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Salmon-capelin Interactions

by

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Abstract

Possible interactions of salmon and capelin are discussed in relation to their ecology. Adult capelin are known to be important but not exclusive components of the diet of adult salmon. There is very little information on feeding of post-smolt salmon. Possible relationships between capelin and salmon abundance were suggested by statistically significant curvilinear regressions relating salmon and abundance of capelin on which they might be feeding. However, direct biological relationships could not be concluded. The decline of capelin in recent years due to poor recruitments, cannot be totally blamed for the poor sea survival of the 1977 smolt year-class.

Résumé

Les auteurs analysent les interactions possibles entre le saumon et le capelan en relation avec leur écologie. On sait que le capelan adulte est un élément important, sans toutefois être exclusif, du régime alimentaire du saumon adulte. On a très peu de renseignements sur l'alimentation des saumons postsmolts. Des régressions curvilignes, significatives à l'analyse statistiques, suggèrent des relations possibles entre l'abondance des saumons et celle des capelans dont ils se nourrissent. Il a toutefois été impossible d'établir des relations biologiques directes. Le déclin récent du capelan par suite d'un faible recrutement ne peut être entièrement tenu responsable de la mauvaise survie en mer de la classe de smolts de 1977.

Introduction

Much attention has been generated by the low abundance of 1-sea-winter (1SW) fish in Atlantic salmon (Salmo salar) catches in 1978, low abundance of 2-sea-winter (2SW) fish in 1979, and relatively normal catches of 1SW in 1979. Since this phenomenon occurred throughout eastern Canada from northern Labrador to Maine (with the exception of the stocks of salmon in the inner Bay of Fundy), it seems probable that something unusual happened to the 1977 smolt year-class. Carter (1979, 1980) suggested that overfishing of capelin (Mallotus villosus) stocks in the Northwest Atlantic in recent years may be the major cause of declining salmon stocks. This paper reviews salmon and capelin ecology and discusses the possible interactions.

Salmon Landings

Canadian landings (commercial plus recreational) of 1SW Atlantic salmon from smolt year-classes 1969-76 ranged from 505 to 945 tonnes and had a mean of 734 tonnes. The landings of multi-sea-winter salmon (mainly 2-sea-winter) ranged from 1142 to 1798 tonnes and had a mean of 1486 tonnes. The total Canadian Atlantic salmon landings from smolt year-classes 1969-76 ranged from 1647 to 2575 tonnes and had a mean of 2221 tonnes. The total landings from the 1977 smolt year-class were 1025 tonnes or a decrease of 46% of the 1969-76 mean. Landings from this same year-class of 1-sea-winter and multi-sea-winter salmon were 320 and 705 tonnes respectively, declines of 44% and 47% of the 1969-76 mean (Table 1). These catches are not exceptionally low since low catches have previously been recorded in the late 1950's and during the period of 1910-20.

Independent estimates of sea survival of Atlantic salmon returning to a number of Canadian research facilities showed a decline in sea survival of the 1977 smolt year-class. For example, at Western Arm Brook, Newfoundland sea survival rates (after commercial fisheries) of smolts returning for 1971-76 smolt year-classes was 6.3%, while that of 1977 was 3.3% (M. Chadwick, pers. comm.). There is as well, no suggestion that Canadian smolt production in 1977 was unusually low.

Canadian salmon are also exploited at West Greenland, but only those salmon that would have returned as multi-sea-winter salmon are caught in this fishery. Landings at West Greenland of salmon from the 1977 smolt year-class were 992 tonnes, a figure that is 200 tonnes below the quota of 1191 tonnes. Thus, it is unlikely that overexploitation in either the Canadian or West Greenland fisheries caused the poor survival of the 1977 smolt year-classes. Whatever happened to the 1977 smolt year-class probably occurred in the period from the springs of 1977 and 1978.

Salmon feeding

During their homeward migration along the Newfoundland coast, adult Atlantic salmon are known to feed mainly on capelin and launce as well as small amounts of shrimp, smelt, cod, herring and brook trout (Blair 1965; Lindsay and Thompson 1932; Lear 1972), while just before entering their home rivers feeding almost ceases (Kendall 1935; Power 1969; Keenleyside 1962; Jones 1959). In the major inshore feeding area of West Greenland, salmon that would be returning to homewaters as either 2-sea-winter or 3-sea-winter salmon were feeding mainly on capelin and launce (approximately 80% by weight) and amphipods, euphausiids, fish remains, Paralepidae and some Gonatus sp. (Lear 1980; Templeman 1968). The other known major feeding area for Atlantic salmon is in the Labrador Sea where it is suspected that stocks of salmon that would be returning to their home rivers as 2- or 3-sea-winter salmon overwinter. The main items of diet consists of Paralepis coregonoides borealis, Gonatus fabricus, amphipods, lantern fish and small amounts of other fish species (Templeman 1968; Lear 1980).

The feeding areas and diet of Atlantic salmon in the post-smolt phase are largely unknown. However, they are occassionally caught in herring-mackerel gear along the coast of eastern Canada. It is speculated that they remain fairly close to the coast during the first few months at sea perhaps moving farther offshore to overwinter in the warmer waters of the Labrador Sea where food is abundant. The diet of a post-smolt caught in a herring gillnet in December 1979, was amphipods, euphausiids and larval and juvenile fish remains. Because of the small size of salmon at this stage (less than 40-45 cm and 0.6-0.7 kg) and because diet of the adults suggests that salmon are opportunistic feeders at all stages, the main prey items must be small and abundant. Thus, prey species could be larval or juvenile stages of capelin, herring, mackerel or any other abundant fish species.

Salmon migration patterns

Templeman (1967) and May (1972) suggested that movements of salmon to and from their feeding areas are related to the patterns of oceanic circulation in the North Atlantic. After smolts enter the sea in spring they remain relatively close to the coast until winter and the onset of cold water temperatures (Fig. 1). During the winter some are probably found in the warm waters of the mid-Labrador Sea where prey species are also abundant (Fig. 1). Then following this first winter at sea those salmon returning to their home waters to spawn as grilse and some non-maturing 1-sea-winter salmon return to the waters around the coast of Newfoundland and Labrador. Most of the grilse enter Newfoundland or Labrador rivers and the others move down around the coast to enter their home rivers in Quebec, New Brunswick, Nova Scotia or Maine (Fig. 2). The non-maturing 1-sea-winter salmon may form the basis for the stocks of salmon that are caught annually in a small fall-winter fishery in northeast Newfoundland. The other non-maturing 1-sea-winter salmon either remain in the Labrador Sea or migrate to the west coast of Greenland or Irminger Sea (Fig. 2). During their second sea-winter these fish are again found in the eddy system of the mid-Labrador Sea (Fig. 3). Beginning in the following spring maturing 2-sea-winter salmon migrate towards the Newfoundland and Labrador coasts and return to home rivers in Newfoundland, Labrador, Quebec, New Brunsiwck, Nova Scotia and Maine (Fig. 3).

Linear regressions of multi-sea-winter salmon catches on grilse catches from the same smolt year-class were significant ($R^2 = 0.62$, $Y = 505.65 + 1.2985 X$, $F = 11.55$) at less than the 5% level indicating that once at sea, environmental conditions and food resources favourable for grilse are also favourable for multi-sea-winter fish and survival within a year-class follows similar trends.

The abundance of smolt year-classes was estimated using Canadian landings of known 1-sea-winter and multi-sea-winter salmon. Thus, it is assumed that over this period of time fishing mortality has remained relatively stable. Recent estimates of F have suggested this to be the case (Reddin, unpublished data; M. Chadwick, pers. comm.).

Capelin distribution and migrations

Capelin are currently managed as two major stocks - the northern (NAFO SA2 + Div. 3K) stock and the southern (NAFO Div. 3LNOPs) stock (Fig. 4). In fact these are stock complexes although the delineations of the stocks are not clear. This is especially true for stocks making up the northern stock complex (stock A in Fig. 4) although differences in growth rates (Winters 1974) suggest that there may be a Labrador and a northeastern Newfoundland component. Most of the fishery and research activity has occurred in NAFO Div. 2J and Div. 3K; hence for the purposes of this paper, this stock complex will be referred to as the NAFO Div. 2J3K stock. Stocks composing the southern stock complex are more clearly defined. Capelin spawning inshore in Bonavista, Trinity and Conception bays and the Avalon Peninsula make up a stock (stock B in Fig. 4) (Campbell and Winters 1973, Carscadden and Misra 1980). Capelin spawning inshore on the south coast of Newfoundland comprise another stock (stock D in Fig. 4). Another major stock spawns on the Southeast Shoal, the only offshore area where capelin are known to spawn (stock C in Fig. 4). Stocks occurring in the Gulf of St. Lawrence are considered separate from Atlantic Coast stocks; the Gulf stock is also a stock complex and there is evidence that there may be as many as six stocks in the Gulf of St. Lawrence (Sharp et al. 1978).

The northern Grand Banks (southern NAFO Div. 3K and northern NAFO Div. 3L) are believed to be the major over-wintering area for capelin that will later spawn inshore in Newfoundland and on the Southeast Shoal. As the ice recedes northward, capelin begin forming schools and as a result become accessible to a fishery. Traditionally, a fishery began in NAFO Div. 3L during late March or early April, taking a mixture of fish from the inshore spawning stock and the Southeast Shoal stock. There is a migration of capelin inshore in NAFO Div. 3L and southeast over the Grand Banks to the Southeast Shoal and spawning occurs in both areas during June and July. After spawning virtually all of the males die while a small proportion of the females survive.

The major over-wintering area for maturing capelin belonging to the northern stock appears to be in NAFO Div. 3K. It is likely that there are other over-wintering areas along the Labrador coast since capelin spawn on the entire Labrador coast and there is no evidence of a massive northward migration in the spring. Beginning in late August or early September capelin that are beginning to mature to spawn the next year begin forming feeding schools. At this time a major commercial fishery develops and in most years the fishery occurs first in NAFO Div. 2J in the Hamilton Bank area. There is a gradual southward movement so that by late November and early December over-wintering schools are found in NAFO Div. 3K.

The other over-wintering area is in the St. Pierre Bank. Although little information is available for this stock, it appears that the biomass is small in relation to the stocks in other areas.

In addition to the large offshore stocks of capelin, there are local stocks of capelin in some bays of Newfoundland. Evidence for this is found in reports of mass mortalities of capelin in winter, vessel catches and feeding on capelin by Greenland halibut, cod and sea-birds. Winters (1970) reported biological characteristics of over-wintering capelin in Trinity Bay.

Detailed information on the distribution of immature capelin in the NAFO Div. 2J3KLNO area is not available although it is known that some stay in bays. The northern Grand Bank is reported to be a major nursery area for immature capelin (Kovalyov and Kudrin 1973).

Although mature and immature capelin are distributed in the same areas at certain times of the year, for example in early spring on the northern Grand Banks, they do not usually occur in the same schools. The general distribution of capelin is shown in Fig. 5.

The capelin fishery

Catches of capelin in NAFO Subareas 2 and 3 (Table 2) increased rapidly from less than 3000 tonnes in 1971 to approximately 366,000 tonnes in 1975. Catches declined to approximately 23,000 tonnes in 1979. About 92% of the total catch in the northern area (NAFO Subareas 2 and Div. 3K) was taken by USSR (midwater trawlers) and 60% and 23% of the total catch in the southern area (NAFO Div. 3LNOPs) was taken by USSR (midwater trawlers) and Norway (purse seiners), respectively. The northern stock first came under quota regulation in 1974 when a TAC of 110,000 tonnes was recommended. This was increased to 300,000 tonnes in 1975 and remained at that level through 1978. Evidence of poor recruitment in this capelin stock resulted in a reduction in the TAC in 1979 to 75,000 tonnes and a closure of the offshore capelin fishery in 1980. The southern stock also came under quota regulation in 1974 with a TAC of 200,000 tonnes. This TAC was increased to 200,000 tonnes in 1975 and remained at that level until 1978. The TAC was reduced in 1979 to 10,000 tonnes and increased in 1980 to 16,000 tonnes; the TAC's in 1979 and 1980 were to be taken in Div. 3L only.

Because of interest by Canadian fisherman in catching capelin for the Japanese roe market, there has been an increase in capelin catches inshore in recent years especially in NAFO Div. 3L. The high prices for roe have also prompted development of the capelin fishery in the Gulf of St. Lawrence although catches have been relatively low (Table 3). A TAC of 30,000 tonnes for the Gulf of St. Lawrence (NAFO Div. 4RST) was imposed for 1980.

Population dynamics of capelin

To better understand the population dynamics of capelin, sequential capelin abundance models (SCAM) have been developed (Carscadden and Miller 1979, Miller and Carscadden 1979) for the northern stock (SCAM 2J3K) and southern stock (SCAM 3LNO) as well as the NAFO Div. 3L component (SCAM 3L) of the southern stock. These models are similar in many ways to other sequential models (e.g. cohort analysis and virtual population analysis) in that they provide historical estimates of biomass and year-class strengths.

