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Analysis of the southern Gulf of St. Lawrence herring stock and implications concerning its future management

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Abstract

The purse-seine fisheries which developed in the southern Gulf of St. Lawrence and Southwest Newfoundland in the mid-1960's were based mainly on the southern Gulf of St. Lawrence stock complex of herring at different times and places along its seasonal migration route. Landings from this stock complex increased rapidly from 50,000 tons in 1964 to nearly 300,000 tons in 1969 and subsequently declined to 60,000 tons in 1972. Total stock size, estimated by cohort analyses, declined from 1,840,000 tons in 1965 to 506,000 tons in 1971, a reduction of 75%. Over the same period the decline was equally pronounced in the adult stock size which by 1972 had been reduced to only 12% of its original level in 1965. The very large 1958 year-class of autumn-spawners and the large 1959 year-class of spring-spawners accounted for nearly 60% of the exploitable stock size in 1965 and remained dominant until 1970. Recruitment to the southern Gulf of St. Lawrence herring stocks has been relatively poor since the late 1950's for both spring- and autumn-spawners, the strongest year-classes being the 1960 year-class of spring-spawners (about 1/5 of the 1959 strength) and the 1962 and 1963 year-classes of autumn-spawners (about 1/5 the strength of the 1958 year-class). Fishing mortality rates increased steadily from 0.04 in 1965 to 0.56 in 1970 and subsequently declined to probably less than 0.30 in 1972. Adjusted catch-per-unit-effort data adequately reflected the change in stock abundance estimated by cohort analyses.

The proportion of the southern Gulf of St. Lawrence herring stocks migrating to Southwest Newfoundland increases continuously with age, from less than 20% in the recruiting age-groups to 100% at age-group 10. Stock sizes in Southwest Newfoundland, estimated by several methods, declined from about 700,000 tons in 1966 to less than 50,000 tons in 1972

It is shown that, excluding the effects of the fishery, the abundance of the southern Gulf of St. Lawrence herring stocks would have declined significantly from 1965 to 1971 due to inadequate recruitment. The effect of the purse-seine fishery was therefore to accelerate the rate and to increase the magnitude of the decline. It is also indicated that the low recruitment since the late 1950's is probably normal for this stock rather than the exception, large year-classes occurring only infrequently. In the future, therefore, average yields will probably be substantially less than those of the late 1960's. This will be particularly so for Southwest Newfoundland which is dependent mainly on large, old herring.

Introduction

Prior to 1965 annual landings from the Newfoundland and Gulf of St. Lawrence herring fisheries tended to reflect the demand for the product rather than the abundance of the resource. These fisheries were traditionally carried on with fixed gears and were associated largely with the demand for herring as bait and food. With the exception of the periods during and just after World Wars I and II, when large quantities of pickled herring were required as food, landings were undoubtedly substantially lower than potential yields (Hodder, 1966a; Tibbo, 1966). This situation rapidly changed after 1965 when large concentrations of herring were found to overwinter in the fjords along the western half of the south coast of Newfoundland (hereinafter referred to as Southwest Newfoundland or Area J; see Fig. 1). From a single vessel in the winter of 1964-65 the seiner fleet increased rapidly to more than 50 vessels by 1968-69 (Hodder, 1969). The increased interest in the herring fishery also resulted in the expansion of fishing operations so that by 1967 the mobile purse-seine fleet had expanded their activities to include various areas of the southern Gulf of St. Lawrence (Fig. 1, Area T) and nearly all months of the year (Iles and Tibbo, 1970).

Coincident with the rapid development of the purse-seine fishery was the construction of several large reduction plants at various places in Areas J and T. There was thus a dramatic increase in the production of herring meal and oil which soon far exceeded the utilization of herring as food and bait (Hodder, 1969). This trend continued until 1970 when markets for food herring became available in Europe as a result of the drastic decline in the Northeast Atlantic herring stocks. Consequently since 1970 an increasing proportion of the herring caught in Areas J and T has been diverted to food and by 1972 more than 60% of the total herring landings were utilized in this manner.

Investigations into the herring stocks supporting the winter fishery in Southwest Newfoundland (Area J) were begun at the St. John's Biological Station, Newfoundland, in 1965, involving the intensive sampling of the mobile fleet catches, the collection of detailed catch and effort statistics, spawning and larval surveys, acoustic surveys and tagging (Hodder, 1966a; Hourston, 1968; Winters, 1970). Similar but less intensive investigations were conducted in the southern Gulf of St. Lawrence by the St. Andrews Biological Station, New Brunswick (Tibbo *et al.*, MS 1969). These studies soon revealed that the winter fishery in Area J was based almost entirely on mature adult herring consisting of a mixture of both spring and autumn spawning types (Hodder, 1971) which migrated to the area in November and remained until early April, and the fisheries in Area T were based mainly on spring-spawners at Magdalen Islands and the Chaleur Bay area (Fig. 1) during April to June and on autumn-spawners in the Gaspé-Chaleur Bay area during July to October. The comparisons of various biological characteristics of herring from different areas (Hodder and Parsons, 1971a, 1971b; Parsons and Hodder, 1971b) together with the results of extensive tagging (Winters, 1970, MS 1971a; Beckett, MS 1971) have confirmed the hypothesis of Hodder (1969) that the herring which support the winter fishery in Area J represent the over-wintering phase of a stock complex of herring largely derived from spring and autumn spawnings in the southern part of the Gulf of St. Lawrence (hereinafter referred to as the southern Gulf of St. Lawrence stocks). Thus the purse-seine fisheries which developed in Areas J and T during the mid-1960's were not based so much on completely different stocks but rather mainly on parts of the same stock complex at different times and places along its seasonal migration route. This has important implications in so far as conservation and management of the resource is concerned.

The lack of significant recruitment to the fishable stocks (Hodder, 1971; Winters and Parsons, MS 1972) together with the dangerously high rates of exploitation (Winters, MS 1971b) has precipitated concern about the future of the fishery, and conservation measures have recently been imposed on the catches of herring in Areas J and T by the Canadian Atlantic Herring Management Committee. In this paper we have attempted to assess the status of the southern Gulf of St. Lawrence stock complex in relation to the yields as the purse-seine fisheries in Areas J and T developed, employing the most recent virtual population techniques as well as information from tagging experiments and catch/effort statistics, and to predict potential yields from the resource under rational management and the effect of such management on the fisheries in the various areas.

Materials and Methods

Compilation of length and age data

The basic data used to determine the length and age composition of the catches in the Area J winter fishery (November to early April) for the 1965-71 seasons were obtained from Hodder *et al.* (MS 1972) and for the 1971-72 season from Winters and Parsons (MS 1972). Since Area J represents only a part of ICNAF Div. 3P, the catches statistics for the fishery in this area were derived from detailed statistical records on file at the St. John's Biological Station rather than from ICNAF Statistical Bulletins. For the Area T spring and summer fisheries, catch statistics pertain to nominal catches for

Div. 4T in ICNAF Statistical Bulletins, and the length compositions of catches are based on length frequencies given in Tibbo *et al.* (MS 1969) and in ICNAF Sampling Yearbooks. Although Tibbo *et al.* (MS 1969) provide age-length keys for samples taken up to 1968, for consistency in compiling the age compositions of the catches over the entire period under consideration (i.e. 1965-72), the age-length keys for the Area J fishery (Hodder *et al.*, MS 1972) were applied to the Area T length frequencies to obtain the age compositions of the Area T catches. In this context it should be noted that the techniques of age and year-class designation used at the St. John's Biological Station have been recommended for use by ICNAF Scientists in herring investigations of the Northwest Atlantic (Hunt *et al.*, MS 1973). In accordance with the recommended convention, age-groups have been used instead of ages. Thus a fish is placed in age-group 0 in the year of its birth, regardless of whether it was spawned in the spring or autumn, and both types enter the next age-group at the same time of the year. To maintain consistency of age-group designation throughout the fishery year, a cohort is considered to enter an age-group at the start of the fishery year, i.e. in April.

The assessment of the southern Gulf of St. Lawrence stock complex is complicated by the mixture of spring- and autumn-spawners in the catches and these have to be treated separately because of differences in growth and in age composition. In the Area J winter fishery the separation of the two components is relatively simple because the maturity stages corresponding to each component are readily distinguishable in the samples and immature fish are relatively scarce. Consequently the age composition and relative contribution of spring and autumn spawners were readily obtainable from the sampling data in order to determine the age compositions of these two components in the catches for Area J. No such separation of sampling data into spring- and autumn-spawners was available for the Area T summer fishery. However, Messieh and Tibbo (1971) have indicated that herring taken during April to June consisted mainly of spring-spawners, whereas those taken during July to October were mainly autumn-spawners. Consequently the age-length key for spring-spawners of the preceding winter fishery in Area J was applied to the length frequencies for the April-June period to obtain the age composition of the catch of spring-spawners for that period. Similarly all fish caught in Area T during July to October were assumed to be autumn-spawners, and the age-length key for autumn spawners in the subsequent winter fishery in Area J was applied to the Area T length frequencies to obtain the age composition of the catch of autumn-spawners for the summer-autumn period. The application of the age-length keys in this manner has the effect of minimizing differences in growth. For spring-spawners growth is negligible between the Area J over-wintering period and the period of the spring fishery in Area T, because feeding does not resume until mid-April and spawning occurs in May. For autumn-spawners most of the growth in length probably occurs during the pre-spawning period, as Hodder *et al.* (MS 1973) indicate that most of the post-spawning feeding is probably associated with the replenishment of fat reserves rather than growth in length.

All length and age composition data were initially compiled and weighted (using appropriate length-weight data) to monthly catches. These were then combined to represent the age compositions of the yearly catches for the two spawning components separately. In this context the yearly catches pertain to the 12-month period from April of one year to March of the next, and the stock sizes pertain to the beginning of the fishery year in April.

