-78.

and survey abundance indices. Also, the available time series is limited and includes points varying widely in magnitude, and thus predictive regressions for estimation of year-class size would be expected to be quite sensitive to deletion of existing data points and/or incorporation of additional ones. Consequently, estimates of year-class size predicted from such regressions should be treated with caution, although results from this study are consistent with survey data and industry reports indicating the 1975 and 1978 year-classes to be strong ones. The 1975 and 1978 year-classes appear to have been comparable in size, based on spring and autumn survey abundance indices (Tables 4 and 5), and estimates obtained from a linear regression of VPA numbers at age 2 on mean catch per tow of age 1 fish in autumn surveys, calculated from *ln*(x+1) values (Fig. 14), were very similar (77 million fish, with a 95% confidence interval of ±21 million fish). Estimates of the sizes of the 1976 and 1977 year-classes at age 2 were substantially lower (19 million and 3 million fish respectively). Similar relationships based on untransformed data provided estimates of 165 million and 138 million fish for the 1975 and 1978 year-classes (Clark and Overholtz, MS 1979; Clark and Essig, MS 1980). The above estimate of 77 million fish at age 2 for the 1975 year-class implies a total stock size of 84 million fish (73,000 tons) and a spawning stock size of 45 million fish (45,000 tons) in 1977 (Table 11).

The reliability of the above estimates is difficult to verify, but ancillary information does support the 1975 year-class size estimate of 77 million fish. A similar regression of VPA numbers at age 3 on mean catch per tow at age 2 in autumn surveys provided an estimate of

32 million fish at age 3 (95% confidence interval of '12 million fish). This value is obviously incompatible with nominal catch-at-age data for this year-class, but it does not appear unreasonable in view of information on discarding in 1977 and total mortality estimates from survey data. Interviews conducted in August 1977 indicated that quantities discarded may have exceeded the reported landings in weight by a factor of 4, and if the smallest fish were discarded, the factor in terms of numbers was probably considerably larger. A total catch (including discards) of 36 million fish, implying a discard rate equal to 5 times the reported catch of the 1975 year-class in 1977, would have generated F [0.71 or Z [0.91, very similar to the average Z (0.89) for 1977 based on spring and autumn survey data.

Pronounced differences are evident in the distribution of recruiting year-class size (age 2) between 1935–60, when stock size was relatively stable, and 1961–80, when stock abundance peaked and then declined precipitously (Fig. 15). During 1935–60, year-class size was relatively constant, with almost half of the recruiting year-classes being in the order of 40–50 million fish. The frequency distribution of year-class size for this period is noticeably skewed (mean of 61 million fish, with a range of 19–108 million fish), but variation was small compared to that for later years. "Strong" year-classes (75–100 million fish) occurred on an average of once every 3 years, and "very strong" year-classes (>100 million fish) occurred occasionally. During the same period, spawning biomass was generally in the range of 100,000–160,000 tons (Table 11, Fig. 16). The 1961–80 period was marked by recruitment of the very strong 1959 and 1962 year-classes and the outstanding 1963 year-class. Subsequently, no year-classes of even average size were produced until 1975, although spawning stock biomass peaked at 314,000 tons in 1965 and did not decline below 100,000 tons until 1968.

