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On the Cod-capelin Interaction off Northeast Newfoundland and Labrador<sup>1</sup>

by

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INTRODUCTION

It is probable that cod (*Gadus morhua*) and capelin (*Mallotus villosus*) are the two most important fish species in the Northwest Atlantic, cod because of its position as the dominant commercial species (Pinhorn 1976) and capelin because of its importance as both a forage (Winters and Carscadden 1978, Bailey et al. 1977) and commercial species (Anon. 1980). It is well documented that cod feed heavily on capelin both offshore (Turuk 1968, Minet and Perodou 1978) and inshore during the capelin spawning migration (Templeman 1965). However, apart from the feeding data little is known of the degree of dependence of cod on capelin although it has been speculated upon in the public media for years. For instance, even as early as 1835 fishermen were complaining that the "hauling of capelin for manure had proved very prejudicial to the success of the cod fishery" (Journal of the Newfoundland House of Assembly 1835).

The question of the impact of capelin on cod dynamics and migrations might have remained unaddressed but for the initiation of a capelin fishery in 1972. At that time, catches of approximately 71,000 t were reported in NAFO (formerly ICNAF) Subarea 2 and 3. Catches rose rapidly and peaked at 360,000 t in 1976 and have declined since then. At about the same time, the Newfoundland-Labrador cod stock (2J3KL) had declined to its lowest levels. This combination of low abundance of a commercially important predator and a heavy fishery on a major food source has promoted scientific interest in

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cod-capelin interactions and the extent of dependence of cod on capelin.

The purposes of this study were to review the distributions of both species and the patterns of cod predation on the capelin, and to investigate the effects of fluctuations of capelin biomass on the dynamics of cod, especially cod growth, and on the inshore cod fishery. The relationships between cod growth and cod biomass, capelin biomass and water temperatures as well as the relationships between inshore catches of cod and cod biomass, capelin biomass and water temperatures were investigated. To study these cod-capelin interactions in detail, stocks of both species from northeastern Newfoundland and Labrador were chosen. Although the stocks (Div. 2J3KL cod stock and Div. 2J3K capelin stock) do not occupy exactly the same geographical area, they are reasonably well-defined and do overlap to a large degree. In addition, cod predation on capelin is known to occur in this area and the data on the fishery and population dynamics for both species were generally better than for other areas.

#### CAPELIN DISTRIBUTION

The distribution of juvenile and adult capelin (age 2 and older) is reasonably well known (Jangaard 1974, Hinds 1975; Templeman 1948); however, there are gaps in our knowledge. Hence, the distribution maps (Fig. 1) reflect the known distribution of capelin; the absence of capelin from an area on the maps does not mean that capelin do not occur there. This discussion of capelin distribution encompasses more than just the Div. 2J3K capelin stock. Cod from the Div. 2J3KL stock probably feed to some degree on Div. 3L and Div. 3NO capelin, 2 stocks which are believed to overwinter together on the northern Grand Banks. The time series of data for Div. 3L and Div. 3NO capelin was not as complete as that of Div. 2J3KL capelin and these data were not included in the following analysis. However, their distribution is discussed here because of the probable relationship with Div. 2J3KL cod.

The major overwintering area for capelin appears to be northern Newfoundland for the Div. 2J3K stock and the northern Grand Bank (for the Div. 3LNO stocks) although overwintering capelin also occur to a lesser extent on the southern Grand Banks, St. Pierre Bank and some inshore bays in Newfoundland. It is not known whether capelin overwinter in Subarea 2. However, capelin do spawn in Labrador (Templeman 1948) and since there is no evidence for a northward migration from 3K, it seems probable that there are capelin overwintering in areas north of Div. 3K.

During March, capelin are beginning to form schools and move towards their spawning grounds. In Div. 3L, 3K and probably 2J capelin move inshore during April and May and towards the Southeast Shoal (Div. 3N), the only known major offshore spawning area (Fig. 1).