Estimate of natural mortality used

Using age-composition data given by Day (1957) for herring stocks in the southern Gulf of St. Lawrence during the 1940's, Beverton (1963) calculated values of total mortality coefficients (Z) ranging from 0.20 to 0.35. The relatively low level of the catches during this period (average about 35,000 tons) suggests that the fishing mortality (F) was low, probably less than 0.10. Also the stock complex of herring in the southern Gulf of St. Lawrence (our Area T) has growth, maturity and life-span characteristics very similar to those for Atlanto-Scandian herring, for which natural mortality (M) has been accurately estimated to range from 0.15 to 0.18 (Beverton, 1963). A value of M = 0.2 has therefore been considered realistic for the southern Gulf of St. Lawrence stock complex.

Results

Trends in landings

Yearly landings from the southern Gulf of St. Lawrence stock complex are shown in Fig. 2. In the Area J winter fishery landings increased rapidly from less than 10,000 tons in 1964 to about 140,000 tons in 1968 and 1969 and declined to less than 10,000 tons in 1972. In the Area T summer fishery, purse-seining did not become a significant factor until 1967, after which landings increased to a peak level of 175,000 tons in 1970 and declined to about 50,000 tons in 1972. The continued increase in the

Area T landings after the Area J landings had peaked is attributed to a significant diversion of effort from the southwest Nova Scotia summer fishery in 1969 to Area T (Iles and Tibbo, 1970).

The trend in yearly landings from the stock complex as a whole (Fig. 2) indicates a rapid increase from about 50,000 tons in 1964 to a peak level of 300,000 tons in 1969 followed by a decline to about 60,000 tons in 1972. The rapid increase was associated with the expansion of purse-seining activities and reduction facilities. The equally rapid decline was due to reduced stock abundance, the reasons for which are discussed later.

Length and age composition of catches

Although the southern Gulf of St. Lawrence stock complex is exploited at different times of the year in different areas, length and age-composition data (expressed as percentages), for both spring- and autumn-spawning components, reveal a remarkable degree of similarity for herring sampled in the Area J winter fishery and in the Area T summer fisheries from 1965 to 1969 (Fig. 3). During this period the fisheries in both areas were based mainly on adult herring (age-group 6 and older). The Area J fishery in 1970 and 1971 continued to be based on adult fish, whereas the Area T fishery gradually shifted to the exploitation of smaller and younger fish which apparently did not migrate to Area J. The differences in the length frequencies for spring-spawners during 1965-68 are attributable to seasonal growth, the fishery in Area T being carried on in April-June whereas in Area J it occurs in the following November-March period.

For autumn-spawners in both areas the fisheries during 1965-69 were dominated largely by the very abundant 1958 year-class (Fig. 3) and this pattern continued into 1970 and 1971 in Area J, where the modal length of herring in the catches gradually increased from 32 cm in 1965 to 35-36 cm in 1971. The change in modal length for Area T after 1969 is reflected in the change in age composition due to the exploitation of smaller and younger fish.

For spring-spawners the dominant year-class was that of 1959, which contributed to the bulk of the catches during 1965-69 in both areas and during 1970-71 in Area J (Fig. 3), where the modal length gradually increased from 31 cm in 1965 to 33-34 cm in 1971. As for autumn-spawners, the catches of spring-spawners in Area T consisted mainly of smaller and younger fish in 1970 and 1971.

Stock size estimates

For the Gulf of St. Lawrence stock, numbers of spring- and autumn-spawning herring in each year of the fishery were derived by sequential computation, using cohort analysis (Pope, 1972), from the numbers caught at each age-group (Table 1). An assumed value of $M = 0.20$ and starting values for F_T (fishing mortality in the terminal year) increasing with age were used. To provide reliable estimates of stock size and fishing mortality rates in 1970 and 1971 age-group compositions of anticipated catches in 1972 and 1973 have been estimated and used in the cohort analyses.

There has been a continuous and pronounced decline in the stock sizes of both spring- and autumn-spawners since the development of a significant purse-seine fishery began in 1965 (Table 2). The spring-spawning stock declined from 2,782 million fish weighing 604,000 tons in 1965 to 679 million fish weighing 128,000 tons in 1971. Over the same period the autumn-spawning stock was reduced from 7,670 million fish with a biomass of 1,236,000 tons to 2,076 million fish with a biomass of 378,000 tons. Total stock size declined from 10,452 million fish weighing 1,840,000 tons in 1965 to about 2,750 million fish weighing 506,000 tons in 1971, a reduction of approximately 75% both in numbers and in biomass. The relative contributions of spring- and autumn-spawners to the total stock complex have remained almost constant throughout the entire period.

The large 1959 year-class accounted for over 50% by number of the spring-spawning stock in 1965 and remained the dominant year-class in that stock until 1970, when the 1968 year-class became partially recruited as 2-year-olds, but by 1971 the 1959 year-class constituted only about 5% of this stock. Similarly, the very large 1958 year-class comprised nearly 35% by number of the autumn-spawning stock in 1965 and remained dominant until the 1967 year-class was partially recruited as 3-year-olds in 1970, but by 1971 the 1958 year-class was reduced to less than 6% of the stock.

Fishing mortality rates

Estimates of fishing mortality rates (Table 2), obtained from cohort analysis, indicate that recruitment to the fishery is essentially complete at age-group 5 for spring-spawners and at age-group 6 for autumn-spawners. Values of F for fully recruited age-groups of spring- and autumn-spawners combined increased from a very low level of 0.04 in 1965 to a high of 0.56 in 1970. Since there was a significant reduction in fishing effort during the 1971-72 winter fishery in Area J (Winters and Parsons, MS 1972) and no apparent increase in effort in Area T during the 1971 summer fishery, the overall fishing mortality rate declined to 0.48 in 1971. The relatively low level of stock abundance during 1972 resulted in poor fisheries in both Areas T and J, and undoubtedly the fishing mortality rate was substantially reduced, F in 1972 probably being less than 0.30.

The average values of F during 1965-71 for fully recruited spring-spawners are consistently higher than those for autumn-spawners. The reason for this is not clear, but it may be related to the greater vulnerability of spring-spawners to both purse seiners and fixed gears during their spawning period.

For both spring- and autumn-spawners, values of F increase with age, particularly after 1967 (Table 2). This coincides with the period of major increase in the Area J catches (Fig. 2). Since only the older mature herring migrate to Area J, the increase in F with age is probably due to the effects of the selective fishery in that area during the over-wintering period.

Recruitment to the exploitable biomass

Recruitment rates (Table 2, last column) for the young age-groups were estimated as the ratio of the weighted mean F values for these age-groups to the F corresponding to the age-group at which recruitment to the fishable stock is considered to be complete, i.e. at age-group 5 for spring-spawners and age-group 6 for autumn-spawners. Spring-spawners recruit fairly rapidly with 40% of the available population recruited by age-group 3 and nearly 90% by age-group 4. Autumn-spawners recruit more slowly with less than 30% recruited at age-group 4 and about 64% at age-group 5. The slower recruitment of autumn-spawners is probably related to their later age at reaching maturity compared to spring-spawners. The estimated ages at 50% recruitment are 3.5 years for spring-spawners and 4.7 years for autumn-spawners.

The population numbers of recruiting age-groups (2-6) were adjusted for partial recruitment and converted to weights to obtain the recruitment biomass for each year as follows:

Year	Recruitment Biomass ('000 tons)		
	Spring Sp.	Autumn Sp.	Total
1965	41	105	146
1966	54	100	154
1967	44	147	191
1968	23	140	163
1969	24	81	105
1970	27	59	86
1971	30	40	70

The recruitment biomass of both spring- and autumn-spawners was generally very low during the 1965-71 period, mainly because of the succession of a series of poor year-classes since the late 1950's (Table 2). The 1964-68 year-classes of autumn-spawners have been particularly poor as were also the 1963-67 year-classes of spring spawners. This explains the general decline in the recruitment biomass of each spawning group in recent years. The 1968 year-class of spring-spawners was somewhat better than those of 1963-67 and the recruitment biomass of spring-spawners will probably increase slightly in 1972. However, since this year-class is only about 1/8 as good as the abundant 1959 year-class of spring-spawners, its effect on the total recruitment biomass will be insignificant. There is no evidence to date to indicate that year-classes of autumn-spawners since 1968 are large enough to significantly increase the recruitment biomass in 1972 and 1973, if current levels of fishing intensity are maintained.

Relationship between exploitable biomass, recruitment and catch

Mean weights for age-groups were applied to the adult population numbers given in Table 2 to obtain the adult biomass for each spawning group at the start of each fishing year. These were combined and added to the total recruitment biomass (see preceding section) for each year to obtain the biomass of the stock available to the fishery, i.e. the exploitable biomass. Although stock sizes of year-classes recruiting to the exploitable stock in 1972 and 1973 are not completely known, estimates for those year-classes which will contribute to the adult stock in those years are available (Table 2).

Consequently, adult stock biomass has been estimated for 1972 and 1973, and these are shown in Fig. 4, together with exploitable biomass, adult biomass and recruitment biomass for 1965-71 and the catch for 1965-72.

The adult biomass has constituted 80-90% of the exploitable biomass since the mobile fishery began in 1965, despite the fact that the adult biomass has been drastically reduced in recent years. This reflects the lack of good year-classes recruiting to the exploitable stock since the fishery began. With the current low level of the adult biomass, the entrance of a strong year-class to the exploitable stock would significantly change the ratio of adult biomass to exploitable biomass.

Although recruitment exceeded the catches during 1965-67 (Fig. 4), the differences were insufficient to maintain the exploitable stock at its initial level and by 1967 the latter had declined by 20%. The continued increase in the fishing effort (see Table 3) and the general decline in the recruitment biomass after 1967 resulted in catches which greatly exceeded the recruitment biomass. Consequently, by 1969 the exploitable biomass was only about 60% of its initial 1965 level and by 1971 it had declined to less than 25%. The attrition in the adult biomass during this period was equally pronounced and by the start of the 1972 fishery year it had been reduced to only 12% of its initial level in 1965. The low level of the catch in 1972 (about 60,000 tons) should allow the adult biomass in 1973 to remain at approximately the same level as at the start of 1972 (i.e. 170,000-180,000 tons).