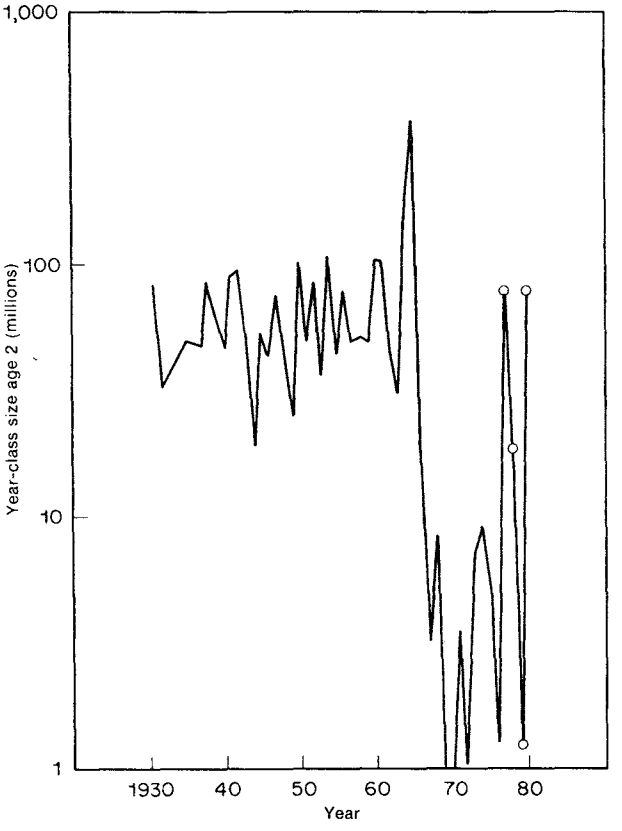

Fig. 15. Recruiting year-class size of haddock (age 2) on Georges Bank from virtual population analysis, 1931-80. (Estimates for last 4 year-classes are predicted.)

Herrington (1948) obtained a dome-shaped stock-recruitment relationship for Georges Bank haddock by plotting, for 1914–40, commercial abundance index values for small (scrod) haddock against values for spawning adults (lagged 2–3 years). However, catch-effort data on which this analysis was based may not have been representative for earlier years (1914–30) (Herrington, 1948; Grosslein, MS 1966), thus casting doubt on the validity of this apparent relationship. Subsequent analyses based on more recent data (since 1931) have been inconclusive (Grosslein and Hennemuth, 1973). Similarly, no empirical basis for a stock-recruitment relationship was found in the present study (Fig. 16), although a tendency does appear evident for reduced recruitment at lower levels of stock abundance, as noted by Grosslein and Hennemuth (1973). During 1968–73, when spawning stock size

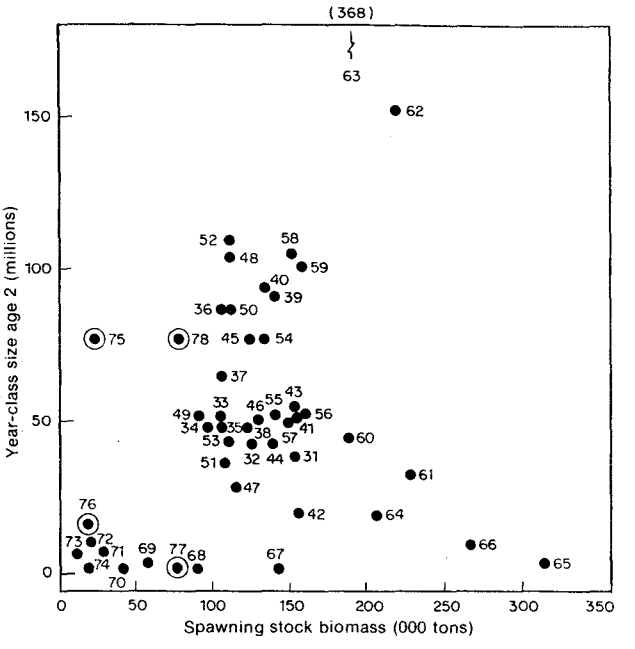

Fig. 16. Relation between recruiting year-class size (age 2) and spawning stock biomass (50% of age 2 and 100% of age 3 and older fish) for Georges Bank haddock from virtual population analysis, 1931-78. (Predicted points are circled.)

declined rapidly from 90,000 to 12,000 tons, no year-classes of even average size were produced, and during 1974–77, when spawning stock size averaged 26,000 tons, only one such year-class was produced. However, full recruitment of the 1975 year-class to the spawning stock in 1978 was accompanied by the appearance of the strong 1978 year-class. Consequently, it might be inferred that recruitment is affected at low levels of abundance, although, in general, stock effects are probably obscured by environmental factors (Sissenwine *et al.*, 1979; Hennemuth *et al.*, 1980). In any event, maintenance of spawning biomass within a range of 100,000–160,000 tons during 1935–60 did provide relative stability in recruiting year-class size, even in the absence of a quantifiable relationship.