By late May, most of the mature capelin are near the spawning grounds, either inshore or on the Southeast Shoal. Spawning begins on the beaches in late May or early June in southern Newfoundland and at about the same time on the Southeast Shoal. Spawning is progressively later further north; thus, spawning may not begin until late June or early July in northern Newfoundland and late July in Labrador. Capelin spawn on suitable beaches when water temperatures are 5.5°-8.5°C although spawning has been reported in water temperatures as high as 10°C. When water temperatures exceed 10°C, the capelin spawn away from the beaches in colder, deeper water. Spawning continues for a period of approximately 4-6 weeks in each area.

Post-spawning mortality in capelin is very high and the few survivors (mostly females) move offshore in small scattered schools. (Fig. 1). In early fall, these survivors and capelin maturing for the first time from feeding schools with the largest concentrations occurring in Div. 2J and 3K. Historically, there was a large commercial fishery at this time. The pattern of the commercial capelin fleet suggests that there is a gradual southward movement from Div. 2J to the overwintering area in Div. 3K during October to December and that the major concentrations of capelin are within the 200 m isobath.

#### CAPELIN FISHERY AND POPULATION TRENDS (NAFO DIV. 2J3K)

Nominal catches of capelin reported to ICNAF by Canada for Div. 2J3K were less than 1,500 mt in the late 1960's and early 1970's. However, it is known that historically capelin have been widely used on a domestic basis for food, fertilizer and bait and Templeman (1968) reported that total annual Newfoundland landings were once as high as 20-25,000 t. An offshore fishery developed in Div. 2J3K in 1972 with reported catches of 46,000 mt which rose to 216,000 mt in 1976 and declined to 11,000 mt in 1979 (Fig. 2). The offshore fishery was conducted by midwater trawls in September-December with peak catches usually in October and November.

There are two series of capelin biomass estimates available (Carscadden and Miller 1980, Carscadden and Winters 1980). The absolute biomass values differ quite markedly in the series; the patterns are similar in total biomass

but there is no correlation between biomass estimates of mature capelin. In terms of total capelin biomass, one series (Carscadden and Miller 1980) shows a peak in 1976 of 7,300,000 t and a decline to 780,000 t in 1979 (Table 1). The other series (Carscadden and Winters 1980) shows a peak in 1975 of 1,300,000 t (although the 1976 biomass of 1,250,000 t approaches this level) and a decline to 350,000 t in 1979 (Table 1). Although the difference in the capelin estimates have not been resolved, both analyses indicate that fishing mortalities have been relatively low; hence it appears that poor recruitment in recent years has been the major cause of the decline in capelin biomass. Wide variations in capelin recruitment are not unusual. For example, recruitment in Barents Sea capelin during 1951-61 fluctuated by a factor of 17 times (Gjosæter 1972).

#### COD DISTRIBUTION

During January-May cod in Div. 2J3KL are concentrated mainly on the outer slopes of the Labrador and northeast Newfoundland shelf from Harrison Bank to the north cape of the Grand Bank (Templeman 1979) (Fig. 1). By May in the southern areas, there is some movement to shallower water. Spawning concentrations are in depths from 200 to 600 m and possibly deeper and in bottom water temperatures about 2.5°-4°C. Off Labrador cod spawn mainly in March-April with most of the remainder spawning in May (Templeman 1964, 1965, 1967). Some of the cod from northern Labrador migrate southward during April-May to the southern Labrador coast and by June and July are appearing along the northeast coast of Newfoundland (Postolaky 1966). In general, however, during April and May the schools of cod are beginning to disperse and move over the tops of the banks and towards the coast.

The main coastward migration in June when the cod of the Labrador-East Newfoundland stock move southward and westward toward the Labrador and Newfoundland coast also coincides with the spawning migration of capelin to shallow water (Templeman 1979). These cod are homing to the general areas where they grew up as immature fish (Templeman 1979). The 2J3KL cod stock during June-July is distributed from northern Labrador, southwards along the Newfoundland coast in declining numbers as far as Cape Race and the Virgin Rocks and as far westwards as the entrance of the Strait of Belle Isle (Templeman 1974, 1979). It appears that the inshore migrations of cod are completed by August and the pattern of distribution is similar to that during June-July. Cod are also dispersed widely over the offshore and coastal banks during July and August.

During September cod are still in the inshore areas of Labrador and eastern Newfoundland but there may possibly be some offshore movement.