The total catch of the exploitable stock during 1965-70 was about 1,130,000 tons. Subtracting this value from the total stock biomass of 1,840,000 tons in 1965 (Table 2) gives a value of 710,000 tons which is an estimate of what the residual stock biomass would have been at the start of 1971 if recruitment to the exploitable stock and growth had balanced the losses in biomass due to natural mortality during the period. Since the estimated stock biomass at the start of 1971 was only about 474,000 tons (Table 2), the losses from the stock due to natural mortality was substantially greater than the production of biomass due to growth and recruitment.

Trends in catch-per-unit-effort and effort

Detailed catch and effort information has been collected for most of the individual vessels participating in the Area J purse-seine fishery since its development in 1965. The size of the seiners operating in the area have ranged from 40 to over 600 tons, but most of those which maintained a consistent association with the fishery were in the 150-325 ton range. The data from a selected group of these were compiled and analysed for trends in catch-per-unit-effort and effort.

The actual fishing operation involves searching, catching, delivery of loads to port, unloading and return to the fishing area. Analysis of the data available for individual vessels revealed that the most appropriate effort measure was the total operating time in days. For some vessels the actual operating time (excluding such factors as bad weather, engine breakdowns, etc.) could be determined fairly precisely. For other vessels, when the non-operating time was not completely known, it was estimated using the criterion (based on information on the fishing behaviour of the vessels) that a vessel was out of operation if the time between the last landing date and the next catch date exceeded six days. The number of operating days for the standard fleet was accumulated on a monthly basis and applied to the total catch of these vessels to obtain the seasonal catch-per-unit-effort in terms of catch per operating day (Table 3, column 3).

In the early years of the fishery the fishing capability of the purse-seine fleet was restricted by the lack of sufficient processing facilities on shore. For example, in Area J the total processing capability was less than 500 tons per day in 1965; this subsequently increased to more than 2,000 tons per day in 1968, after which the normal fishing operations of the mobile fleet could be accommodated. A similar situation occurred in Area T. This is reflected in the ratio of the standard fleets catch to its total carrying capacity (Table 3, column 4). During 1966-68 this ratio (80-84%) was probably at or close to the saturation level for the fleet, but it declined to 50% by 1971, thus also reflecting the general decline in the availability of the resource. This implies that relative to the first 2-3 years of the fishery, seiners would have had to operate longer in subsequent years to attain the same saturation level. In order to take this factor into account, the standard catch-per-unit-effort values (column 3) were multiplied by the ratios (column 4) to provide adjusted catch-per-unit-effort values (column 5). These were then applied to the total catches (column 2) to obtain adjusted total effort estimates for the fishery as a whole (column 6).

The information in Table 3 show that, while the total catch declined by 43% after 1969, the adjusted catch-per-unit-effort decreased by 70% since 1968 and the total adjusted effort more than doubled between 1968 and 1971. The decrease in catch from 1970 to 1971 was nearly 40% while the adjusted effort barely decreased at all (less than 1%).

The increasing trend in catch-per-unit-effort for 1966-68 is not indicative of the trend in stock abundance as shown by cohort analysis (Table 2) but rather of increase in the catchability coefficient, due to such factors as increasing processing facilities, increasing familiarity of fishermen with the fishing grounds and fish distributions, etc. Assuming that catchability was relatively constant during 1968-71, an indication of what the 1966 and 1967 catch-per-unit-effort values might have been can be obtained by extrapolation from a straight line fitted to the values for 1968 to 1971 (Fig. 5). The extrapolated values (bracketed in Table 3) suggest that the purse-seine fleet operated at about 50% efficiency in 1966 and about 75% efficiency in 1967.

Adjusted catch-per-unit-effort values for 1968-71 and extrapolated values for 1966-67 plotted against mean exploitable stock abundance (Fig. 6) show a direct linear relationship between the two variables. The regression line has a y-intercept value very close to zero (+ 1.062), indicating that the catch-per-unit-effort values adequately reflect the changes in stock abundance. The slope of the line (catchability coefficient, $q = 5.75 \times 10^{-5}$), when applied to the adjusted total effort values in column 6 of Table 3, provides fishing mortality coefficient values which are very similar to those obtained from cohort analysis in Table 2.

Estimates of stock size in Southwest Newfoundland

Length and age-composition data (Fig. 2) indicate that not all of the fish in southern Gulf of St. Lawrence herring stock complex migrate to overwinter in Southwest Newfoundland (Area J). If the proportions of the survivors of the Area T fishery migrating to Area J in the autumn were known for each age-group (hereinafter referred to as $N_J/N_{T.}$ ratios, where $N_{T.}$ is the residual stock size in numbers at the end of the Area T fishery in October, and N_J the initial stock size at the start of the Area J fishery in late November) for both spring- and autumn-spawners, estimates of the stock at the beginning of the Area J winter fishery can be obtained.

Reliable stock size estimates for the Area J fishery in 1969 and 1970 are available from tagging data (Winters, MS 1971b). The Area J age-composition data for 1969 and 1970 (Fig. 2) were applied to these stock size estimates, adjusted for natural mortality, to obtain the population numbers by age-group (N_J) for spring- and autumn-spawners at the start of the Area J winter fishery in those years. Residual population numbers by age-group at the end of the Area T summer fishery ($N_{T.}$) were determined by applying survival rates (as calculated from partial mortality rates) to the initial stock size at the beginning of the fishery year. The $N_J/N_{T.}$ age-group ratios, averaged for 1969 and 1970, are shown in Fig. 7. For both spring- and autumn-spawners the proportion of the southern Gulf of St. Lawrence stock which migrates to Southwest Newfoundland continuously increases with age from less than 20% for the recruiting age-groups to 100% for fish older than age-group 10. Spring-spawners tend to migrate at an earlier age-group than autumn-spawners with 50% migration occurring at age-group 6 for the former and at age-group 8 for the latter. This difference in age at 50% migration is largely attributable to the earlier maturity of spring-spawners.

The $N_J/N_{T.}$ age-group ratios from the curves of Fig. 7 were applied to the residual population numbers at the end of the Area T fishery in the years 1966 to 1968 and 1971 to estimate the stock sizes (by weight) of spring-spawners and autumn-spawners at the start of the Area J fishery for those years (Table 4).

Using the more reliable of the tagging data estimates (the 1969 estimate was based on returns from 25,000 fish tagged and the 1970 estimate on returns from 10,000 tagged fish) as the base, i.e. 418,000 tons, independent estimates of stock size at the start of the Area J fishery in the years 1966-68 and 1970-71 were computed from the adjusted catch-per-unit-effort values given in column 7 of Table 3 (Table 4).

Both sets of estimates agree reasonably well (Table 4) and their averages indicate that the stock size available to the Area J fishery declined from about 700,000 tons in 1966 to about 130,000 tons in 1971.

Figure 8 shows the trends in the residual exploitable and adult portions of the southern Gulf of St. Lawrence stock together with trends in the exploitable stock available to the Area J fishery and the Area J catch. Comparison of the Area J and residual exploitable stock sizes indicate that during the 1966-71 period about 50-60% of the southern Gulf stock migrated to over-winter in Southwest Newfoundland. Relative to the residual adult stock in Area T, the proportion migrating to Area J increased from 60% in 1966 to about 75% in 1971, this being attributable in part to poor recruitment to the adult stock during the period and in part to the progression of the dominant 1958 and 1959 year-classes through the fisheries. Despite the maintenance of the 1972 residual adult stock at about the 1971 level due to the recent influx of younger age-groups, preliminary information from the Area J fishery indicates a further decline in stock size in that area in 1972 to probably less than 50,000 tons.

Yield-per-recruit considerations

The Beverton and Holt (1957) constant parameter yield-per-recruit curves were calculated for spring- and autumn-spawners separately using the following parameters (Parsons and Hodder, MS 1973):

	Spring	Autumn
M	0.20	0.20
K	0.282	0.260
t_o	-1.87 yr	-2.29 yr
$t_o' = t_o$	3.5 yr	3.7 yr
t	15 yr	15 yr

The curves for spring- and autumn-spawners were essentially identical in curvature and elevation and a single curve for the southern Gulf of St. Lawrence stock complex of herring is shown in Fig. 9. The curve is flat-topped with the maximum yield-per-recruit occurring at a level of fishing mortality (F) greater than 2.0. Consequently the fishing mortality corresponding to the maximum yield-per-recruit is unrealistic from a practical viewpoint. However, Gulland (MS 1972) defines the optimum fishing mortality as close to the level of F at which the marginal yield-per-recruit is 10% of the yield-per -recruit per unit mortality in a very lightly exploited stock. This value, called F_{opt}, was estimated to be approximately 0.4 for both spring- and autumn-spawners. Thus the fishing mortality exerted on the southern Gulf of St. Lawrence stock complex was lower than F_{opt} during 1966-68, near the F_{opt} level in 1969 and higher than the optimum level in 1970 and 1971.

Discussion and Conclusions

The great abundance of herring in the southern Gulf of St. Lawrence and Southwest Newfoundland during the 1960's was due largely to the accumulation of biomass produced by two large year-classes spawned in the autumn of 1958 and in the spring of 1959. These year-classes had passed their age of maximum biomass before the purse-seine fishery developed in 1965, at which time the total stock size was estimated to be 1,840,000 tons. Therefore, at the age of maximum biomass in 1964 the stock size was undoubtedly of the order of 2,000,000 tons. During most of the 1965-72 period the purse-seine fishery was supported mainly by the 1958 and 1959 year-classes, and as the abundance of these year-classes declined so did the fishery.