Gulf of Maine

Available catch-at-age data for this stock are not sufficient for application of VPA, and accordingly trends in abundance have been evaluated primarily by examination of nominal catch and research-vessel survey data (Tables 1 and 3). Both sets of data indicate trends in abundance similar to those observed for Georges Bank, with precipitous declines from the early 1960's to the mid-1970's and recovery in the late 1970's following recruitment of the 1975 year-class. However, the 1976–79 year-classes appear to have been much weaker and stock size has again declined following peak levels in 1977–78 (Table 3).

Nominal catches in 1977–78 (average of 4,250 tons) were comparable to those observed during 1964–68 (average of 4,915 tons). The estimated recreational catch in the Gulf of Maine for 1978 was in the order of 400–500 tons. Recreational catches in the mid-1960's are uncertain due to variability in the estimates, i.e. the 1965 estimate of 9,702 tons (Deuel and Clark, 1968) appears unrealistically high in view of the 1960 and 1970 estimates averaging 957 tons (Clark, 1962; Deuel, 1973). The pooled estimate of Z for 1964–68 from autumn survey data was 0.58, implying an F of 0.38 (assuming M = 0.2). Biomass levels for 1977–78 appear to have been comparable to those for 1964–68 (average autumn survey index values were 12.8 kg and 11.2 kg respectively).

Combination of the average annual nominal catch for 1964–68 (4,915 tons) and the average estimated recreational catch for 1960 and 1970 (957 tons) gives an average catch of 5,872 tons. Use of this value with the above estimates of F and Z in the equation

$$C = \frac{F}{Z-G} B[1 - e^{-(Z-G)}]$$

where C is average catch, B is average stock biomass, G is instantaneous growth rate (0.44 being the average for dominant age-groups 2–4 in the fishery), and F and Z are as previously defined, provides an average annual stock biomass of 16,000 tons for 1964–68. In view of the above-mentioned similarity of autumn survey index values for 1964–68 and 1977–78, it appears that stock biomass had increased by 1977–78 to approximately the observed 1964–68 level.

Summary and Conclusions

The Georges Bank haddock stock has been intensively studied since 1930, and a large volume of biological and statistical data has been accumulated for assessment and management purposes. Important earlier papers dealt with evaluation of trends in abundance and harvest potential, stock identification, and environmental factors affecting year-class size. Interest during the 1950's was focused on gear selectivity and evaluation of mesh regulations, and more recent work has been oriented largely towards stock assessment.

Management originated under ICNAF in 1953, with implementation of a regulation specifying a minimum mesh size of 4.5 inches (114 mm) for Subarea 5. This regulation substantially increased harvesting efficiency and reduced discarding of haddock. The documented severe reduction of the Georges Bank stock during the 1960's led to more intensive management, including total allowable catches and closure of haddock spawning areas. Responsibility for management of the Georges Bank and Gulf of Maine haddock stocks was assumed by the USA New England Regional Fishery Management Council in early 1977, following the extension of jurisdiction over fisheries to 200 miles. Initially, previous ICNAF management measures were continued, but recruitment of the strong 1975 year-class in 1977 and a rapid increase in USA harvesting capacity led to increased optimum yields in subsequent years.

Georges Bank haddock spawn between January and June, with peak activity in late March and April. Juveniles are pelagic in habit for several months but subsequently settle to the bottom for the rest of their lives. Approximately 50% of age 2 and 100% of age 3 and older haddock are sexually mature. The Georges Bank population east of the Great South Channel appears to be relatively isolated from those of adjacent areas, but one or two smaller units, which may intermingle to some degree, also exist in the Nantucket Shoals and western Gulf of Maine area.