Results from SCAM 2J3K

Two series of historical estimates of year-class strength of capelin (Table 4) are based on different methods of calculating the proportion of each year-class of capelin mature at the start of the year (Carscadden and Miller 1980, Carscadden and Winters 1980). Although the absolute values of numbers of 2-year-olds are very different in the two series, the patterns of year-class strength are similar. Both series indicate that the 1973 year-class was the strongest year-class in recent history followed by the 1969 year-class. The relatively strong 1974 year-class in one series is considered to be an over-estimate (Carscadden and Miller 1980). Sampling data support the conclusions that the 1973 and 1969 year-classes were strong.

Both series of estimates of year-class strength reveal that year-classes subsequent to 1973 have been very low.

Results of SCAM 3LNO and SCAM 3L

Because the offshore fishery was suspended in 1979, data from the fishery were not available. In addition, parameter estimation was not as precise and, in fact, one parameter was assumed rather than estimated; as a result, the conclusions from this analysis (Carscadden and Miller, 1979) are probably not as reliable as those from SCAM 2J3K. This analysis reveals that both the 1969 and 1973 year-classes were strong (Table 5). In addition, the 1972 year-class was strong using SCAM 3LNO but was not as strong using SCAM 3L. The 1974 and 1975 year-classes were weak using both models.

Gulf of St. Lawrence

It has not been possible to use SCAM's for Gulf of St. Lawrence stocks because of the short history of the fishery. However, analysis of samples collected from the Gulf suggest that the 1973 year-class was relatively strong.

Capelin Biomass Estimates and Catches

The northern stock, NAFO Div. 2J + 3K

Two series of biomass estimates for the northern stock are given in Table 6 and these series correspond to the different parameters used in the model (Carscadden and Miller 1980, Carscadden and Winters 1980). As in the comparison of year-class strengths, there are large differences in the absolute values. However, the trends agree reasonably well. In the early years of the fishery, population levels were high largely as a result of the contributions of the strong 1969 and 1973 year-classes. However, there has been a dramatic decline since 1976 largely because of poor recruitment. Catches (Table 6) have represented a relatively small proporton of the estimated biomass; the highest exploitation rates were recorded in 1976 and 1977 when approximately 22% of the most pessimistic biomass estimated was removed as catch.

Southern stock, NAFO Div. 3LNO

Biomass estimates for capelin in NAFO Div. 3LNO and NAFO Div. 3L as well as catches in these areas are given in Table 7. The biomass estimates show that there has been a substantial decline in the southern stock in recent years largely due to poor recruitment. The decline in biomass has been more dramatic in the spawning stock in NAFO Div. 3NO. In 1978, most of the biomass of capelin occurring in NAFO Div. 3LNO was from the NAFO Div. 3L stock.

A comparison of NAFO Div. 3L catches and estimated biomass suggests that except in 1974, catches were not high in relation to total population. However, in 1976, 1977 and 1978, the fishery in NAFO Div. 3NO was harvesting an increasing proportion of the declining NAFO Div. 3NO stock. (Note that the 1978 catch in NAFO Div. 3NO is slightly larger than the estimated stock size in NAFO Div. 3NO, thus supporting the previous observation that these population estimates cannot be considered totally reliable). STACRES concluded that "the intense commercial fishery on the spawning grounds in NAFO Div. 3N may have substantially reduced the spawning stock size in recent years, and the possibility of recruitment overfishing should be taken into account" (Anon. 1979b). There is substantial evidence that the NAFO Div. 3NO stock is discrete from other stocks (Sharp et al. 1978, Carscadden and Misra 1980) and as a result any overfishing and decline in this stock would not be noticeable on inshore spawning stocks of capelin.

Gulf of St. Lawrence.

Biomass estimates of Gulf of St. Lawrence are at present very crude. However, in suggesting TAC's for this stock, parallelism in year-class strength has been assumed (1973 year-class) and it has been assumed that total biomass levels have declined in recent years, parallel with declines in biomass in Atlantic coast stocks.

Results and Discussion

Salmon-capelin interactions

There is no doubt that a biological relationship exists between adult salmon and capelin. Adult salmon feed heavily on capelin in the Greenland area and during the spawning migration on capelin in the Newfoundland area. However, a comparison of the distribution of salmon and capelin shows that salmon occupy a much larger geographical area than capelin suggesting that capelin may not be as important in the overall diet of salmon as published reports have previously indicated. It is impossible to speculate on the impact of Greenland capelin on salmon because of a lack of information on population dynamics of capelin. However, up to 1972 catches of capelin were low and the authors know of no large capelin fishery in the area. Analysis of capelin population dynamics indicates that, with the possible exception of the Southeast Shoal stock, capelin fishing has not been the cause of the decline of capelin stocks in the Newfoundland area. Hence, any influences of capelin on salmon in the Newfoundland area would appear to be related more to natural fluctuations in capelin abundance rather than man-induced fluctuations linked to overfishing.

Post-smolt feeding

Because of an absence of feeding information on post-smolts the biological relationships between post-smolt salmon and capelin are unclear. However, based on size distribution of prey and predator, it is probable that larval and juvenile capelin could be important sources of food for post-smolts. In an attempt to quantify possible interactions between post-smolt salmon and capelin we have tested possible feeding relationships. All statistically significant relationships related to capelin and salmon abundance assuming post-smolt feeding on capelin are given in Table 8.

a) Assumption: that post-smolts would be feeding on juvenile capelin (1 year old). Estimates of capelin year-class strength (Table 4) in a given year were related to estimates of smolt year-class abundance (as indicated by catches in the following year) of 1-sea-winter, multi-sea-winter and total salmon from all Canada. While the estimates of capelin year-class strength in Table 4 are for 2 year-olds, it was assumed that mortality up to maturity was constant for all years. As a result the estimates of year-class strength should be a reliable index of abundance of capelin at age 1 and 0 as well as age 2. For example, the 1969 year-class of capelin would have been 1 year old in 1970 and might have been prey for the 1970 smolt year-class. The indices of abundance for the 1970 smolt year-class were the catches of that year-class (Table 1) as 1-sea-winter, multi-sea-winter and total catches. Thus, in this case, the relationship examined was that between capelin year-class abundance, year t, with smolt year-class abundance in year t + 1.

None of the linear curves fitted were significant, except for estimates of smolt year-class abundance of total salmon on estimates of capelin year-class strength from NAFO Div. 2J3K (Carscadden and Miller 1980) after data from 1969 and 1976 were eliminated (Table 8, equation 3). This was done because 1969 and 1976 observed values were considerably less than the expected values (Fig. 6) although the residuals when tested were not significantly different from the mean of the other years. Curvilinear relationships were examined using a logarithmic function and were found to be significant for estimates of capelin year-class strengths from NAFO Div. 2J3K (Carscadden and Miller 1980) and estimates of smolt year-class abundance of multi-sea-winter and total salmon (Table 8, equations 1 and 2 and Fig. 6a and b).

Other possible linear relationships were examined such as capelin year-class strength in a given year and estimates of smolt year-class abundance from the northeast coast of Newfoundland in the following year; and capelin year-class strength in a given year and estimates of salmon abundance in the same year. None of these relationships were significant. In addition, there were no significant relationships when catch per-unit effort of capelin (Carscadden and Miller 1980) as an index of capelin abundance in a given year was related to 1-sea-winter and total salmon abundance of a smolt year-class in the following year.

b) Assumption: that post-smolts would be feeding on juvenile (1 year old) and larval (0 group) capelin. Estimates of year-class strengths of capelin in a given year plus the following year were related to estimates of smolt year-class abundance (from total Canadian landings in the following year) of 1-sea-winter, multi-sea-winter and total salmon. For instance, in this case, smolts of the 1970 year-class were assumed to be feeding on capelin of the 1969 (1 year-olds) and 1970 (0-groups) year-classes (the sum of the indices of abundance of these year-classes in Table 4). The relationship examined was that of capelin year-class abundance year t plus year t + 1 and smolt year-class abundance year t + 1.

The linear relationships between 1-sea-winter salmon abundance and year-class strength of capelin were significant for NAFO Div. 2J3K (Table 8: equations 4 and 5, Fig. 7). In addition the positive curvilinear relationships between multi-sea-winter salmon abundance and capelin year-class strength for NAFO Div. 2J3K (Carscadden and Miller 1980) (Table 8: equation 6, Fig. 8a) and total salmon abundance and capelin year-class strength for NAFO Div. 2J3K (Carscadden and Miller 1980) were significant (Table 8: equation 7, Fig. 8b). It should be noted in Fig. 8a and b that the low salmon landings of the 1979 smolt year-class greatly influence the curvilinear relationship; without these points, the slope would approach 0 and no relationship would exist.

Other possible linear relationships were tested such as capelin year-class strength (NAFO Div. 2J3K) in a given year plus the following year to estimates of smolt year-class abundance (from commercial landings along the northeast Newfoundland coast in the following year) of 1-sea-winter, multi-sea-winter and total salmon. None of the relationships were significantly correlated.

c) The significant relationship between 1-sea-winter salmon abundance and capelin year-class strength in a given year plus the following year suggests that salmon, especially multi-sea-winter fish, would have an opportunity to feed on a number of year-classes of capelin. One-sea-winter salmon on the other hand would be expected to show a poorer relationship, if any, because they would be feeding at sea only one year. Thus, estimates of capelin biomass, January 1, age 2 and older in NAFO Div. 2J3K in a given year were related to smolt year-class abundance (catches of the same year) of 1-sea-winter, multi-sea-winter and total salmon. In fact, the relationship was significant for 1-sea-winter salmon in one case (Table 8: equation 8, Fig 9), for multi-sea-winter salmon and for total salmon abundance in all cases (Table 8: equations 9 and 10, Fig. 10; Table 8: equations 11 and 12, Fig. 11). In Fig. 10, the landings in 1979 of the 1977 smolt-class greatly influence the regression; without this point, the slope would approach 0 and the relationships would be almost meaningless. Other similar relationships were investigated using salmon landings from the northeast Newfoundland coast to estimate smolt year-class abundance. In this case only two relationships were significant: Multi-sea-winter landings and capelin biomass (Carscadden and Miller 1980) (Table 8: equation 13, Fig. 12a) and total salmon landings and capelin biomass (Carscadden and Winters 1980) (Table 8: equation 14, Fig. 12b).

d) It was previously assumed that post-smolts would be feeding on juvenile capelin (1 year olds) and so capelin year-class strengths in a given year were related to mean weights of grilse and multi-sea-winter salmon from smolt year-class in the following year. None of the regressions were significant.

e) To test the relationship between a number of capelin year-classes on salmon growth (as expressed by mean weight at capture) we related capelin biomass January 1, NAFO Div. 2J3K of a given year to mean weight of 1-sea-winter salmon from the smolt year-class of the previous year and mean weight of multi-sea-winter salmon from the smolt year-class two years previous. None of the linear regressions were statistically significant. However, the curvilinear relationship between weight of multi-sea-winter mean weights and capelin biomass (Carscadden and Miller 1980) was significant (Table 8: equation 15, Fig. 13). Again the 1979 point (1977 smolt year-class) has a great influence on the relationship; all the points are are in cluster and without the 1979 point it is possible that the relationship would not be statistically significant.

Adult salmon feeding

Studies have shown that salmon which have spent one or more winters at sea consume a wide variety of prey species and are therefore likely opportunistic feeders. However, in inshore waters the major component of the diet of salmon is adult capelin probably 3+ and older. Possible relationships between salmon and capelin based on adult salmon feeding were tested and statistically significant relationships are given in Table 9.

a) It is known that salmon feed on adult capelin in coastal waters during their homeward migration. It is assumed that these capelin would be 3+ in age and so numbers of 3-year-old capelin (Carscadden and Miller 1980, Carscadden and Winters 1980) were related to the total Canadian salmon landings, multi-sea-winter salmon landings and 1-sea-winter salmon landings in the same year. There were no significant linear relationships although the relationships between capelin in NAFO Div. 2J3K and both total and multi-sea-winter landings approached significance. The curvilinear fits for these relationships are significant at less than 5% (Table 9: equations 1 and 2, Fig. 14a and b; Table 9: equations 3 and 4, Fig. 15a and b). This wasn't the case for 1-sea-winter salmon; all of the linear regressions were very weak probably because 1-sea-winter salmon are caught closer to their home rivers than are multi-sea-winter salmon and would not be feeding as heavily on capelin in coastal waters over an extended period as might older salmon.

b) It was also assumed that adult salmon in coastal waters could be feeding on 3 and 4 year old capelin. Thus, numbers of 3 plus 4 year-old capelin (Carscadden and Miller 1980, Carscadden and Winters 1980) were related to 1-sea-winter, multi-sea-winter and total salmon landings in the same year. There was a significant linear relationship for multi-sea-winter salmon of both Carscadden and Miller estimates (Table 9: equation 5, Fig. 16a and b) and Carscadden and Winters estimates of capelin year-class strengths (Table 9: equation 6, Fig. 17 a and b). The logarithmic curvilinear fit is much stronger in both cases and is also significant for the total salmon landings on both estimates of capelin year-class strengths from NAFO Div. 2J3K in a given year plus that of the following year.

Approximately 19% of the biologically possible relationships tested between post-smolt salmon, adult salmon and capelin were statistically significant. There were weak linear and strong curvilinear relationships between both capelin biomass, capelin year-class strengths and salmon catches. However, the presence of statistically significant relationships does not necessarily imply that a direct biological relationship exists. It may be that the two species are influenced in the same way by some other factor or factors (eg. environment). In addition, it should be emphasized that all post-smolt feeding relationships are based on the possibility (no sampling data) that post-smolts are feeding on young capelin.