Yield-per-recruit calculations show that the stocks have been overfished since 1969 at least in so far as the amount of effective fishing effort is concerned. The rapid decline in stock abundance cannot however be attributed solely to the disproportionate removal of biomass due to fishing. Recruitment to the exploitable biomass has been relatively poor since the mobile fishery developed. For spring-spawners the large 1959 year-class was estimated to number about 4 billion fish at age-group 2; the next largest was the 1960 year-class which was 1/5 that of 1959 and the largest since then was the 1968 year-class which at age-group 2 was only 1/8 as large; and the others up to 1969 have ranged from 1/10 to 1/60 the size of the 1959 year-class. For autumn-spawners the 1962 and 1963 year-classes were about 1/5 the size of the 1958 year-class (about 7 billion fish at age-group 2) and the others up to 1968 were 1/10 to 1/30 as large. It therefore appears that the recruitment to the stocks has been at or below the replacement level since the purse-seine fishery began. In fact the application of the assumed natural mortality coefficient ($M = 0.2$) to the stock sizes present at the beginning of 1965 and adding recruitment at age-group 2 for each subsequent year indicates that the total stock would have declined by nearly 50% up to 1971 even if the fishery had not existed. Thus the purse-seine fishery did not cause the decline in stock abundance but rather precipitated and increased the magnitude of the decline. On the assumption that there is no filial-parental relationship over the range of stock sizes estimated, overfishing in terms of biological yield has not occurred. In fact from 1965 to 1971 nearly 55% of the reduction in total stock size of the 1958 and 1959 year-classes was due to natural mortality. Under conditions of optimum fishing mortality the elimination of standing crop due to natural mortality would have been less than 35%.

At the start of 1972 the total adult biomass of spring- and autumn-spawners was only about 12% of that present at the beginning of 1965. Because landings were relatively low in 1972 (Fig. 2) and because the 1968 year-class of spring-spawners will recruit to the adult stock in 1973, the adult stock size during 1973 will probably be maintained at about the 1972 level (Fig. 4). While the delineation of a critical spawning biomass remains a contentious and unresolved subject, the severe attrition in the size of the spawning stocks of the southern Gulf of St. Lawrence should be recognized as possibly detrimental to the recovery of the resource. Recent experiences in a number of heavily exploited fish stocks, such as the Grand Bank haddock (Hodder, 1966b), the Georges Bank haddock and the Arcto-Norwegian cod (Garrod,

1970) and the California cardine (Iles, 1970), have indicated that a small spawning stock can only produce large year-classes under exceptionally favourable circumstances and consequently a stock in this condition would be extremely vulnerable to unfavourable environmental conditions occurring in succession. Garrod (1970) also points out that for a number of stocks there seems to be a maximum rate of survival beyond which a further reduction in stock size cannot be intrinsically compensated for. Under such circumstances the rapid recovery of the stock cannot be assured even by the most stringent management measures. The biomass of the southern Gulf of St. Lawrence spawning stocks of herring is probably approaching the level at which compensatory survival cannot be expected to maintain sustainable recruitment. Immediate and effective conservation measures are therefore required to ensure the best possible chance of stock recovery. In this regard, the Canadian Atlantic Herring Management Committee has recently recommended conservation measures, such as the imposition of minimum size limits and catch quotas and closure of spawning grounds to mobile gears.

During the initial exploratory phase in the development of the purse-seine fishery along Southwest Newfoundland, Peuvion (1966), on the basis of acoustic surveys carried out over a 3-month period (January-March) in 1966, estimated that up to 1,000,000 tons of herring present during winter. Extrapolation of the Area J exploitable biomass curve (Fig. 8) to 1965 (i.e. to the start of the Area J fishery in November 1965) provides a stock size estimate of slightly less than 800,000 tons. Since the acoustic surveys extended over a 3-month period during which there is a gradual westward movement of herring along the coast (Hodder, 1971), some of the schools were probably included in the acoustic estimate more than once. Taking this into consideration would reduce the estimate based on acoustic surveys to a level in close agreement with the stock size estimate (800,000 tons) projected from the analysis of data presented in this paper.

The large stock size of herring present in the Southwest Newfoundland area during the 1960's and the associated high yields from the fishery in that area were probably fortuitous in that they resulted from several unrelated factors acting concurrently. First of all, the very large 1958 and 1959 year-classes which supported the purse-seine fishery since its inception were produced under exceptional circumstances, occurring in succession shortly after a fungus disease (*Ichthyosporidium hoferi*) had caused widespread mortalities of herring in the southern Gulf of St. Lawrence during 1953-57 (Tibbo and Graham, 1963). The fact that in the decade following the production of the large 1958 and 1959 year-classes not a single large year-class was produced suggests that the occurrence of large year-classes (like 1958 and 1959), particularly in successive years, is not a regular feature of the biology of this stock complex; more likely, the much smaller year-classes which prevailed after 1959 represent the normal situation. Secondly, the two large year-classes were relatively old (age-groups 7 and 8) before they were subjected to significant exploitation, and consequently large numbers of them were able to survive to ages at which the migration ratios were high enough to allow significant quantities of them to migrate to Southwest Newfoundland. Also the slower development of the purse-seine fishery in the southern Gulf of St. Lawrence enabled a large residual biomass to be available to the Southwest Newfoundland fishery even up to 1969 (Fig. 8), as the dominant 1958 and 1959 year-classes migrated to the area in increasing proportions, and enabled Southwest Newfoundland catches to increase substantially to a peak level of 140,000 tons in 1968 and 1969. Finally, the decline and collapse of the British Columbia herring fishery occurred coincidentally with the discovery of the large over-wintering concentrations of herring in the fjords along Southwest Newfoundland in the mid-1960's, and this provided a ready surplus of purse seiners and experienced fishermen which enabled the resource to be exploited almost immediately upon its discovery.

The obvious implication of the above discussion is that the magnitude of the future herring fishery in Southwest Newfoundland will be considerably reduced and will be greatly dependent on the extent and intensity of the fishery in the southern Gulf of St. Lawrence. Some indication of the biomass available to, and the yield from the Southwest Newfoundland fishery relative to the fishing mortality in the southern Gulf of St. Lawrence can be obtained from a hypothetical model of the fisheries based on the data presented in this paper. In the model it has been assumed that the present migration pattern, migration ratios (averaged for spring- and autumn-spawners (Fig. 7)), growth rates and other biological characteristics of the southern Gulf of St. Lawrence herring stocks remain unchanged and that a fleet of purse-seine vessels exists which is capable of exploiting the resource at its optimum yield. An initial stock size at age-group 2, approximately equal to the average size of the 1958 and 1959 year-classes at the same age-group (5 billion fish) is assumed and to this stock have been applied a range of fishing mortality rates which are the same for each year in the southern Gulf of St. Lawrence and in the Southwest Newfoundland areas. Estimates of yield and biomass thus obtained have been cumulated over the age-groups and plotted against fishing mortality (Fig. 10). As expected, there is a monotonic decline in both the cumulative residual biomass at the end of the southern Gulf of St. Lawrence fishery and that available to the Southwest Newfoundland fishery as fishing mortality increases. This decline amounts to over 70% in the latter area from the lightly exploited state ($F = 0.10$) to the level of optimum fishing ($F = 0.40$). In terms of cumulative yield, increases in the fishing mortality rate would both increase the total yield and the yield from the southern Gulf fishery but would cause a decrease in the yield from the Southwest Newfoundland fishery. If the fishery were regulated at the optimum level, the cumulative yield from the stock would be slightly over 400,000 tons in the southern Gulf of St. Lawrence and about 75,000 tons in Southwest Newfoundland. On an annual basis average yields for the three peak years would be about 100,000 tons for the southern Gulf fishery and about 20,000 tons for the Southwest Newfoundland fishery.

The effect of a varying fishing mortality rate in Southwest Newfoundland on the cumulative yield of a fishery regulated at the optimum level in the southern Gulf has also been examined (Fig. 11). An increase in the fishing mortality rate in Southwest Newfoundland will increase the cumulative yield from that area but will also result in a concomitant decrease in the cumulative yield from the southern Gulf fishery to the extent that the yield from the stock as a whole will increase only slightly. It would therefore appear that the yield from the total stock exploited at the optimum level is not substantially increased by a fishery in Southwest Newfoundland.

In summary the large purse-seine fisheries characteristic of the southern Gulf of St. Lawrence and Southwest Newfoundland during the 1960's were based mainly on the accumulation of biomass produced by two very large year-classes, and as such, yields from these fisheries are not representative of the average yield of the southern Gulf of St. Lawrence herring stocks. Since the expansion of the fisheries occurred during a period of declining stock abundance due to poor recruitment initial increases in catch were at the expense of substantial increases in fishing effort which eventually reduced the stocks to a very low level. Rational management is now required to ensure the recovery of the stocks to a viable level. Under optimum fishing rates and with large year-classes occurring only infrequently the average yield from the southern Gulf of St. Lawrence stocks of herring will be considerably lower in the future, perhaps reaching 150,000 tons in peak years of strong year-classes. Since the southern Gulf herring are fairly old before they migrate to Southwest Newfoundland in significant proportions, a fishery regulated at the optimum level in the southern Gulf of St. Lawrence will considerably reduce potential yields from Southwest Newfoundland.

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Table 1. Numbers of spring- and autumn-spawning herring (millions) caught per year (April - March) and age-group in the southern Gulf of St. Lawrence (Area T) and along southwest Newfoundland (Area J), 1965-71. (Weights caught (Wc) are in metric tons.)