Following high levels of exploitation in the late 1920's, the Georges Bank haddock fishery entered a period of relative stability during 1935–60, with nominal catches averaging 46,000 tons. During this period,

the fishery was prosecuted almost exclusively by USA vessels and catches were dominated by age 2–4 fish. Strong recruitment in the early to mid-1960's resulted in greatly increased fishing effort by Canadian and distant-water fleets. Nominal catches increased rapidly to 150,400 tons in 1965 and declined precipitously to an average of 4,700 tons during 1974–76, due primarily to poor recruitment in the late 1960's and early 1970's. During 1967–72, the fishery was supported largely by the remnant of the 1963 year-class. Subsequently, the catch on Georges Bank increased to 22,300 tons in 1978 due to recruitment of the strong 1975 year-class. Similar trends were evident for the Gulf of Maine haddock fishery, in which nominal catches declined from an average of 5,100 tons in 1959–66 to only 600 tons in 1973 but increased to 5,200 tons in 1978. The 1963 year-class primarily supported the fishery during 1966–70 and the 1975 year-class dominated during 1977–79, the intervening year-classes having been poor. Recreational catches of haddock in the Gulf of Maine appear to have fluctuated considerably, but the quantities taken in recent years were small (in the order of 400 tons).

Research vessel survey data for the Georges Bank–Gulf of Maine area indicate a decline in biomass of over 90% during 1964–74, with spawning stock size reaching an apparent all-time low in the early 1970's. Subsequently, catch per tow increased substantially with recruitment of the 1975 year-class. The 1978 year-class was comparable in size to the 1975 year-class on Georges Bank but was much weaker in the Gulf of Maine. Changes in abundance on Georges Bank were accompanied by changes in geographical distribution and spatial density and a marked increase in variability in survey catch-per-tow data.

Analysis of survey data for Georges Bank indicates high levels of mortality ($Z>1.0$) during the mid 1960's, implying that F substantially exceeded F_{max} during that period. Estimates of Z were considerably lower (about 0.5) during 1968–72 but increased in subsequent years despite increasingly restrictive management. Estimates of Z for the Gulf of Maine stock were generally lower than those for Georges Bank.

Growth rates for Georges Bank haddock were relatively stable during 1935–60 although declines occurred following periods of strong recruitment as evidenced by commercial weight-at-age data. In the early to mid-1960's, stock size rose to peak levels and growth rates again declined, but rapid increases occurred in the early to mid-1970's coincident with declining stock abundance. Increased growth rates appear to have resulted from increased food availability associated with reduced abundance. A tendency was evident for strong year-classes to have a depressing effect on the growth of succeeding year-classes. Von Bertalanffy growth equations based on length-at-age data from research vessels surveys in 1973–77 indicate slightly faster growth of haddock on Georges Bank than in the Gulf of Maine. For current regulation trawls (130 mm mesh codend), yield-per-recruit calculations indicate F_{max} values of 0.47 and 0.54 for Georges Bank and Gulf of Maine haddock respectively, with corresponding $F_{0.1}$ values of 0.23 and 0.25.

During 1935–60 total stock size (age 2 and older) for Georges Bank fluctuated about an annual average of 140 million fish (153,000 tons) while spawning stock size averaged 109 million fish (131,000 tons). Recruitment was relatively stable, with almost 50% of the recruiting year-classes (age 2) being in the order of 40–50 million fish; the observed mean was 61 million fish with a range of 19–108 million fish. Recruitment of the very strong 1958, 1959 and 1962 year-classes and the outstanding 1963 year-class resulted in a pronounced increase in total stock size to 530 million fish (427,000 tons) in 1965, while spawning stock size also peaked at 346 million fish (314,000 tons). Following heavy exploitation in the mid-1960's and with continued poor recruitment, total stock size declined precipitously to an average of 9 million fish (18,000 tons) in 1972–73. Fishing mortality on age 3 and older fish increased from an average of 0.44 during 1935–60 to 0.79 in 1966 but subsequently declined with reduced abundance and redirection of fishing effort to other stocks. No empirical basis was found for a stock-recruitment relationship, but a tendency was clearly evident for reduced (and more variable) recruitment at low levels of spawning stock size.

In 1977, stock size increased to about 84 million fish (73,000 tons), with recruitment of the strong 1975 year-class. Recent research vessel survey data indicate the 1978 year-class to be similar in size to the 1975 year-class, and the Georges Bank stock appears to be increasing, although it is clearly in a less stable condition than in former years. Since 1977, the fishery has been based essentially on a single year-class and this situation may continue for some time unless good year-classes appear more frequently. Continued dependence of the fishery on a single year-class implies a continued potential for wide fluctuations in recruitment and stock size.

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