The lack of data at the lower ends of the logarithmic curves also raises questions as to the biological significance of the correlations. In some cases, the curves are highly influenced by one point and in many instances, this point results from the one abnormal salmon year (1977 smolt year-class). Catches of 1-sea-winter salmon in 1979 indicate that the 1980 commercial fishery in Newfoundland and Labrador will be good in spite of predictions of low capelin abundance. Thus, the 1980 salmon catch may well be above values projected from the relationships developed here. In fact, such statistical relationships may not be significant with the inclusion of the 1980 data.

The fact that significant relationships exist for estimates of salmon abundance on both capelin biomass and several capelin year-classes suggests that any relationship between capelin and salmon abundance involves multiple year-classes of capelin and is not a simple year-class to year-class relationship.

Log curvilinear regressions exhibited better fits than did linear suggesting that at higher capelin abundances other factors limit salmon abundance i.e. smolt production, etc. But if capelin and salmon abundance are related then capelin abundance may limit salmon abundance, especially at low levels of capelin abundance. However, the effects of low capelin abundance may not be direct since salmon are suspected of being opportunistic feeders. In addition, there are considerable gaps in our knowledge of salmon feeding and migrations of both species.

Information on the 1977 smolt year-class suggests increased mortality occurred between spring of 1977 and spring of 1978 to both the 1-sea-winter and multi-sea-winter salmon components of the year-class. Many of the relationships generated for post-smolt feeding and capelin abundance suggest that salmon abundance was lower than would have been expected from capelin abundance. Thus, the decline of capelin in recent years due to poor recruitment, cannot be totally blamed for the poor sea-survival of the 1977 smolt year-class. However, good salmon catches in recent years in spite of low capelin abundance suggests that, although capelin may have had some influence on the poor survival of the 1977 smolt-class, other factors perhaps as or more important than capelin abundance were also involved. Furthermore, in areas where capelin are rare such as the east coast of Nova Scotia, the one-sea-winter and two-sea-winter salmon exhibited unusually poor runs in 1978 and 1979, respectively, as did runs in the Gulf of St. Lawrence, Newfoundland and Labrador where capelin normally occur.

Summary

1. Adult capelin are important components of the diet of adult salmon in coastal areas.

2. Statistically significant curvilinear regressions relating salmon and abundance of capelin on which they might be feeding suggested that as capelin abundance increases so did salmon but eventually salmon abundance levelled off.

3. Capelin could be an important food source for post-smolt salmon but a feeding study of post-smolts is required to confirm this.

4. Significant linear and curvilinear regressions related capelin year-class strengths and biomass estimates with salmon abundance assuming post-smolt feeding on capelin.

5. A direct biological relationship between capelin and salmon could not be concluded from 2 and 4 but it is evident that salmon abundance and survival may have some relationship to capelin.

6. The decline of capelin in recent years due to poor recruitment, cannot be totally blamed for the poor sea survival of the 1977 smolt year-class.

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Table 1. Landings (commercial plus recreational) of Atlantic salmon for 1969-68 smolt year-classes (tonnes).

	Canadian			West Greenland			NE coast of Newfoundland		
Smolt year-class	1-sea-winter	Multi-sea-winter	Total	***North American origin	Total	Total catches of Canadian salmon	1-sea-winter	Multi-sea-winter	Total
1969	756	1453	2209	751	2146	2960	403	518	921
1970	505	1142	1647	914	2689	2561	212	294	506
1971	554	1589	2143	761	2113	2904	199	569	768
1972	778	1509	2287	1147	2341	3434	347	350	697
1973	945	1509	2454	824	1917	3278	400	501	901
1974	905	1665	2570	893	2030	3463	439	380	819
1975	777	1798	2575	**505	1175	3080	308	588	896
1976	655	1225	1880	582	1420	2462	325	294	619
1977	320	705	1025	407	992	1432	182	126	308
*1978	582			700	1400		306		

* Provisional
** West Greenland catches under quota control beginning 1976 (1191 t).
***(Anon. 1979a) Report of the Working Group on North American salmon. Int. Counc. Explor. Mer. C.M. 1979/M:10.

Table 2. Nominal catches and TAC's (tonnes) of capelin by stock area and country, 1971-79.

NAFO Div.	Country	1971	1972	1973	1974	1975	1976	1977	1978	1979[1]
2+3K	Bulgaria	-	-	-	-	1,394	-	2,892	-	210
	Canada	242	461	598	1,343	698	1,684	2,136	2,419	672
	Cuba	-	-	-	-	-	-	5,089	1,351	238
	GDR	-	11	-	-	7	-	1,014	227	-
	Japan	-	-	-	-	62	51	870	69	-
	Norway	-	-	-	16	2	-	-	-	-
	Poland	-	24	2,356	5,734	20,267	10,494	4,282	1,036	-
	Portugal	-	-	-	-	175	-	-	-	-
	Romania	-	-	-	-	-	-	2,610	2,551	845
	USSR	-	45,127	133,468	119,846	175,896	204,097	133,516	47,294	8,489
	Total	242	45,623	136,422	126,939	198,501	216,326	152,409	54,947	10,454
	TAC	-	-	-	110,000	300,000	300,000	300,000	300,000	75,000
3LNOPs	Bulgaria	-	166	-	-	-	1,271	578	25	-
	Canada	1,869	3,312	5,502	13,693	3,817	7,832	9,715	6,434	12,385
	Cuba	-	-	-	-	-	-	700	63	-
	GDR	-	-	-	-	-	-	-	177	-
	Iceland	-	-	-	-	15,814	8,839	3,394	360	-
	Japan	-	-	-	-	2,819	5,063	3,958	1,018	-
	Norway	-	653	41,293	43,964	37,477	23,178	21,499	5,070	-
	Poland	-	-	744	3,742	4,608	4,627	1,018	502	-
	Portugal	-	-	-	3,500	399	-	-	-	-
	Romania	-	-	-	-	-	-	-	112	-
	Spain	-	-	-	4,016	4,284	-	-	-	-
	USSR	750	21,049	84,568	91,797	98,245	93,030	37,047	16,394	-
	Others	-	-	-	-	-	230	1	-	-
	Total	2,619	25,180	132,107	160,712	167,463	144,070	77,910	30,155	12,385
	TAC	-	-	-	200,000	200,000	200,000	200,000	200,000	10,000[2]

[1] Preliminary statistics
[2] No offshore fishing in NAFO Div. 3LNO

Table 3. Catches (tonnes) of capelin in the Gulf of St. Lawrence.

NAFO Div.	1974	1975	1976	1977	1978	1979
4R	179	68	91	1514	8204	5735
4T	Not available				1219	Not available

Table 4. Estimates of year-class strength (numbers x 10^{-9}) of capelin at age 2, January 1, for the northern capelin stock (NAFO Div. 2J3K), 1969-77.

Source/year-class	1969	1970	1971	1972	1973	1974	1975	1976	1977
Carscadden and Miller 1980	169	102	123	120	290	211*	10	11	18
Carscadden and Winters 1980	32	19	27	24	71	18	12	10	11

* Considered to be an overestimate - see Carscadden and Miller 1980.

Table 5. Estimates of year-class strength (numbers x 10^{-9}) of capelin at age 2, January 1, for the southern capelin stock (NAFO Div. 3LNO), 1969-75. (from Carscadden and Miller 1979).

NAFO Div./ Year-class	1969	1970	1971	1972	1973	1974	1975
3LNO	182	40	17	38	36	15	4
3L	31	5	3	10	29	14	4

Table 6. Biomass estimates (tonnes) on September 1 (approximate start of the fishery) and catches (tonnes) for the northern capelin stock (NAFO Div. 2J3K).

Source/Year	1972	1973	1974	1975	1976	1977	1978	1979
Carscadden and Miller, 1980	3,911,000	4,055,000	3,826,000	6,235,000	6,360,000	4,164,000	738,000	477,000
Carscadden and Wnters, 1980	709,000	919,000	861,000	1,423,000	967,000	681,000	340,000	290,000
Catches	45,632	136,422	126,939	198,501	216,326	152,409	54,947	10,454*

* Preliminary statistics

Table 7. Biomass estimates (tonnes) of 3+ capelin on January 1 and catches (tonnes) for the southern capelin stock (NAFO Div. 3LNO) (from Carscadden and Miller 1979).

NAFO Div./ Year	1972	1973	1974	1975	1976	1977	1978
3LNO	3,212,000	2,295,000	1,119,000	941,000	814,000	507,000	194,000
3L	429,000	388,000	134,000	208,000	585,000	403,000	191,000
Catches							
3L	1,241	3,876	57,713	34,097	33,823	26,802	26,006
3NO	21,417	126,875	100,751	131,783	110,186	50,092	5,247

Table 8. Significant relationships found for post-smolts feeding on 0+ and/ or 1-yr-old capelin. (* Significant at 5%, ** significant at 1%.)

1. Year t + 1, MSW smolt year-class abundance on year t capelin year-class strength NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 6).

   $r^2 = 0.57$, $Y = 497.74 + 204.13 \ln X$ *

2. Year t + 1, total salmon smolt year-class abundance on year t capelin year-class strength NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 6).

   $r^2 = 0.53$, $Y = 755.67 + 300.36 \ln X$ *

3. Year t + 1 total salmon smolt year-class abundance on year t capelin year-class strength NAFO Div. 2J3K (Carscadden and Miller 1980) if data from 1976 and 1969 are eliminated (Fig. 6).

   $r^2 = 0.80$, $Y = 1958.09 + 2.5239 X$ **

4. Year t + 1, 1SW smolt year-class abundance on year t plus year t + 1 capelin year-class strengths NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 7).

   $r^2 = 0.54$, $Y = 453.66 + 0.943 X$ *

5. Year t + 1, 1SW smolt year-class abundance on year t plus year t + 1 capelin year-class strengths NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 7).

   $r^2 = 0.52$, $Y = 405.22 + 5.429 X$ *

6. Year t + 1, MSW smolt year-class abundance on year t plus year t + 1 capelin year-class strengths NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 8a).

   $r^2 = 0.50$, $Y = 546.91 X^{0.18}$ *

7. Year t + 1, total salmon smolt year-class abundance on year t plus year t + 1 capelin year-class strengths NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 8b).

   $r^2 = 0.51$, $Y = 457.78 + 318.83 \ln X$ *

8. Year t, 1SW landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 9).

   $r^2 = 0.51$, $Y = 313.70 + 455.07 X$ *

9. Year t, MSW landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 10).

   $r^2 = 0.77$, $Y = 653.51 + 159.83 X$ **

10. Year t, MSW landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 10).

   $r^2 = 0.49$, $Y = 762.01 + 746.99 X$ *

11. Year t, total salmon landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 11a).

   $r^2 = 0.72$, $Y = 1193.17 e^{0.11x}$ *

12. Year t, total salmon landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 11b).

   $r^2 = 0.78$, $Y = 2307.32 X^{0.54}$ **

13. Year t, northeast coast of Newfoundland MSW landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 12a).

   $r^2 = 0.76$, $Y = 148.17 X^{0.63}$ **

14. Year t, northeast coast of Newfoundland MSW landings on year t capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 12b).

   $r^2 = 0.50$, $Y = 786.28 + 350.44 \ln X$ *

15. Mean weight of MSW salmon on capelin biomass, Jan. 1, NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 13).

   $r^2 = 0.71$, $Y = 4.04 X^{0.08}$ *

Table 9. Significant relationships tested for adult salmon feeding on mature capelin. (*Significant at 5%)

1. MSW Canadian salmon landings on numbers of 3 year old capelin NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 14).

   $r^2 = 0.56$, $Y = 573.64 + 201.38 \ln X$ *

2. MSW total Canadian salmon landings on numbers of 3 year old capelin NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 14).

   $r^2 = 0.67$, $Y = 1044.12 X^{0.16}$ *

3. MSW Canadian salmon landings on numbers of 4 year old capelin NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 15).

   $r^2 = 0.66$, $Y = -128.41 + 699.49 \ln X$ *

4. Total Canadian salmon landings on numbers of 4 year old capelin NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 15).

   $r^2 = 0.57$, $Y = 716.43 X^{0.48}$ *

5. MSW Canadian salmon landings on numbers of 3 and 4 year old capelin NAFO Div. 2J3K (Carscadden and Miller 1980) (Fig. 16).

   $r^2 = 0.76$, $Y = 125.44 x^{0.47}$ *

6. MSW Canadian salmon landings on numbers of 3 and 4 year-old capelin NAFO Div. 2J3K (Carscadden and Winters 1980) (Fig. 17).