Area	Age Group	Spring-Spawners 1965	1966	1967	1968	1969	1970	1971	Autumn-Spawners 1965	1966	1967	1968	1969	1970	1971
T	2	-	0.3	-	5.4	-	-	3.2	-	-	-	0.6	2.4	2.2	4.9
	3	2.1	7.4	3.4	9.5	16.4	7.9	54.9	-	0.7	2.1	5.0	20.1	42.0	32.9
	4	1.9	22.9	11.0	1.9	16.5	38.2	5.8	0.1	2.4	3.5	1.2	18.2	57.6	91.0
	5	26.7	4.6	14.5	13.9	8.9	10.6	11.0	0.6	0.9	13.4	30.5	17.7	28.5	33.6
	6	114.2	15.1	5.2	9.9	12.9	9.3	6.5	0.9	1.5	4.3	45.4	74.3	20.4	56.4
	7	12.6	54.9	17.5	2.9	10.7	19.9	4.8	18.8	3.8	4.2	11.6	80.5	123.6	74.8
	8	1.8	4.1	69.4	14.7	3.0	18.9	6.8	4.4	30.0	8.4	13.0	24.4	60.4	81.0
	9	0.5	0.9	16.6	61.4	15.8	4.8	6.3	1.4	5.9	48.6	32.6	37.4	22.9	31.9
	10	0.1	0.4	2.1	7.6	47.6	15.7	2.5	0.8	1.5	7.3	121.5	54.1	35.8	16.3
	11	0.1	0.2	0.7	4.5	3.3	32.5	6.1	0.4	0.5	6.0	16.6	135.0	34.7	12.7
	12	-	0.1	0.2	1.8	1.9	1.6	12.5	0.3	0.4	2.6	9.6	8.1	77.0	13.5
	12+	-	0.1	0.2	1.0	0.5	1.1	0.6	0.3	0.4	3.6	8.8	7.0	4.0	25.4
	Nc	160.0	111.0	140.8	134.5	137.5	160.5	121.0	28.0	48.0	104.0	296.4	479.2	559.1	474.4
	Wc	37416	24969	36035	35054	33671	39593	23960	6838	11936	26601	77076	120735	135904	107173
J	2	0.4	0.1	0.4	0.8	0.5	11.1	1.1	-	-	-	1.8	0.2	0.2	0.2
	3	1.2	2.2	0.9	1.9	2.5	1.0	11.5	2.8	0.1	0.5	1.8	1.4	1.9	0.2
	4	0.3	4.5	8.5	4.0	2.1	2.6	2.1	0.8	7.8	3.8	1.8	1.7	2.0	0.5
	5	2.3	0.6	7.5	16.4	7.3	3.1	1.1	1.1	3.3	21.3	16.8	5.0	3.6	0.4
	6	9.1	4.9	2.7	14.4	12.7	4.3	2.6	1.4	6.3	10.4	39.2	36.8	14.0	1.2
	7	1.6	19.6	12.6	5.5	16.7	8.5	2.8	24.5	9.1	8.7	14.0	42.8	34.8	4.4
	8	0.6	5.2	48.4	32.8	5.4	8.7	3.8	5.4	96.0	20.6	13.1	20.0	26.7	12.8
	9	0.2	0.8	4.3	107.8	23.6	3.1	4.1	3.1	27.6	128.6	39.9	26.0	15.2	7.9
	10	0.1	0.2	1.4	8.0	80.2	10.9	0.9	1.6	7.6	19.2	156.5	49.5	23.1	5.1
	11	0.1	0.1	1.0	2.5	3.7	37.2	2.8	1.4	3.3	10.0	15.0	145.2	45.9	12.3
	12	0.1	0.1	0.8	1.8	1.0	0.3	9.5	1.1	2.5	4.3	8.8	8.7	101.9	17.0
	12+	-	0.1	1.5	2.8	1.3	0.2	0.1	2.3	2.4	6.0	7.0	7.4	5.3	32.1
	Nc	16.0	38.4	90.0	198.7	157.0	91.0	42.4	45.5	166.0	233.4	315.7	344.7	274.6	94.1
	Wc	3929	9834	24764	56706	46222	25443	11250	10827	42268	61035	82900	93361	77635	26250
T + J	2	0.4	0.4	0.4	6.2	0.5	11.1	4.3	-	-	-	2.4	2.6	2.4	5.1
	3	3.3	9.6	4.3	11.4	18.9	8.9	66.4	2.8	0.8	2.6	6.8	21.5	43.9	33.1
	4	2.2	27.4	19.5	5.9	18.6	40.8	7.9	0.9	10.2	7.3	3.0	19.9	59.6	91.5
	5	29.0	5.2	22.0	30.3	16.2	13.7	12.1	1.7	4.2	34.7	47.3	22.7	32.1	34.0
	6	123.3	20.0	7.9	24.3	25.6	13.6	9.1	2.3	7.8	14.7	84.6	111.1	84.4	57.6
	7	14.2	74.5	30.1	8.4	27.4	28.4	7.6	43.3	12.9	12.9	25.6	123.3	158.4	79.2
	8	2.4	9.3	117.8	47.5	8.4	27.6	10.6	9.8	126.0	29.0	26.1	44.4	87.1	93.8
	9	0.7	1.7	20.9	169.2	39.4	7.9	10.4	4.5	33.5	177.2	72.5	63.4	38.1	39.8
	10	0.2	0.6	3.5	15.6	127.8	26.6	3.4	2.4	9.1	26.5	278.0	103.6	58.9	21.4
	11	0.2	0.3	1.7	7.0	7.0	69.7	8.9	1.8	3.8	16.0	31.6	280.2	80.6	25.0
	12	0.1	0.2	1.0	3.6	2.9	1.9	22.0	1.4	2.9	6.9	18.4	16.8	178.9	30.5
	12+	-	0.2	1.7	3.8	1.8	1.3	0.7	2.6	2.8	9.6	15.8	14.4	9.3	57.5
	Nc	176.0	149.4	230.8	333.2	294.5	251.5	163.4	73.5	214.0	337.4	612.1	823.9	833.7	568.5
	Wc	41345	34803	60799	91760	79893	65036	35210	17665	54204	87636	159976	214096	213539	133423

Table 2. Stock size estimates (millions) at the start of each fishery year and corresponding fishing mortality coefficients during each fishery year for the southern Gulf of St. Lawrence stocks of spring-spawning and autumn-spawning herring, 1965-71.

Type	Age Group	Mean Weight (gm)	Stock size at start of fishery year 1965	1966	1967	1968	1969	1970	1971	F during fishery year 1965	1966	1967	1968	1969	1970	1971	Weighted Mean F	Percent Recruitment
Spring	2	80	325	132	130	193	63	505	30	0.01	0.01	0.01	0.04	0.01	0.02	0.02	0.02	13
	3	150	335	265	108	106	152	51	403	0.01	0.04	0.04	0.08	0.14	0.23	0.18	0.06	40
	4	200	103	271	209	84	80	107	33	0.02	0.06	0.11	0.12	0.31	0.40	0.32	0.13	87
	5	230	426	82	210	153	60	46	59	0.08	0.07	0.19	0.24	0.33	0.43	0.27	0.15	100
	6	254	1409	323	63	142	98	38	24	0.10	0.07	0.15	0.21	0.34	0.45	0.36	0.14	100
	7	268	120	1042	246	44	94	57	20	0.14	0.08	0.14	0.23	0.39	0.56	0.42	0.14	100
	8	280	27	85	785	174	29	52	27	0.01	0.13	0.18	0.36	0.39	0.67	0.59	0.23	100
	9	291	15	22	61	536	100	16	22	0.05	0.08	0.47	0.43	0.57	0.70	0.60	0.43	100
	10	302	10	12	17	31	286	46	7	0.02	0.06	0.27	0.80	0.68	0.88	0.72	0.65	100
	11	312	6	8	9	10	11	119	16	0.02	0.05	0.22	1.37	1.13	0.99	0.75	0.92	100
	12	320	4	5	6	6	2	3	36	0.02	0.03	0.19	1.08	0.74	1.01	0.81	0.89	100
	12+	335	2	5	8	9	4	2	2	0.02	0.04	0.20	1.22	0.99	1.15	0.83	0.70	100
	N_s (X 10^{-6})		2782	2252	1852	1488	979	1042	679	0.10[1]	0.08[1]	0.18[1]	0.37[1]	0.53[1]	0.70[1]	0.52[1]	$\bar{F}_{5-12}$	
	W_s ('000 tons)		604	524	446	356	237	176	128									
Autumn	2	40	1612	860	650	392	640	248	(250)	<0.01	0.01	<0.01	<0.01	<0.01	0.01	0.01	<0.01	3
	3	80	1129	1320	704	532	319	522	201	<0.01	<0.01	<0.01	0.01	0.02	0.07	0.17	0.02	18
	4	150	428	922	1080	574	429	255	398	<0.01	0.01	0.01	0.01	0.05	0.14	0.22	0.03	27
	5	193	562	349	746	877	468	333	182	<0.01	0.01	0.05	0.06	0.09	0.24	0.23	0.07	64
	6	214	885	458	282	579	676	349	214	<0.01	0.02	0.06	0.18	0.20	0.27	0.41	0.11	100
	7	232	2612	723	368	218	398	453	218	0.02	0.02	0.04	0.14	0.42	0.41	0.45	0.10	100
	8	247	234	2099	580	290	155	214	245	0.05	0.07	0.06	0.11	0.38	0.53	0.41	0.11	100
	9	257	109	183	1604	449	214	87	103	0.05	0.23	0.13	0.20	0.40	0.46	0.44	0.18	100
	10	268	47	85	119	1153	302	117	45	0.06	0.13	0.28	0.31	0.48	0.65	0.45	0.34	100
	11	279	30	36	61	74	693	153	50	0.07	0.12	0.34	0.64	0.59	0.74	0.50	0.57	100
	12	290	13	23	26	36	32	314	60	0.12	0.15	0.34	0.84	0.88	0.84	0.59	0.88	100
	12+	310	9	15	26	28	21	15	110	0.27	0.18	0.43	0.89	1.27	0.85	0.65	0.87	100
	N_s (X 10^{-6})		7670	7073	6246	5202	4347	3060	2076	0.02[1]	0.06[1]	0.11[1]	0.24[1]	0.41[1]	0.52[1]	0.46[1]	$\bar{F}_{6-12}$	
	W_s ('000 tons)		1236	1221	1154	1024	825	579	378									
Spring and Autumn	N_s (X 10^{-6})		10452	9325	8098	6690	5326	4102	2755	0.04	0.07	0.13	0.27	0.43	0.56	0.48	F_{5-12}	
	W_s ('000 tons)		1840	1745	1600	1377	1062	755	506									

[1] Weighted mean for fully recruited age-groups

Table 3. Trends in catch, catch-per-unit-effort and effort for the fishery on the southern Gulf of St. Lawrence herring stock, 1966-71.

1	2	3	4	5	6
Fishery Year	Total catch in Areas T and J (m tons)	Catch/day of standard fleet (m tons)	Ratio of catch to capacity standard fleet	Adjusted catch/day of standard fleet (m tons)	Adjusted total effort for Areas T and J (days)
1966	89,007	44.2	0.83	36.7 (74.0)	2,425 (1,203)
1967	148,435	52.5	0.84	44.1 (62.0)	3,365 (2,394)
1968	251,736	62.9	0.80	50.3	5,005
1969	293,989	55.4	0.75	41.5	7,084
1970	278,575	41.7	0.59	24.6	11,324
1971	168,633	30.0	0.50	15.0	11,242

Note: Bracketed values for 1966 and 1967 are based on extrapolation in Fig. 3.