   $r^2 = 0.55$, $Y = 283.44 X^{0.48}$ *

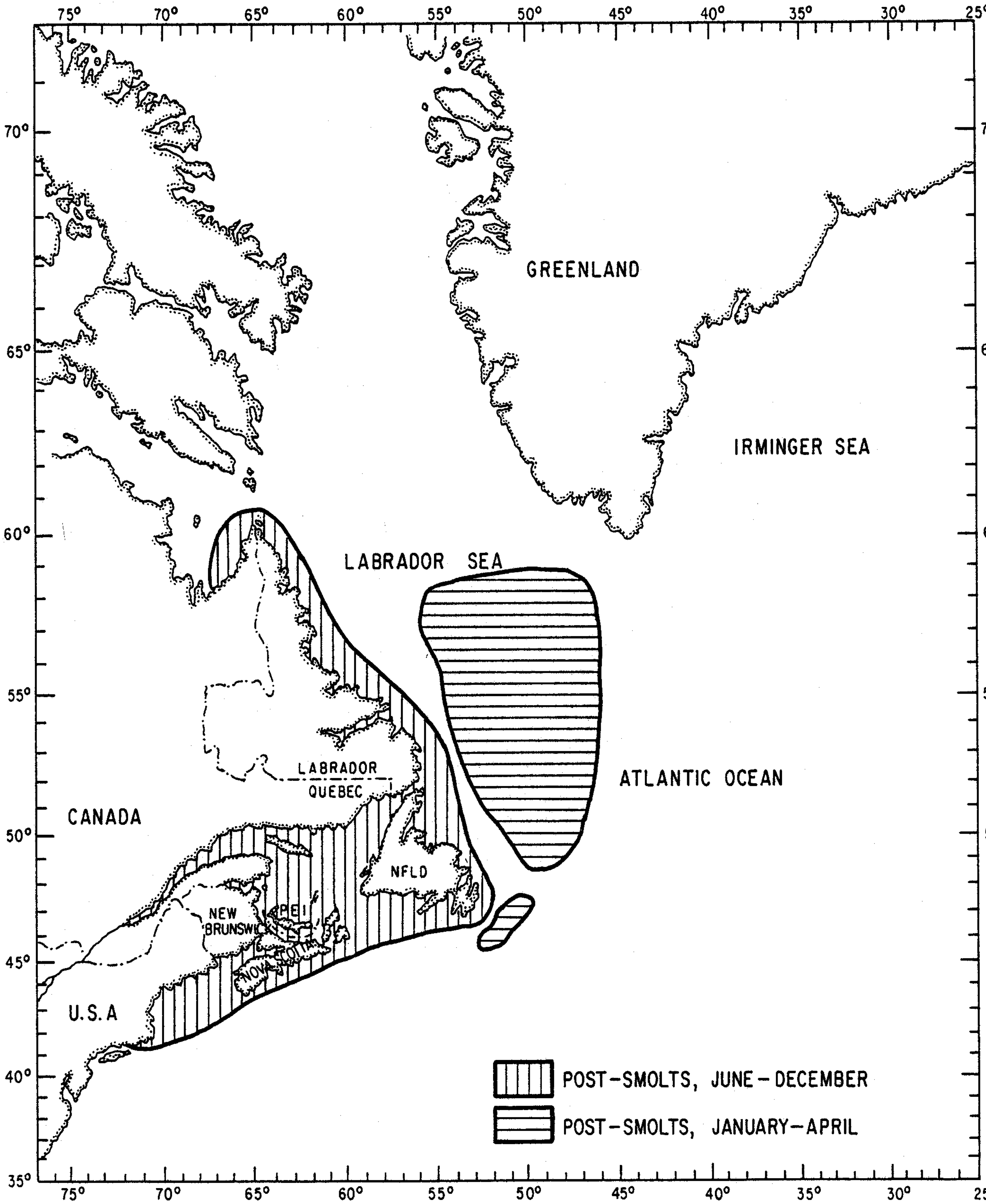

Fig. 1. Major distributions of Atlantic salmon in the Northwest Atlantic.

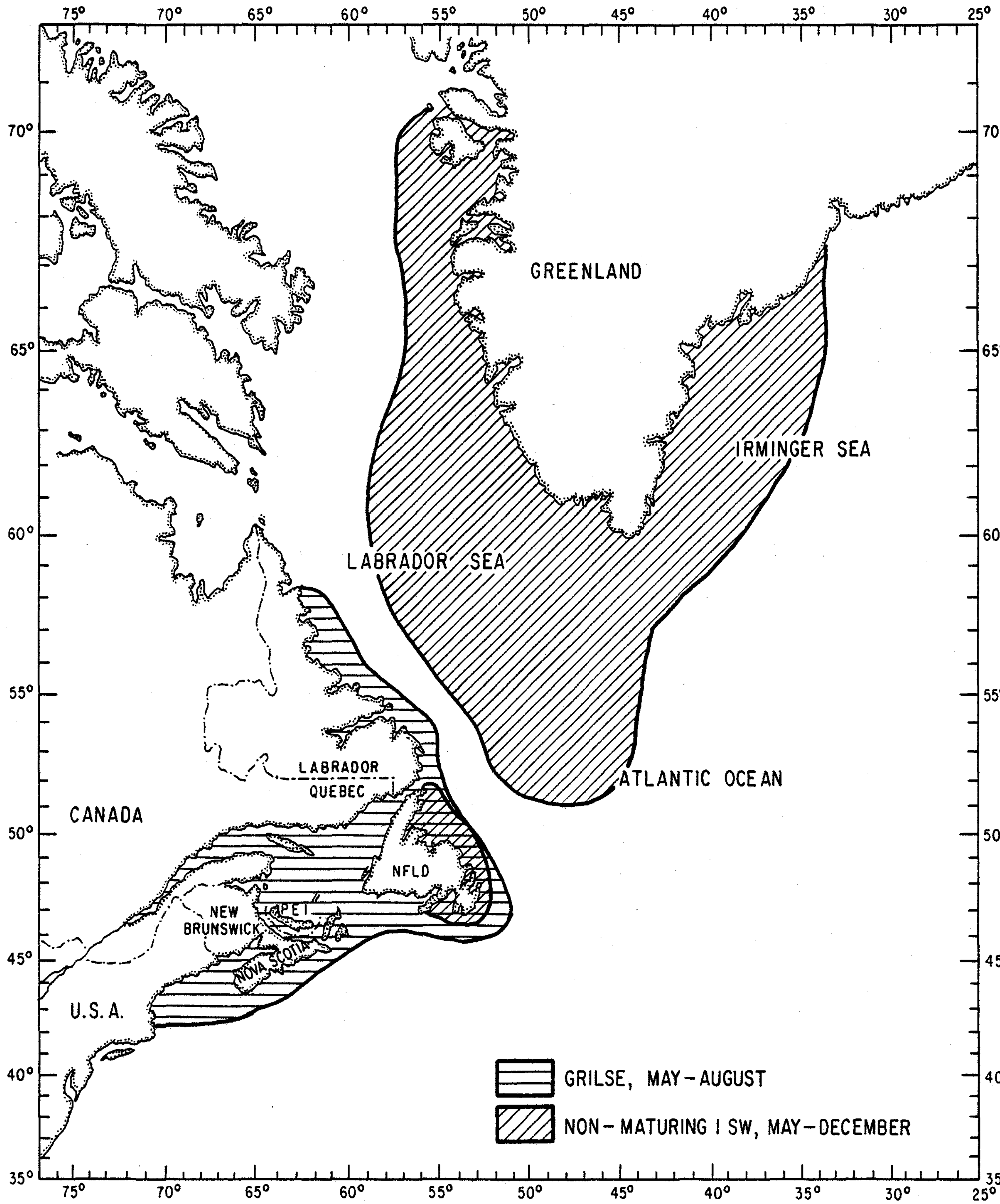

Fig. 2. Major distributions of Atlantic salmon in the Northwest Atlantic.

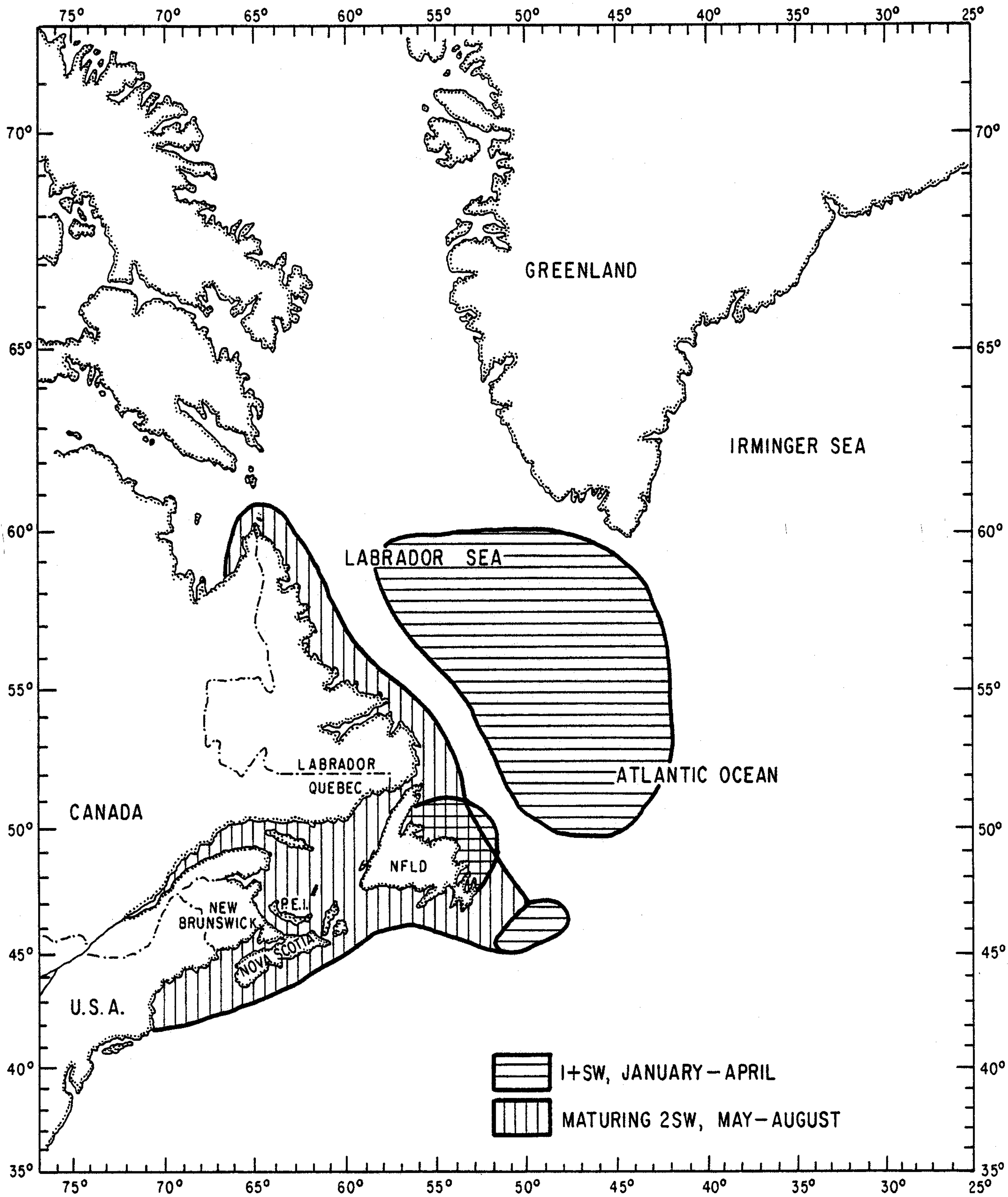

Fig. 3. Major distributions of Atlantic salmon in the Northwest Atlantic.