Table 4. Estimates of stock size available to the southwest Newfoundland fishery (Area J) in November of each fishery year.

1	2	3	4	5	6
	Stock size estimates ('000 m tons)				
Autumn of fishery year	Based on tagging data	Based on migration ratios	Based on catch-per-unit-effort	Range of stock size estimates	Mean stock size estimate
1966	-	655	744	655-744	700
1967	-	622	627	622-627	625
1968	-	553	506	506-553	530
1969	418±22	(418)	(418)	396-440	418
1970	277±18	(277)	247	247-295	262
1971	-	112	151	112-151	132

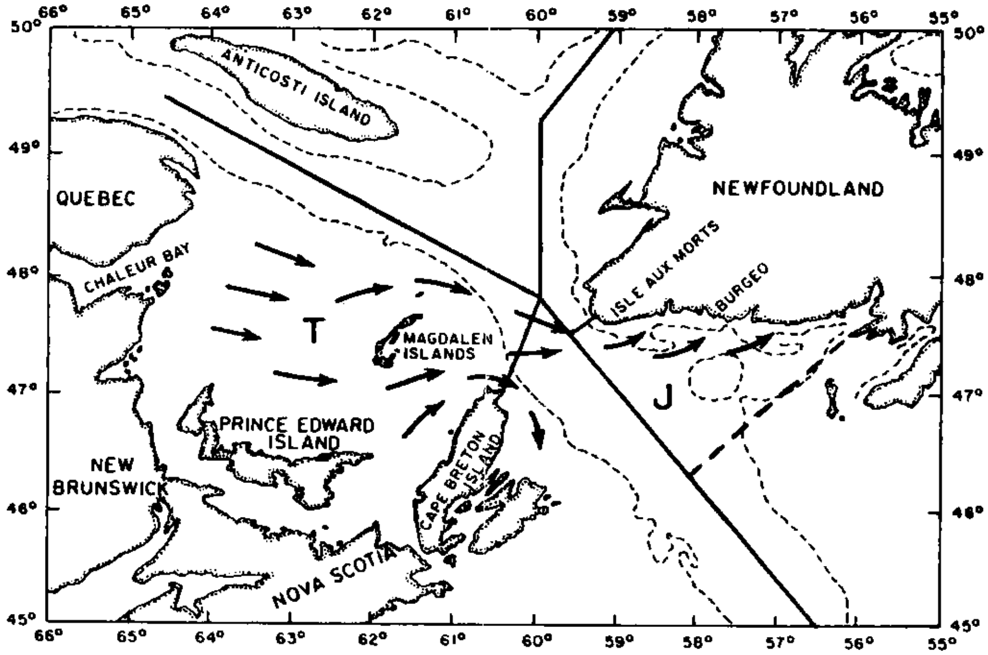


Fig. 1. Map of the southern Gulf of St. Lawrence and Newfoundland showing the autumn migration of herring.

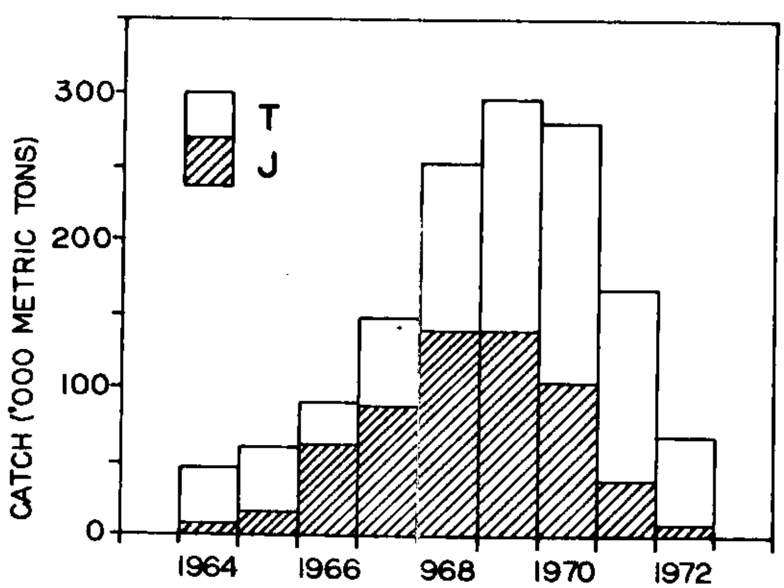
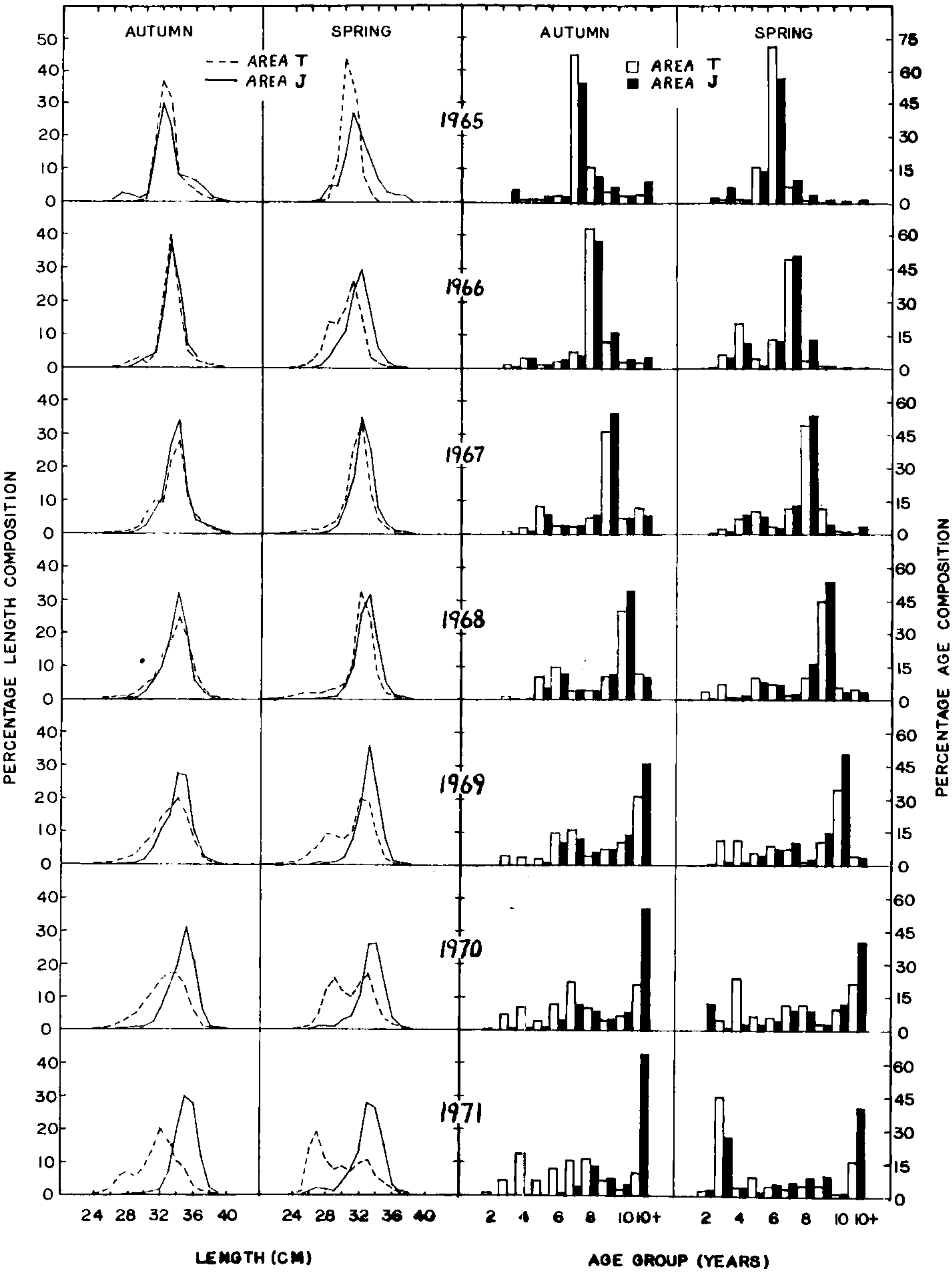


Fig. 2. Herring landings from the southern Gulf of St. Lawrence stock complex, 1964-72.



B 3

Fig. 3. Length and age composition of spring- and autumn-spawning herring in the southern Gulf of St. Lawrence and Southwest Newfoundland fisheries, 1965-71.