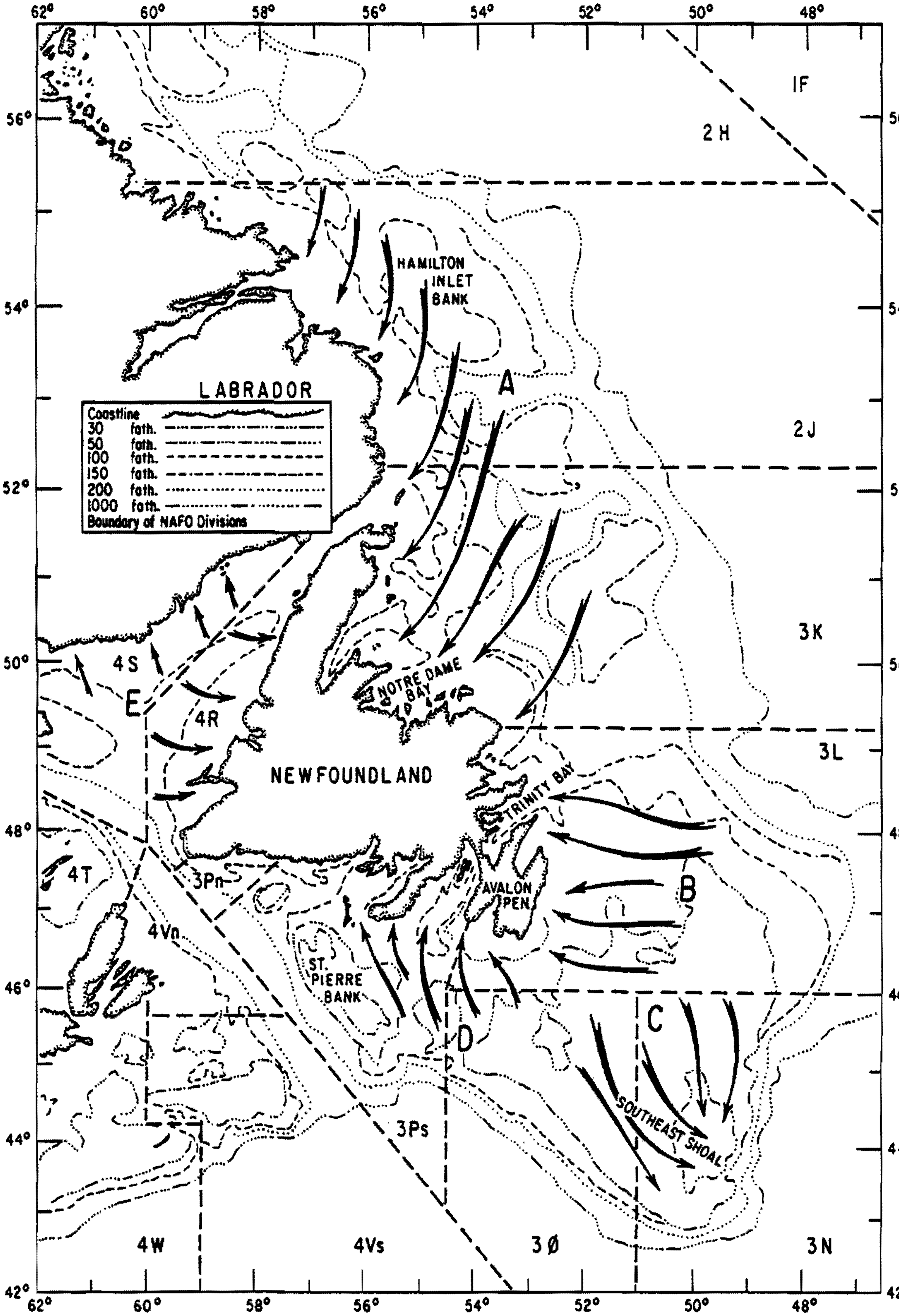

Fig. 4. Migration patterns and stocks of capelin off Newfoundland and Labrador. Arrows indicate spawning migrations. A - Labrador-Northeast Newfoundland stock; B - Northern Grand Bank-Avalon stock; C - South Grand Bank stock; D - St. Pierre-Green Bank stock (from Campbell and Winters 1973); E - Gulf of St. Lawrence.

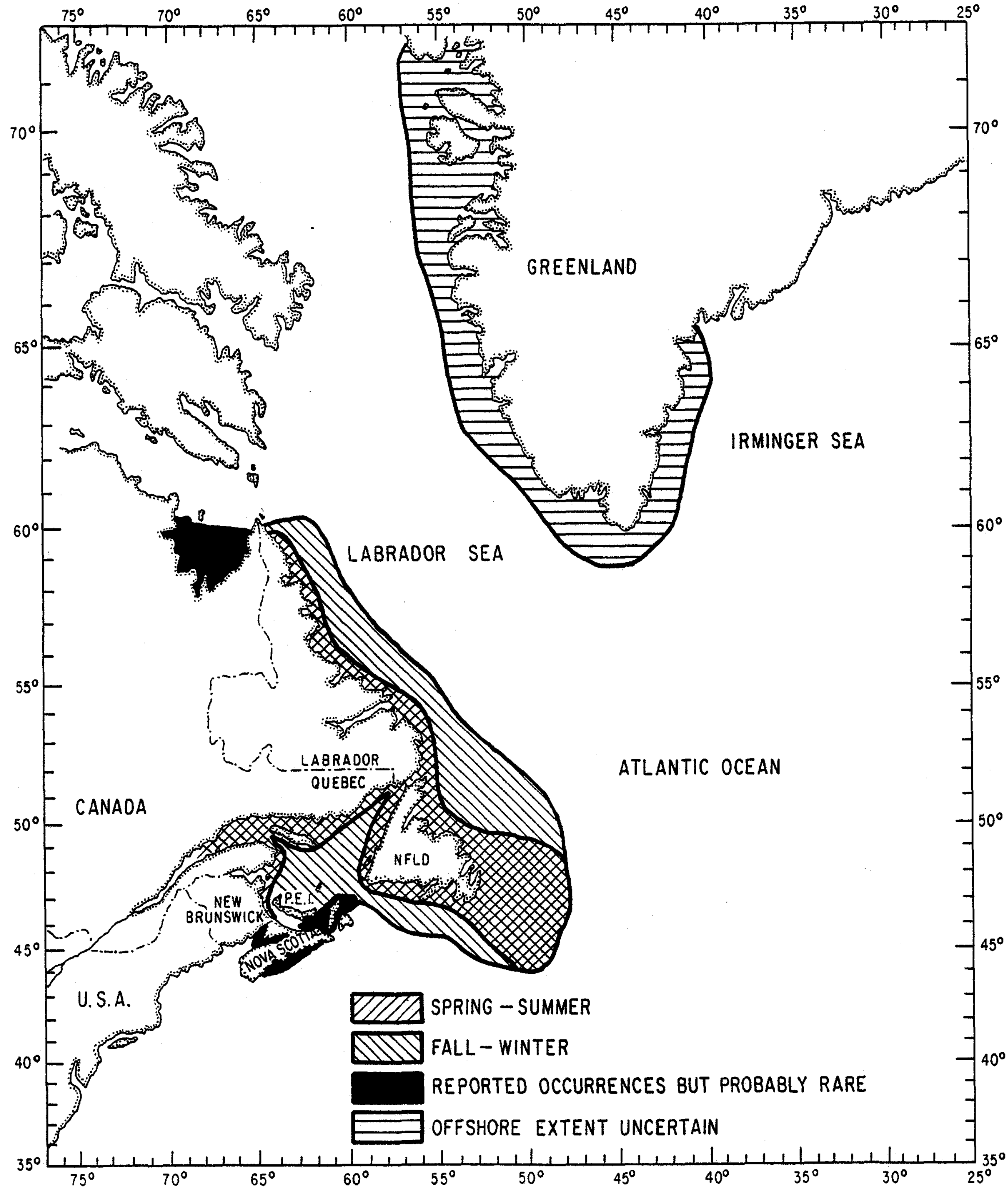

Fig. 5. Capelin distribution in the Northwest Atlantic area.

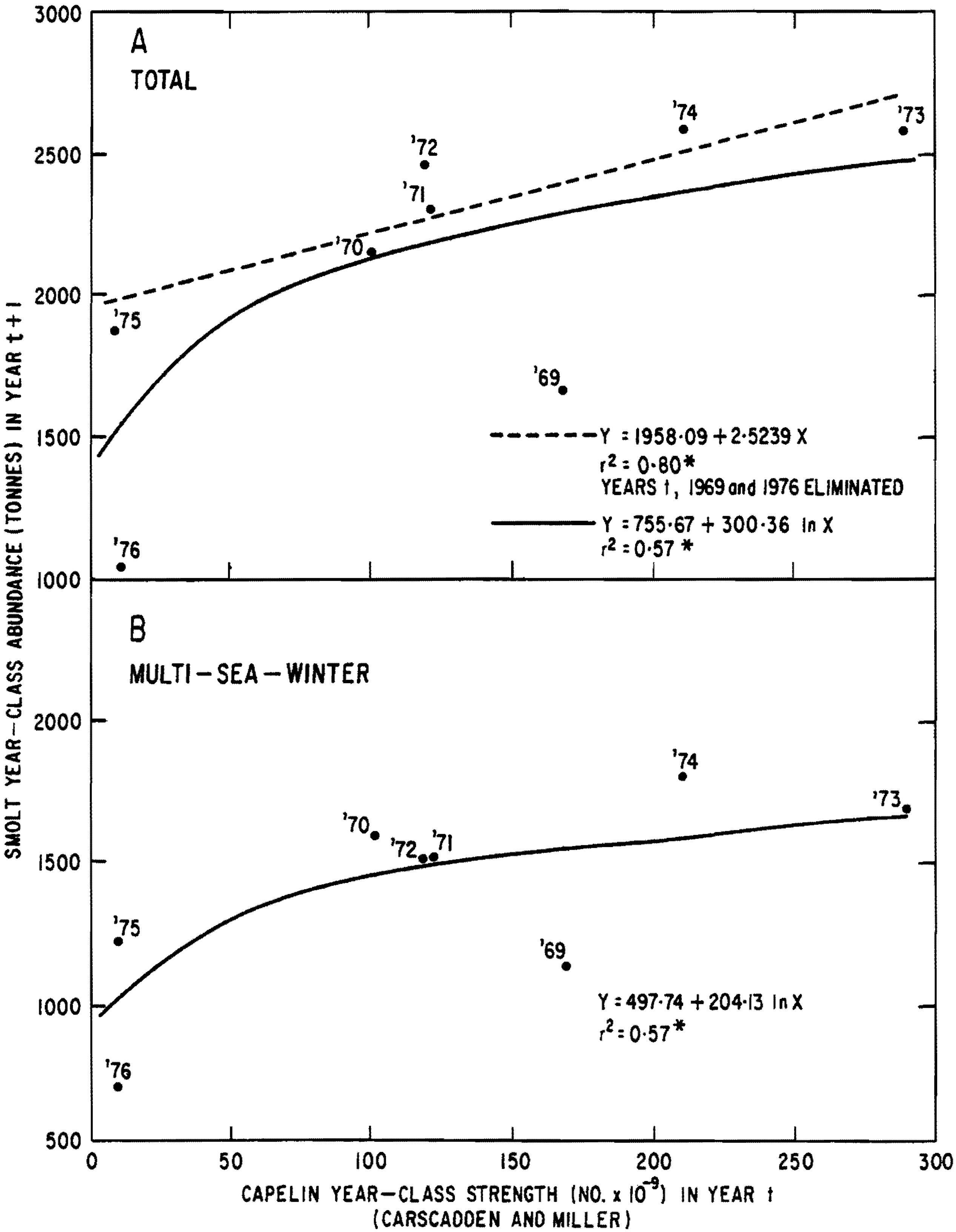

Fig. 6. Relationships between abundance of post-smolts based on total salmon catches (A), catches of multi-year salmon (B) and 1-year-old capelin. Years shown are year t. See text for details.

(*Significant at 5%)

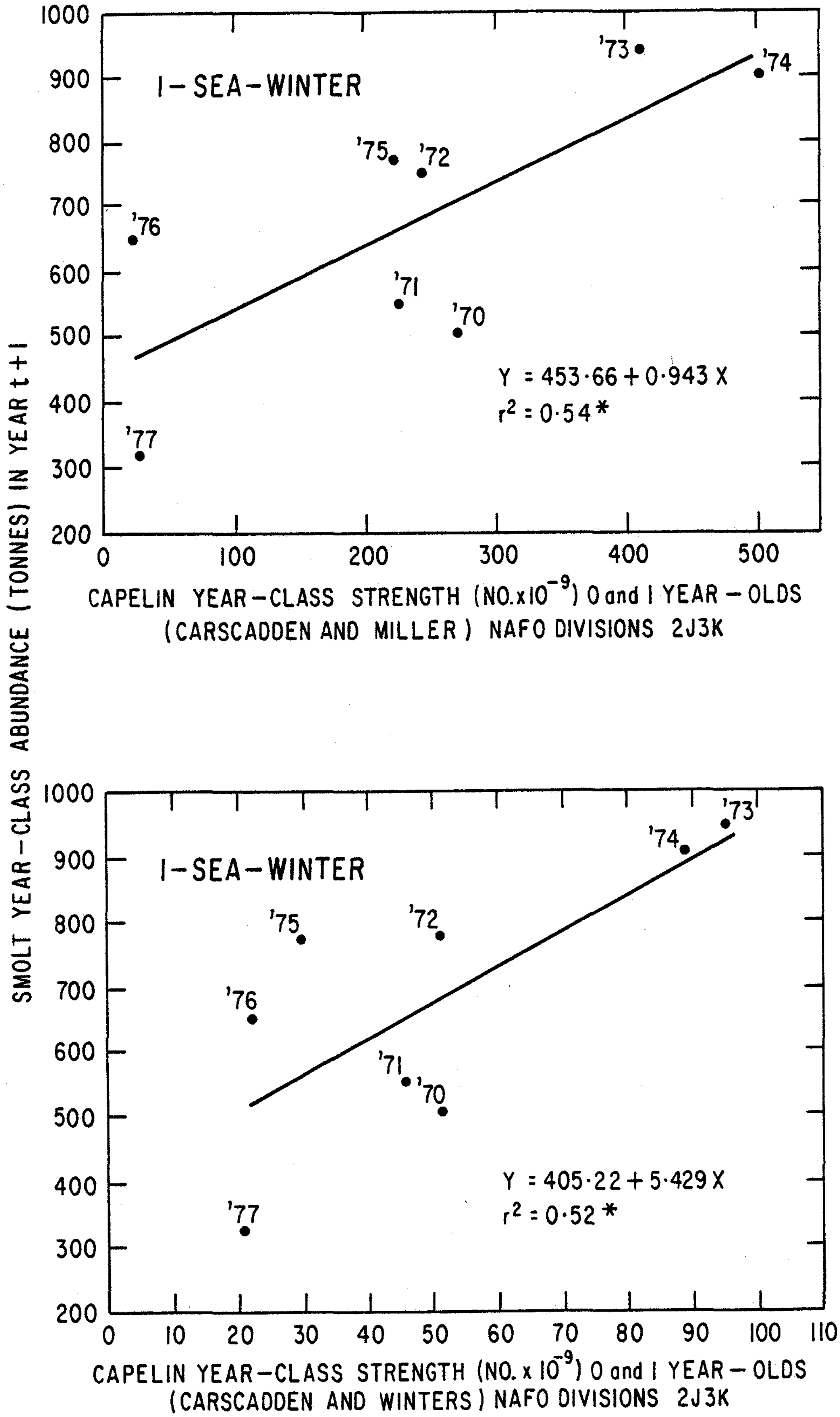

Fig. 7. Relationship between smolt year-class abundance based on catches of 1-sea-winter salmon and abundance indices of 0 and 1-year-old capelin (year t and year t+1) from two data sources (Carscadden and Miller 1980; Carscadden and Winters 1980). Years shown are years t+1.

(*Significant at 5%)

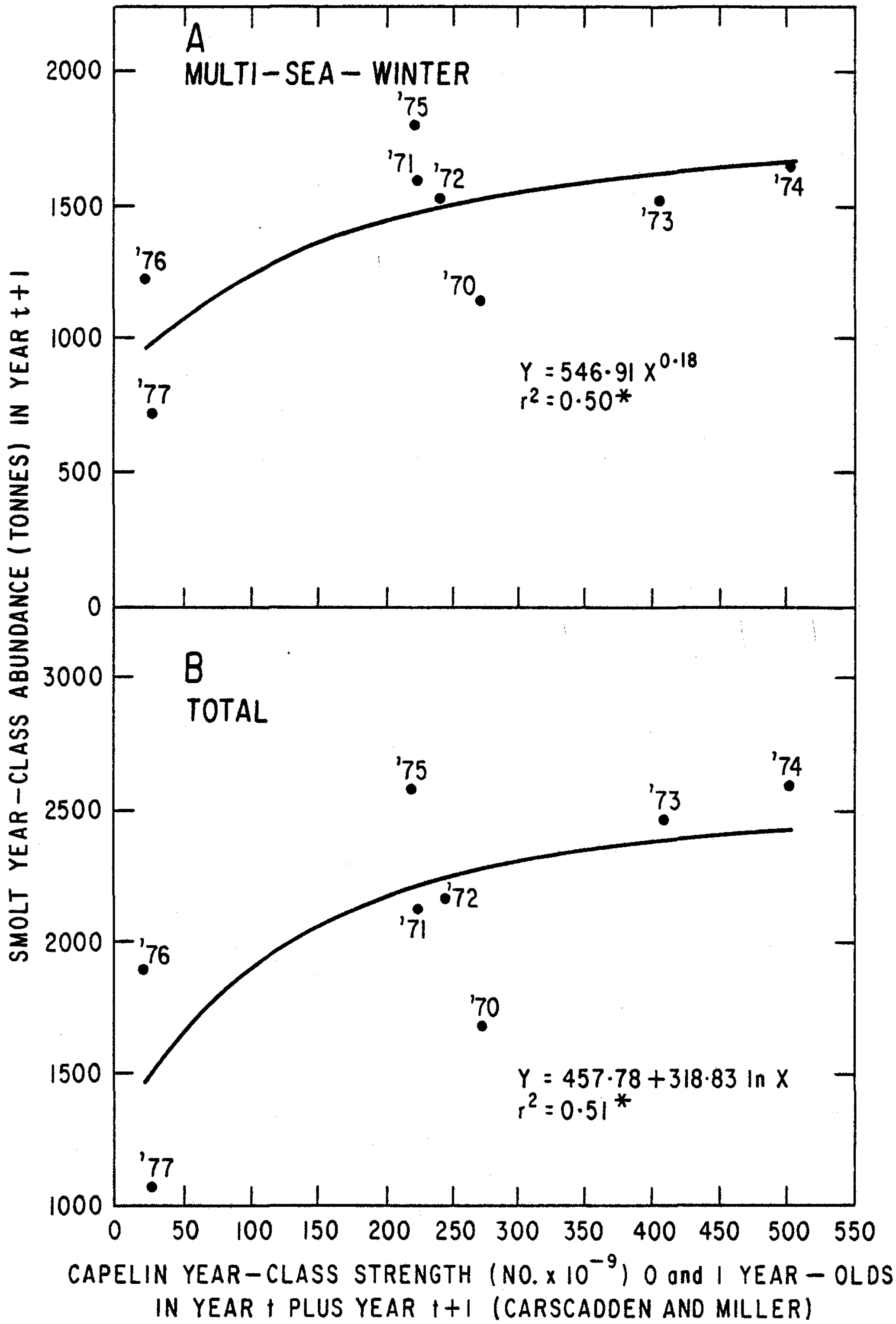

Fig. 8. Relationship between smolt year-class abundance based on multi-sea-winter (A) and total Canadian (B) salmon landings and capelin year-class strengths of 1-year-old and 0-group capelin. Years shown are year t+1.

(*Significant at 5%)

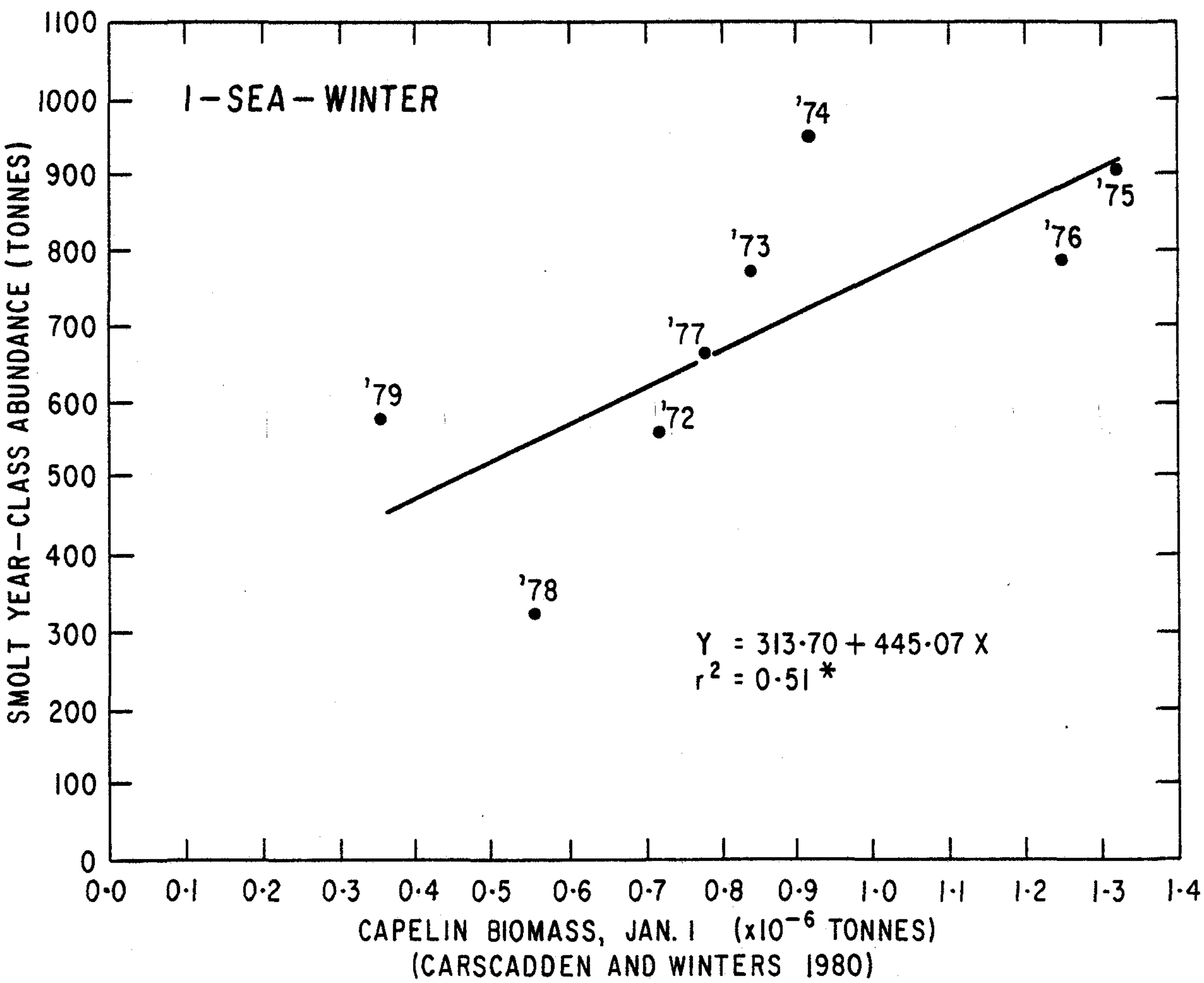

Fig. 9. Relationship between smolt year-class abundance based on 1-sea-winter landings and capelin biomass, January 1.

(*Significant at 5%)

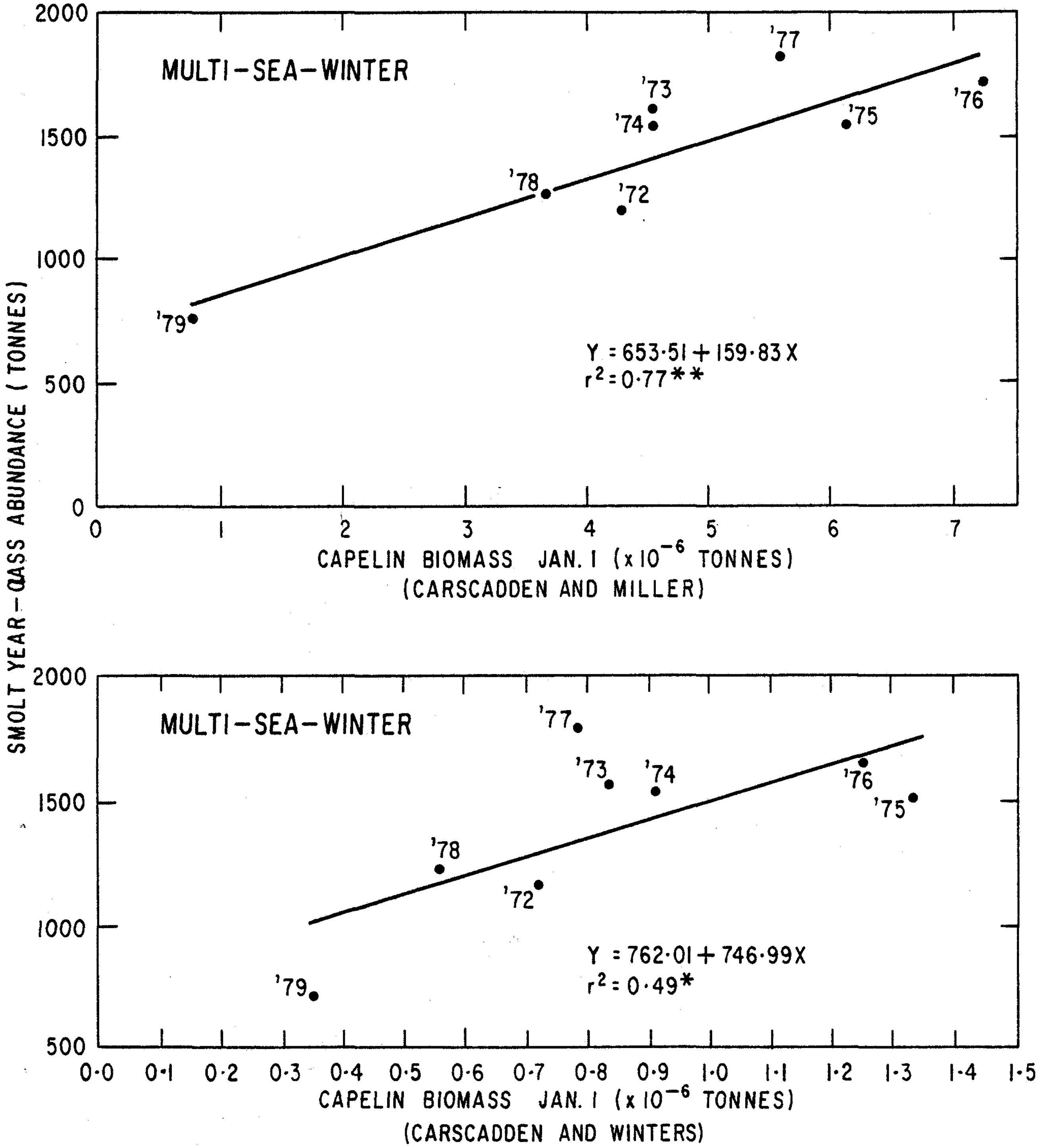

Fig. 10. Relationship between smolt year-class abundance based on catches of multi-sea-winter salmon and capelin biomass, January 1, from two data sources (Carscadden and Miller 1980; Carscadden and Winters 1980).