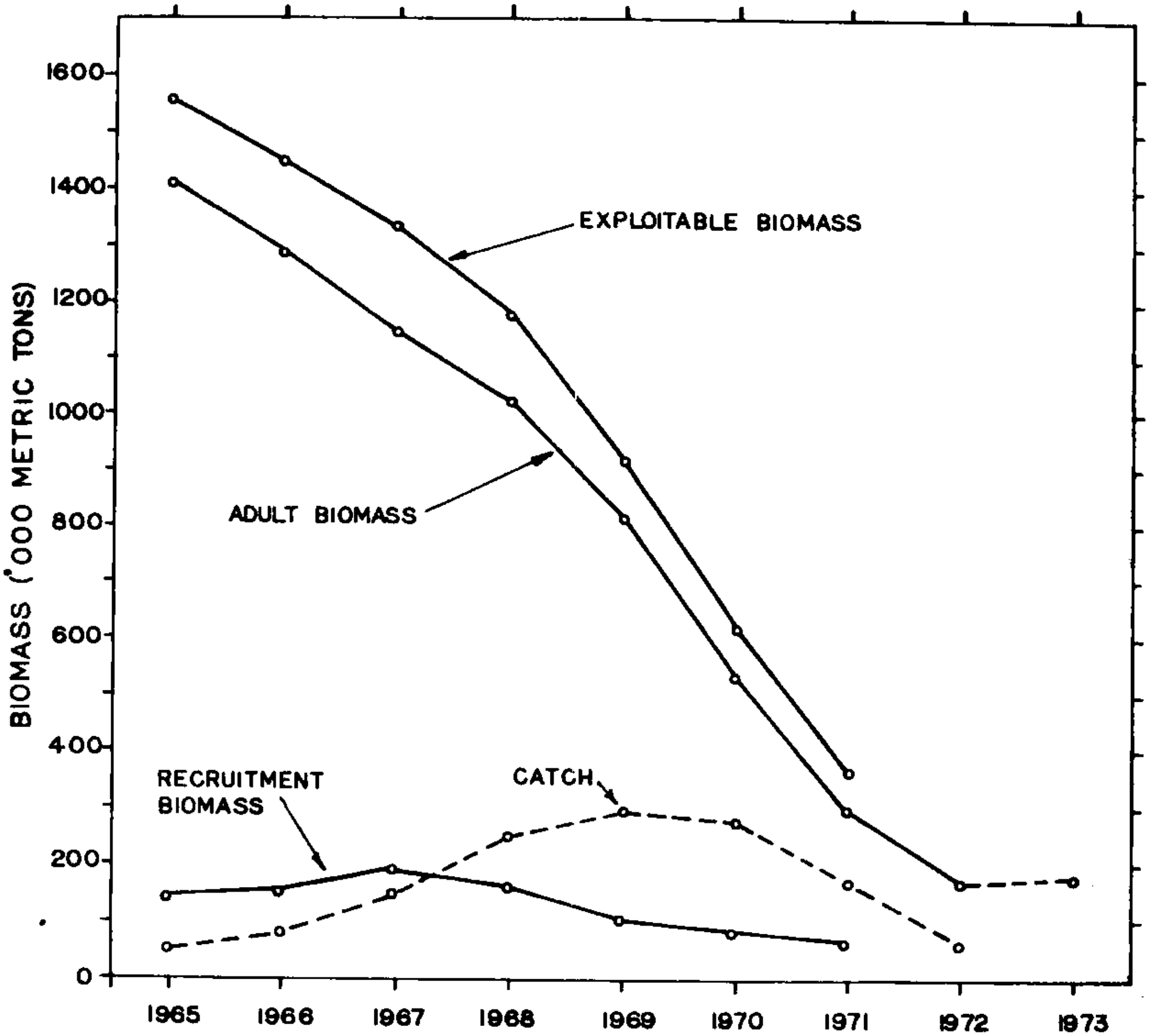


Fig. 4. Exploitable biomass, adult biomass, recruitment biomass and catch for the southern Gulf of St. Lawrence herring stock, 1965-72.

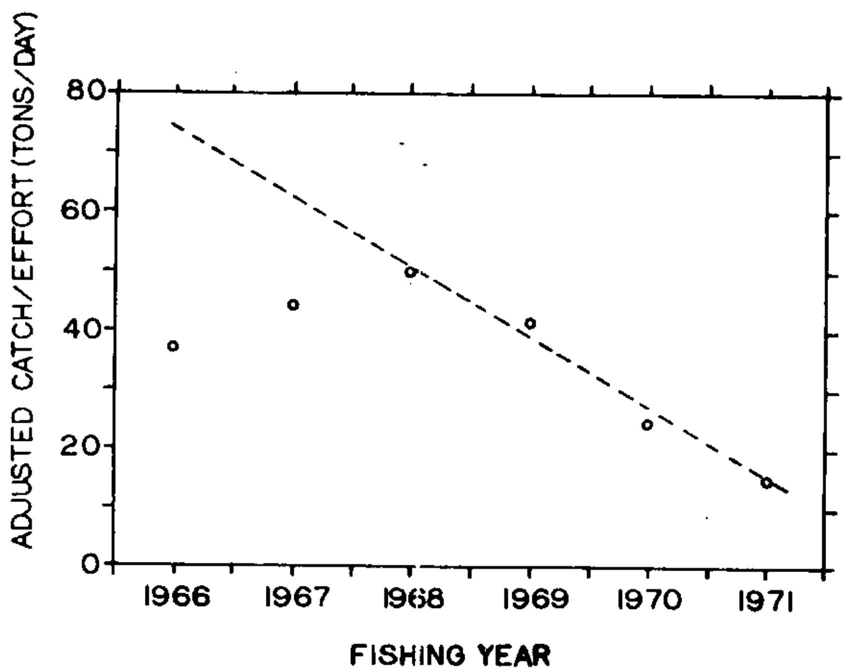


Fig. 5. Adjusted catch-per-unit-effort in the Southwest Newfoundland purse-seine fishery, 1966-71.

B 4

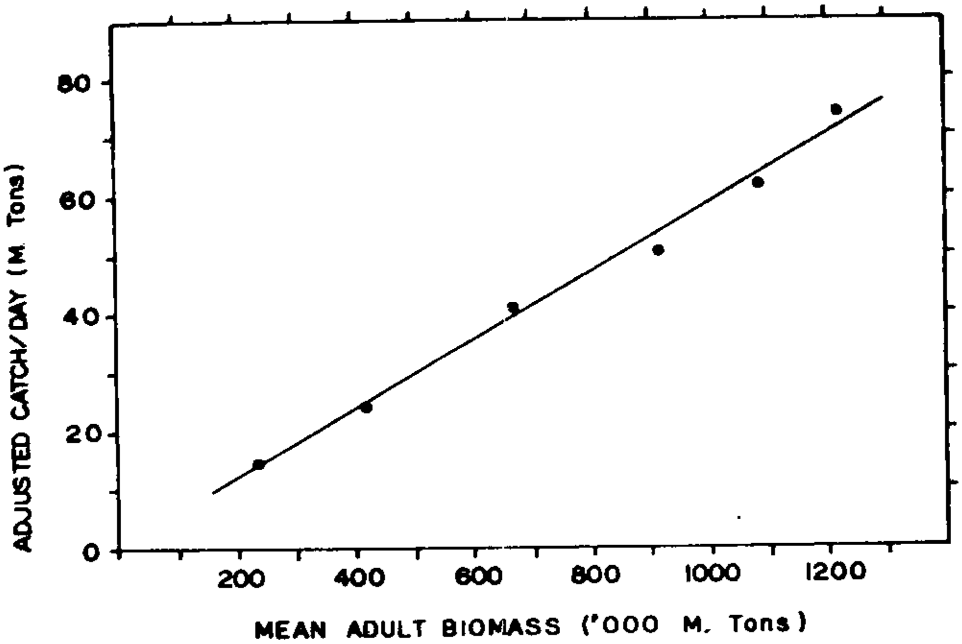


Fig. 6. Relationship between standardized catch-per-unit-effort and mean stock abundance, 1966-71.

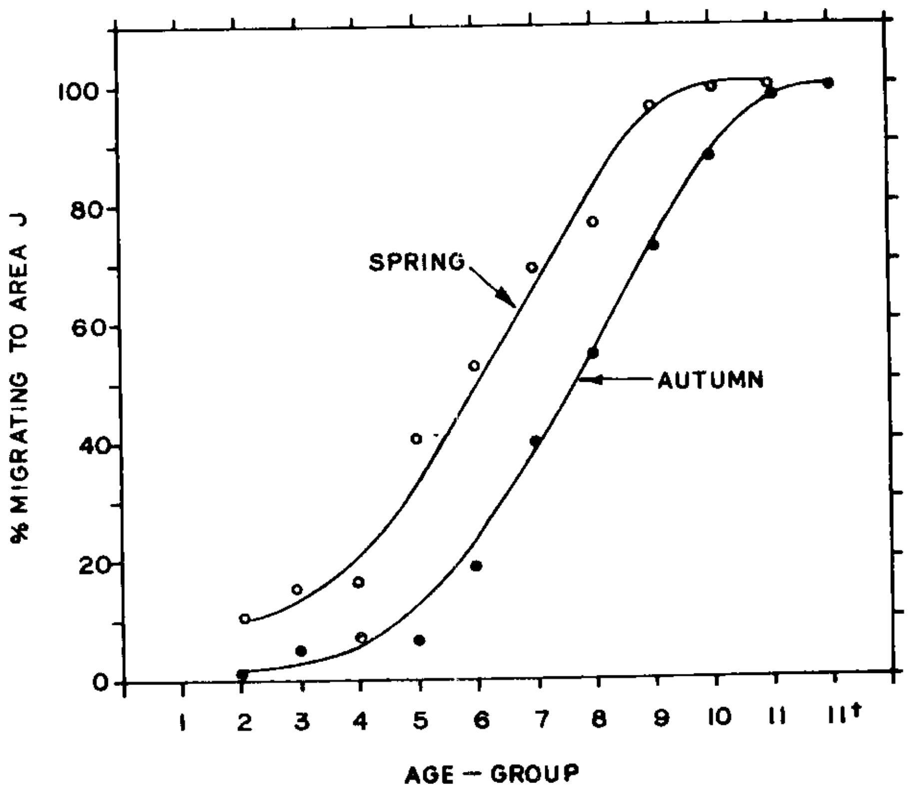


Fig. 7. Migration ogives for spring- and autumn-spawners as estimated for the autumn migration of herring from the southern Gulf of St. Lawrence to Southwest Newfoundland.