(*Significant at 5%, ** significant at 1%)

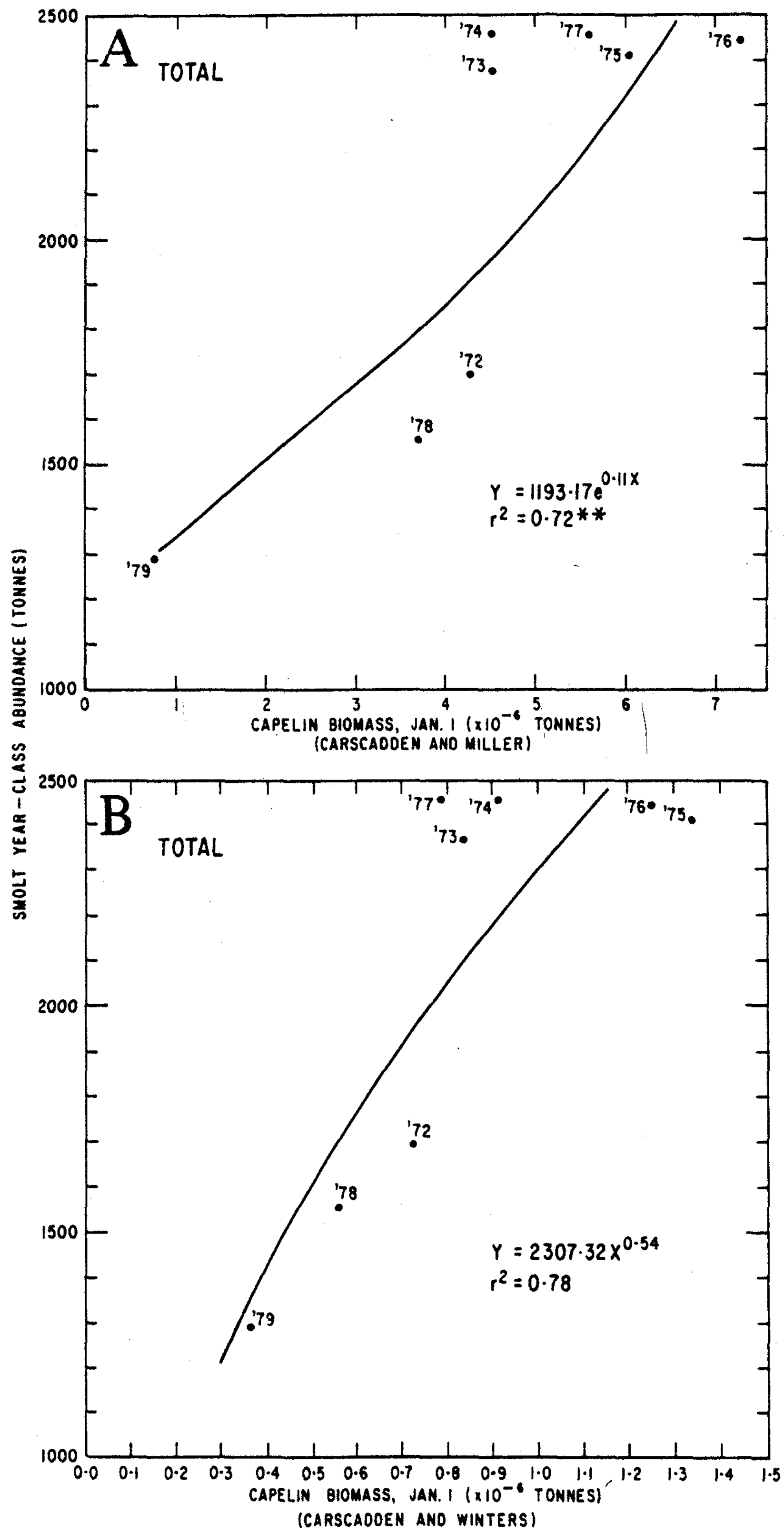

Fig. 11. Relationship between smolt year-class abundance based on total salmon landings and capelin biomass, January 1, from two data sources (Carscadden and Miller 1980; Carscadden and Winters 1980).

(**Significant at 1%)

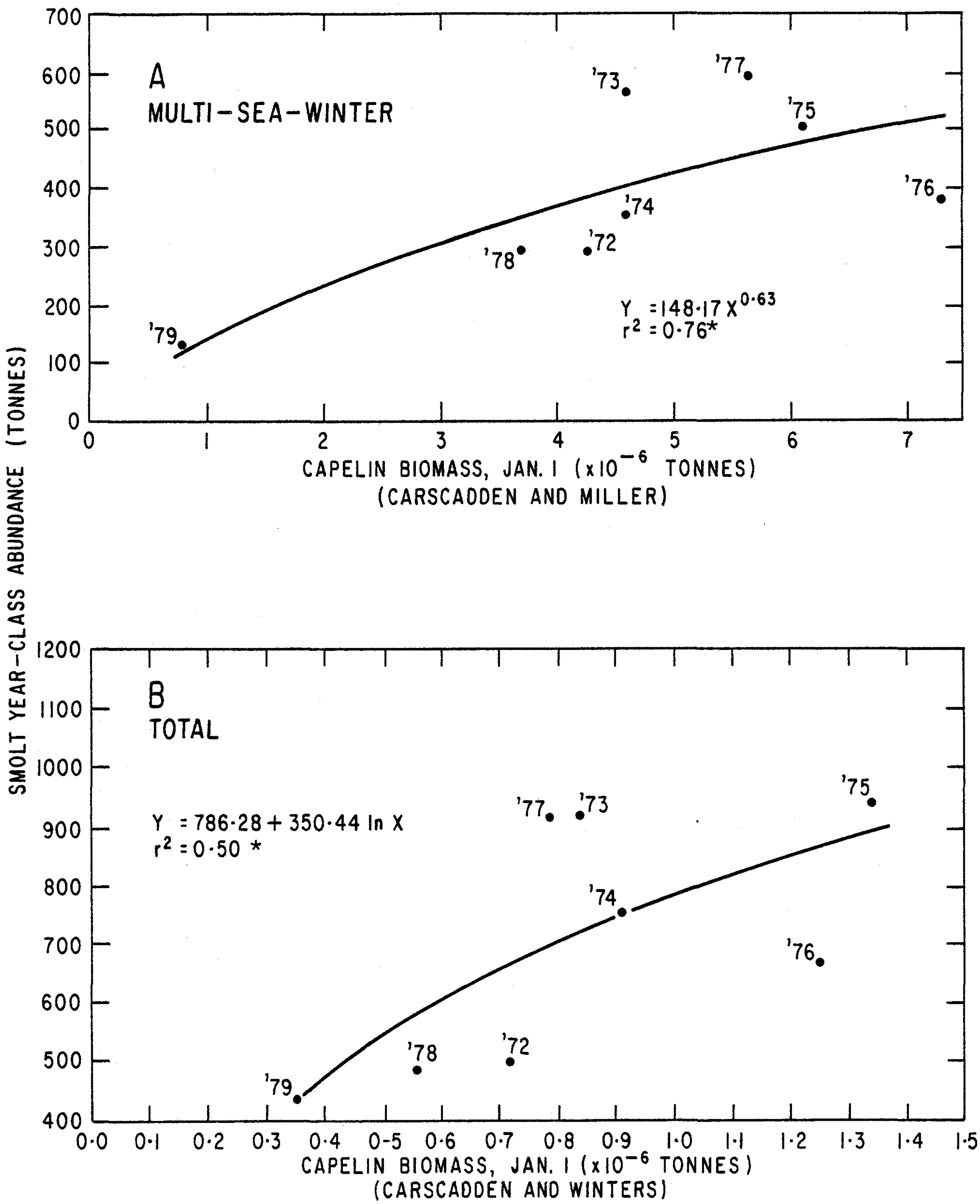

Fig. 12. Relationship between smolt year-class abundance based on landings of multi-sea-winter (A) salmon and total (B) salmon from the northeast coast of Newfoundland and capelin biomass, January 1.

(*Significant at 5%)

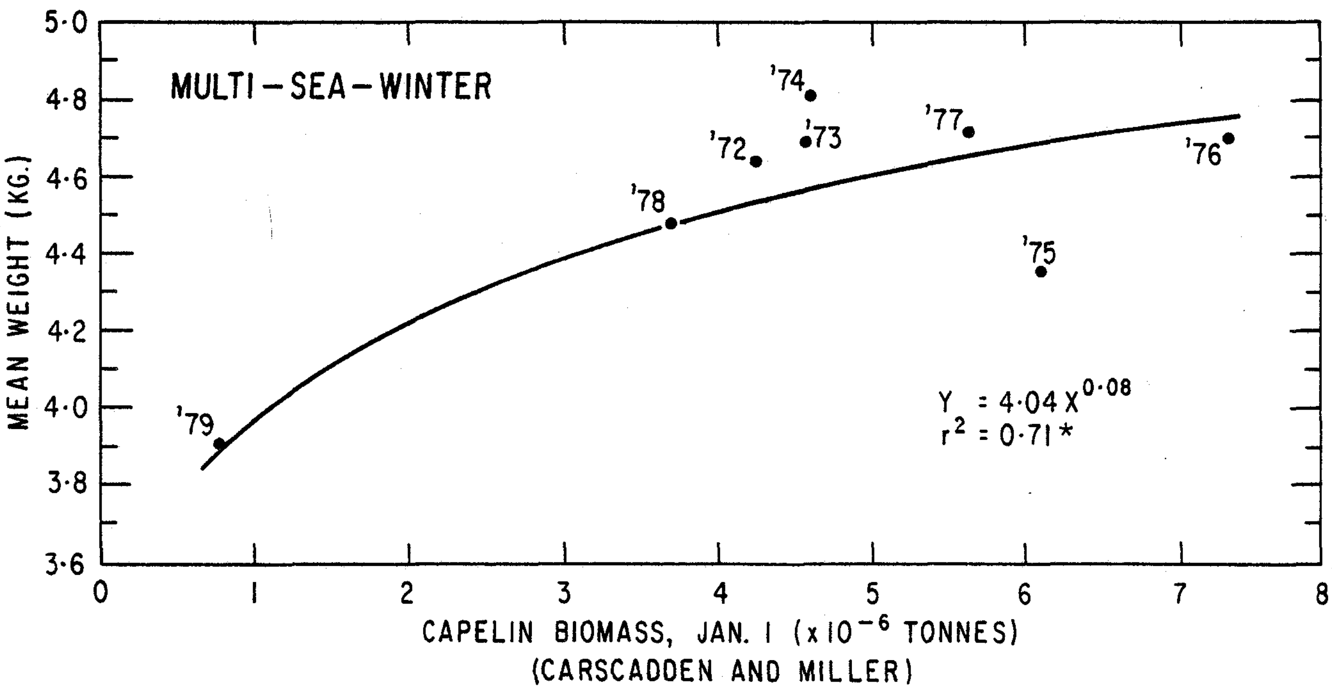

Fig. 13. Relationship between mean weight of multi-sea-winter salmon and capelin biomass, January 1.

(*Significant at 5%)

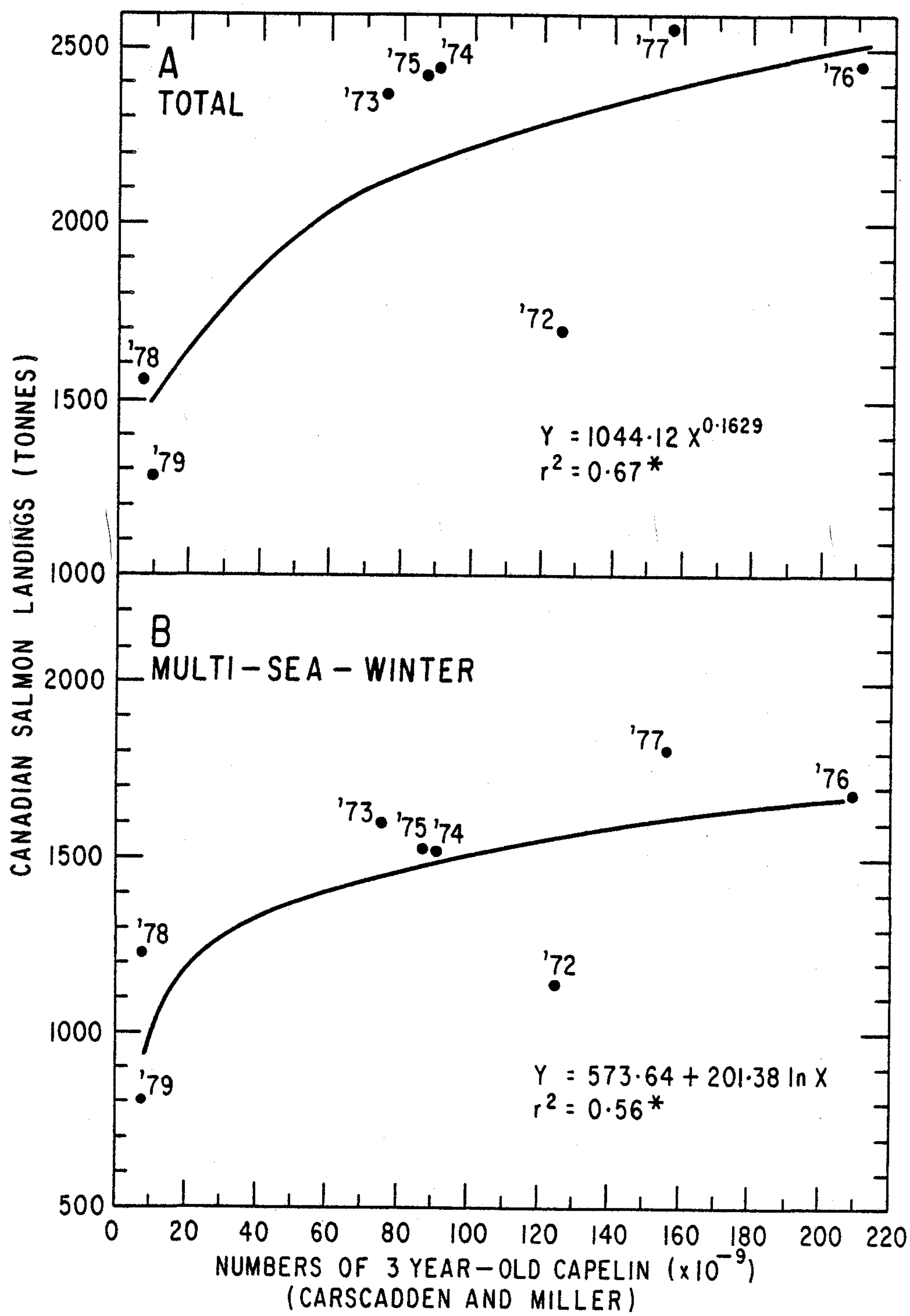

Fig. 14. Relationship between total (A) and multi-sea-winter (B) salmon landings and numbers of 3-year-old capelin.