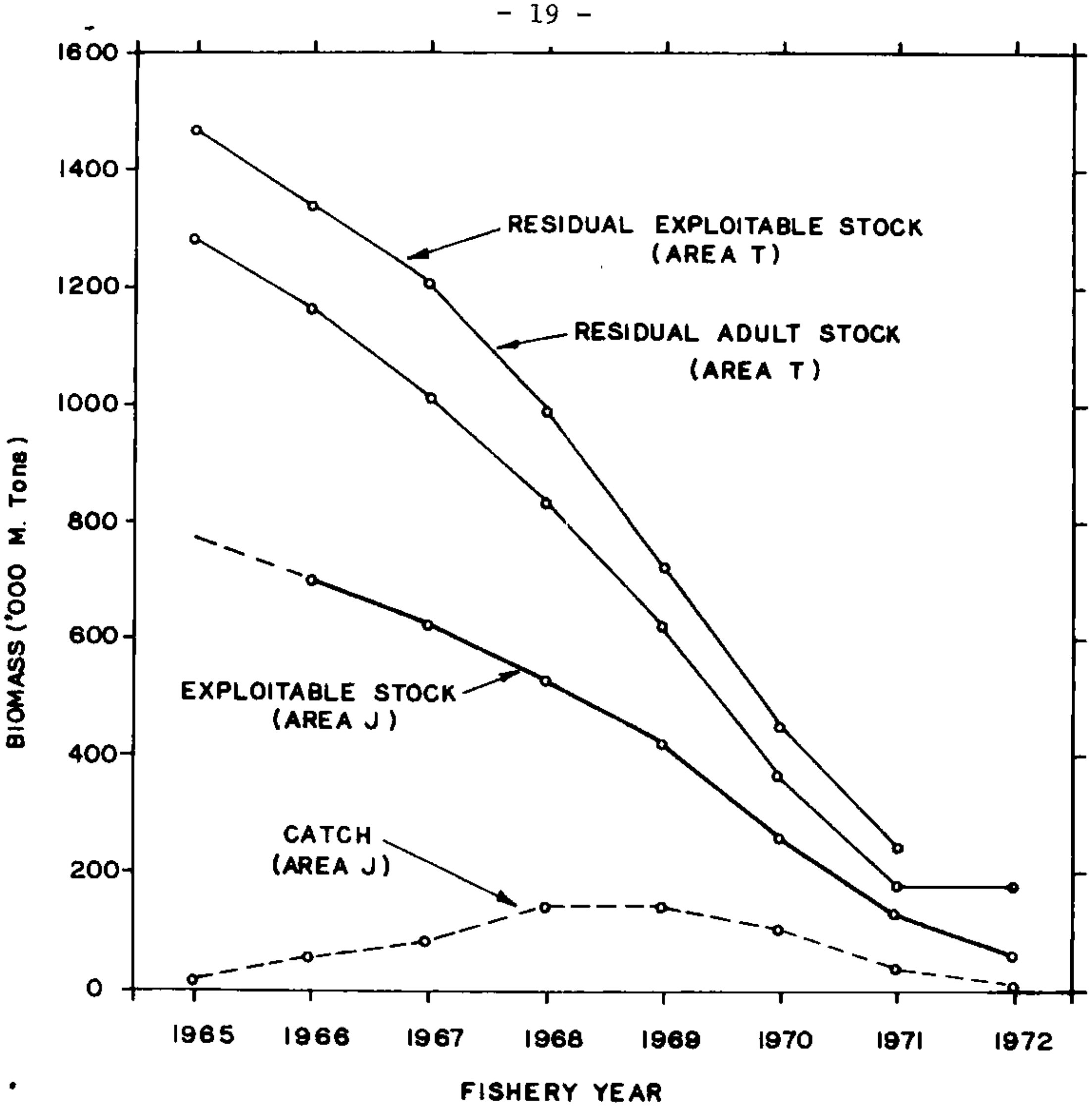
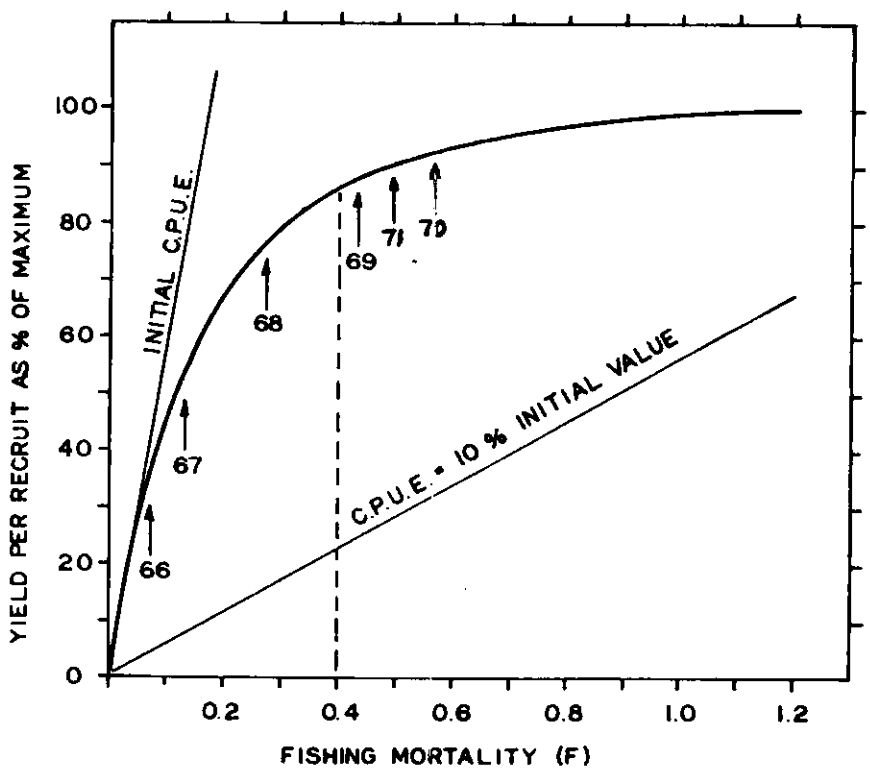


Fig. 8. Residual exploitable and adult stock biomass at the end of the Area T fishery, exploitable biomass at the start of the Area J fishery and the Area J catch, 1965-72.



B 6

Fig. 9. Yield-per-recruit curve for southern Gulf of St. Lawrence herring. Arrows indicate levels of F in various years and the vertical (broken) line indicates the optimum value of F as calculated

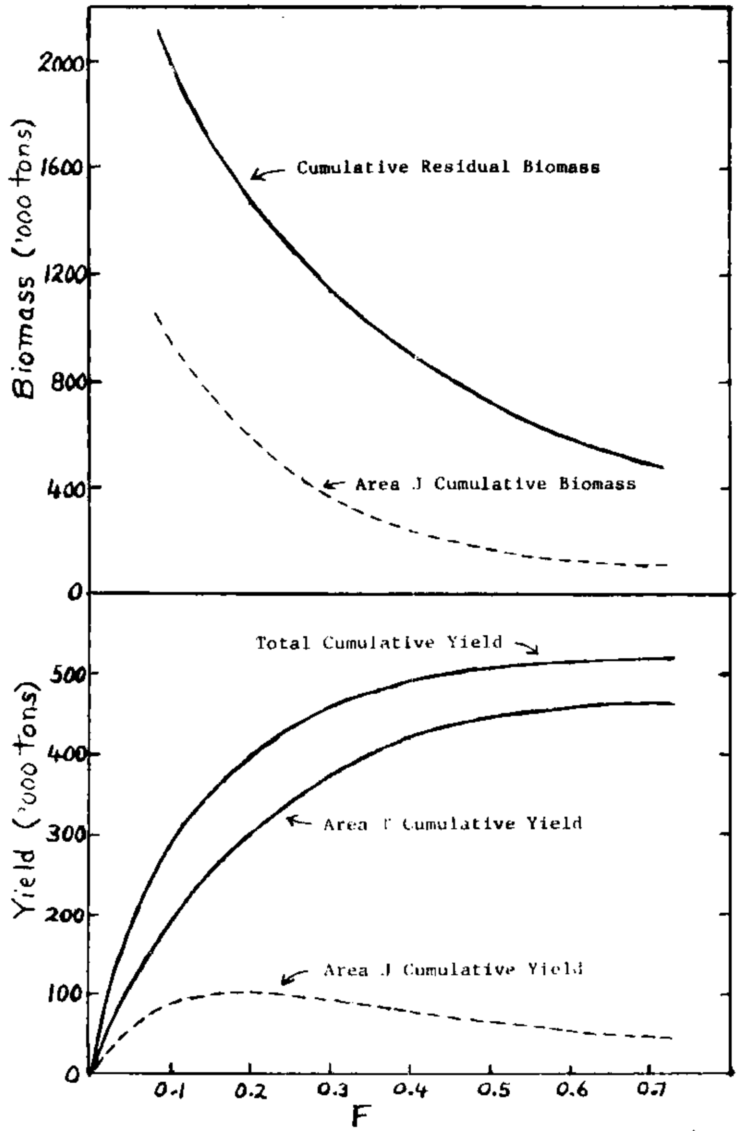


Fig. 10. Cumulative biomass and yield estimates of the southern Gulf of St. Lawrence herring stock complex from a hypothetical recruitment of 5,000 million fish subjected to a range of fishing mortality rates. F is the same in Areas T and J for each year.

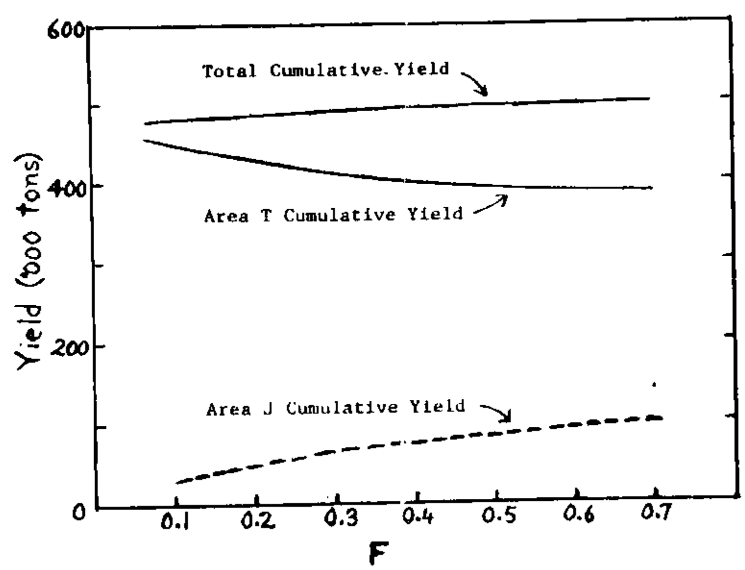


Fig. 11. Effect of increases in the fishing mortality rate in Southwest Newfoundland (Area J) on the cumulative yield of a fishery regulated at the optimum level (F = 0.40) in the southern Gulf of St. Lawrence (Area T).