(*Significant at 5%)

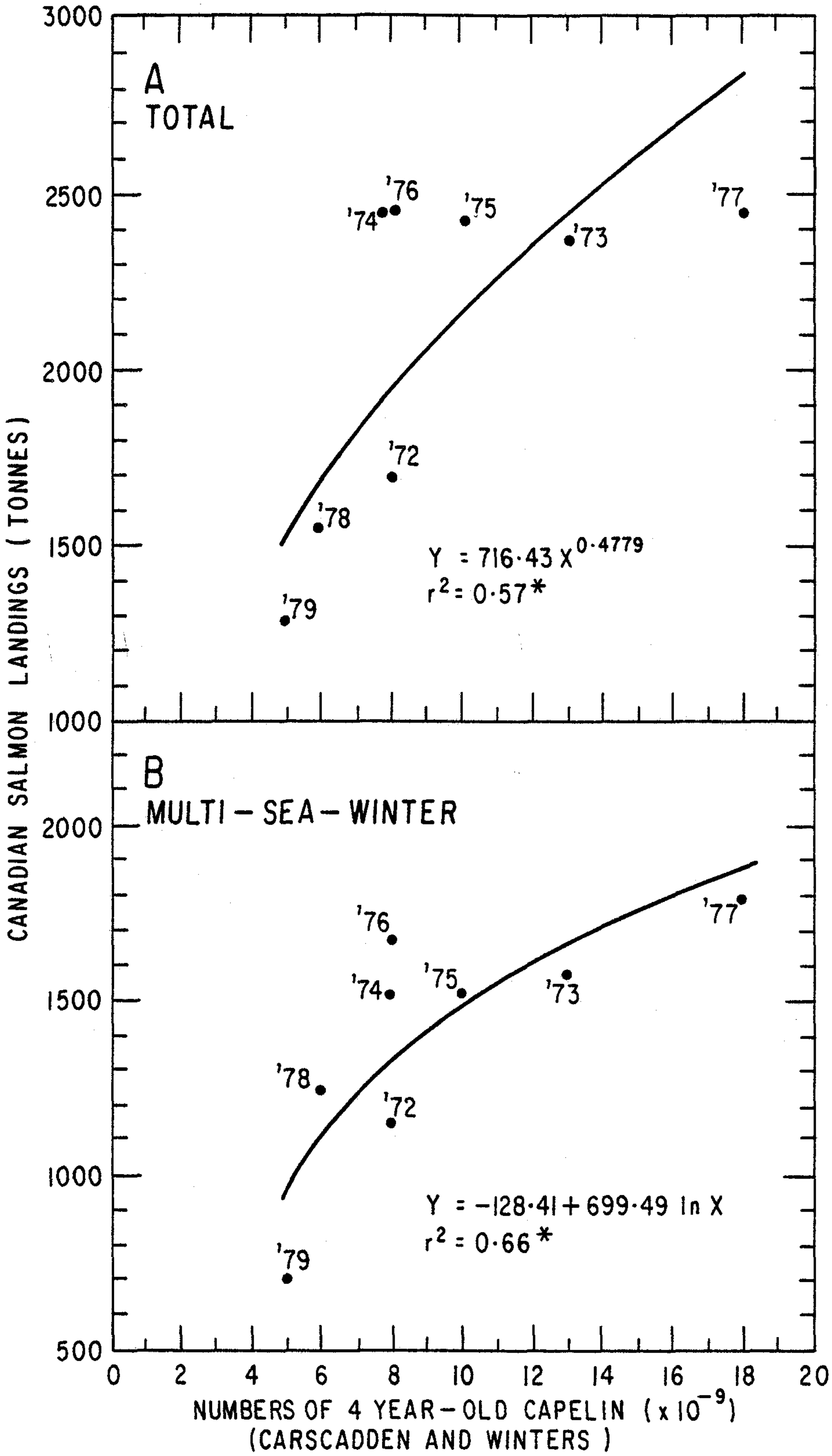

Fig. 15. Relationship between total (A) and multi-sea-winter (B) salmon landings and number of 4-year-old capelin.

(*Significant at 5%)

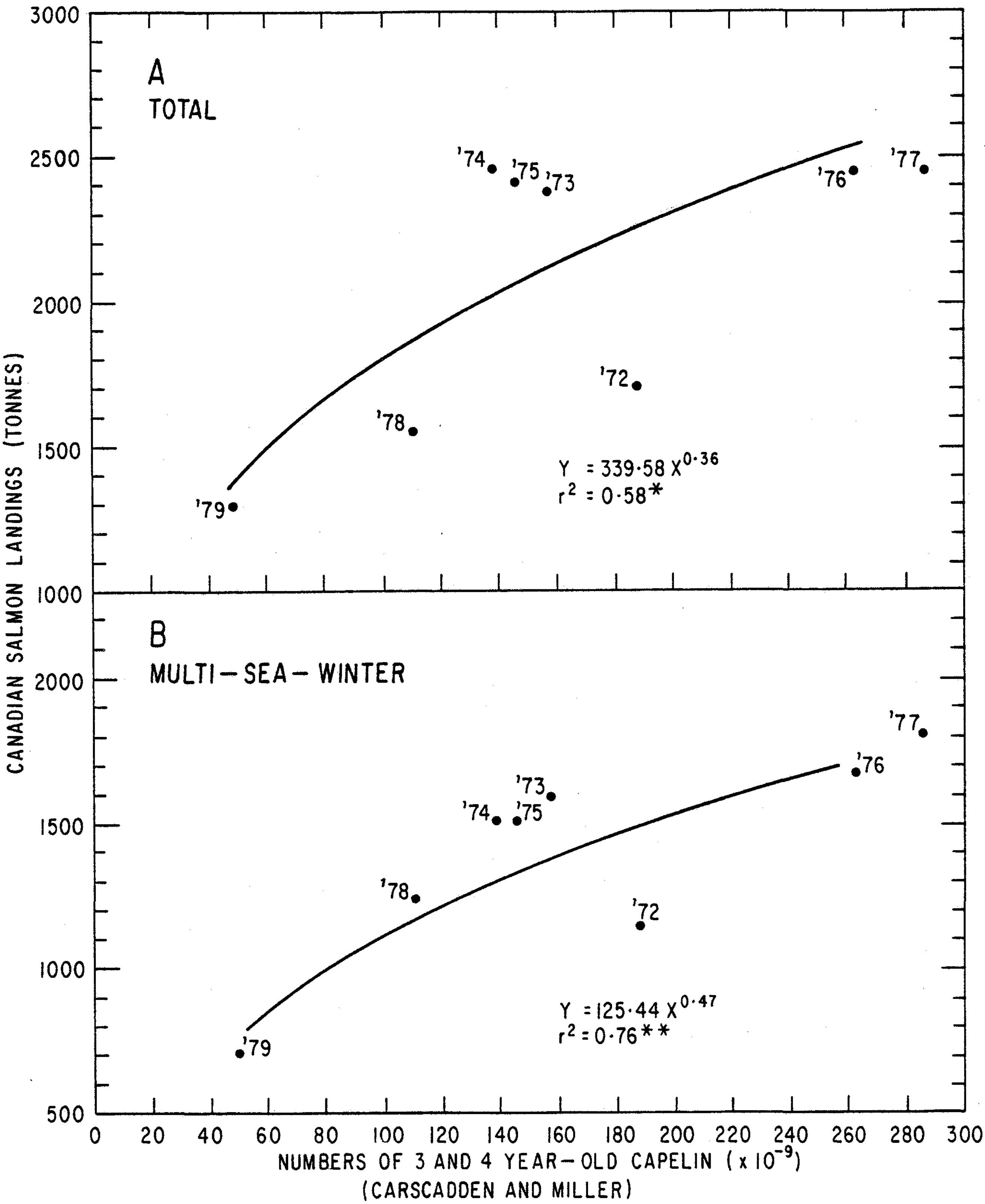

Fig. 16. Relationship between total (A) and multi-sea-winter (B) salmon landings and numbers of 3- and 4-year-old capelin.

(*Significant at 5%, **significant at 1%)

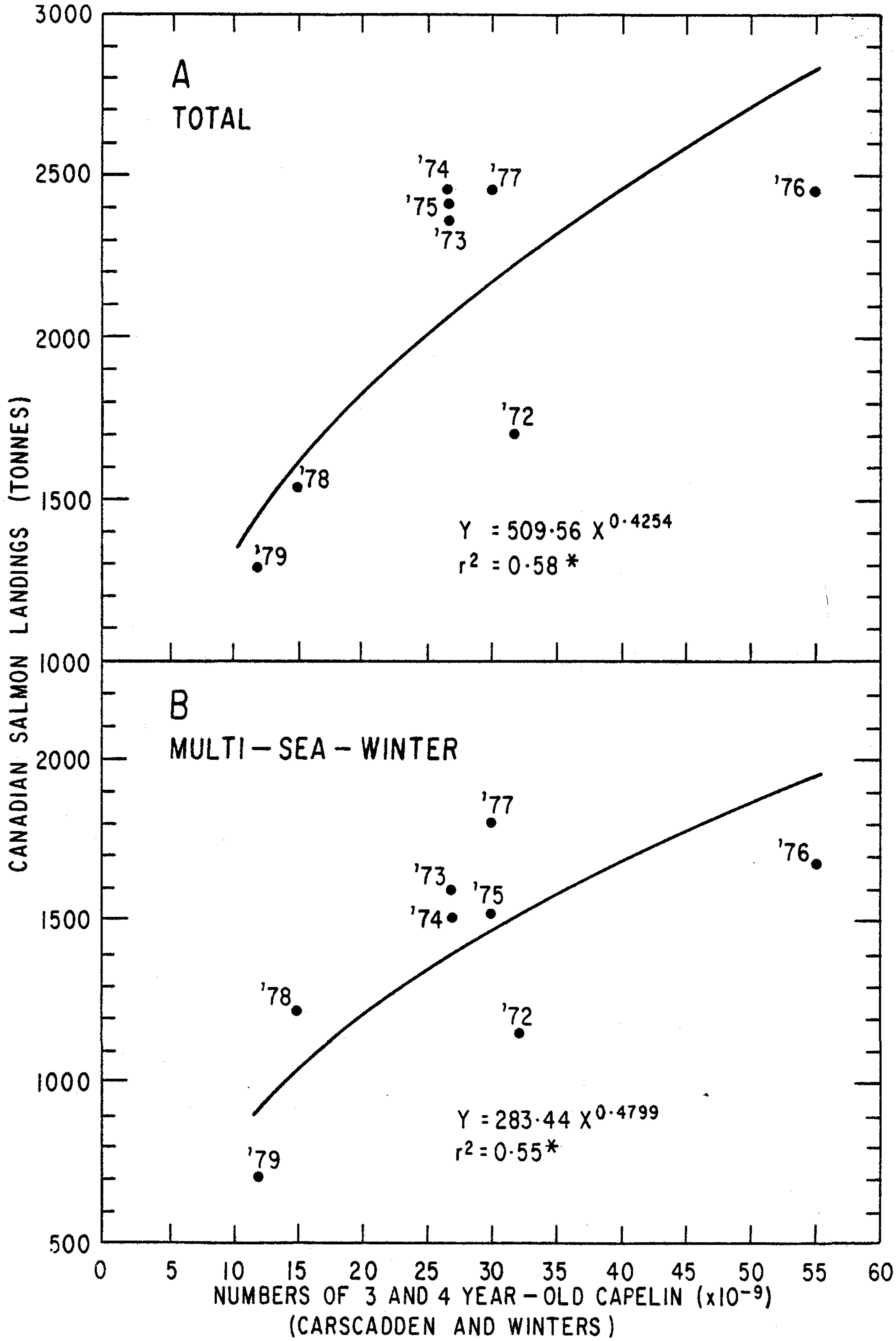

Fig. 17. Relationship between total (A) and multi-sea-winter (B) salmon landings and numbers 3- and 4-year-old-capelin.

(*Significant at 5%)