The main offshore migration occurs during October based on evidence from tagging data which indicated that the tagged fish, migrating out from the coast mostly did not reach the offshore fishing grounds before October (Templeman 1979). By November to December the cod are beginning to congregate on the outer slopes of the continental shelf in the warmer deeper water where they remain and spawn during the winter and spring.

#### COD FISHERY AND POPULATION TRENDS (NAFO DIV. 2J3KL)

Cod have been fished in Div. 2J3KL for hundreds of year mainly by vessels operating in coastal waters. Large numbers of cod migrate in the spring to shallow coastal waters where they are exploited by small vessels using a variety of gears including traps (= pound nets), gillnets, baited lines and handlines. At this time capelin are spawning on or near the beaches and cod feed heavily on them. In the winter and early spring, large spawning concentrations of cod are fished by the otter trawl fleet particularly on the Hamilton Inlet and Belle Isle Banks. In the 1960's catches were unrestricted and were as high as 800,000 t but declined to 160,000 t in 1979 (Fig. 2). During the late 1960's and early 1970's, the cod population declined due to mainly an extensive fishery but also a succession of poor (1969-72) year-classes (Wells and Bishop 1980). The biomass of cod of ages 4-13 in 1976 was about 0.55 million tons, about 1/5 of the biomass in the 1960's. By 1978 cod older than 7 years had declined to about 1/10 of their 1964 level.

#### COD PREDATION ON CAPELIN

Most information on the seasonal feeding behaviour of cod was obtained from Hamilton Inlet Bank in central 2J at the time of high cod stock biomass in the early to mid-1960's. During the January-May period when the cod were concentrated in the warm, deep water they were feeding at a low intensity on invertebrates, but as they moved into shallower water and toward shore in early summer they fed intensively on capelin. Predation on capelin remained high in early fall, but became less intense toward December as the cod returned to the warmer slope waters (Templeman 1965, Templeman and May 1965, Turuk 1968). The distinct seasonality in feeding and the presumed importance of capelin in

the annual cycle were supported by observation that the cod livers enlarged quickly in summer, remained large through the fall, and declined through winter and spring to a low in May-June (Turuk 1968).

The seasonal feeding pattern in 3K and 3L is basically similar to that in central 2J. A spring-summer period of intense predation by cod on capelin in inshore areas during the capelin spawning season is well known (Thompson 1943, Templeman 1965). In addition, there is predation on capelin at this time on the northern Grand Bank (Popova 1962, Turuk 1968, Stanek 1975, Minet and Perodou 1978) and on offshore banks in 3K, particularly in areas toward the coast (Popova 1962). However, unlike cod overwintering on the Hamilton Inlet Bank, cod to the south do feed on capelin in the winter, both on offshore banks in southern 2J and 3K (Stanek 1975, Minet and Perodou 1978) and on the north slope of the Grand Bank in 3L (Templeman 1965, Minet and Perodou 1978, Lilly and Fleming 1980). The extent of this winter feeding on capelin is poorly known.

The length range of cod which prey intensively on adult capelin is approximately 40-70 cm, the minimum length being 35 cm and the upper length being variable, possibly depending on the abundance and availability of the capelin (Popova 1962, Turuk 1968, Stanek 1975, Lilly and Fleming 1980). Cod as small as 20 cm prey on juvenile capelin (Powles 1958, Lilly and Fleming 1980).

Cod are presumed to prey primarily on adult capelin. However, there are reports of predation on 10-12 cm capelin (probably 2-year-olds) in northern 3L in March (Templeman 1965, Lilly and Fleming 1980) and on offshore banks of 3K and 3L in summer (Popova 1962, Lilly and Fleming 1980). There is also one report of cod feeding on 1-year-olds (7-10 cm) inshore in 3K in August (Templeman 1948).

Campbell and Winters (1973) estimated that capelin constitute 32% of the annual diet of cod in 2J3KLN0, and Minet and Perodou (1978) estimated that capelin constitute 28% of the diet in 2J3KL. Both estimates are based on small data sets with inadequate spatial and seasonal sampling.

#### COD GROWTH

One of the most dynamic characters of cod that might be affected by the change in food supply, is growth. However, growth may also be affected by the abundance of the predator, in this case, cod biomass, and by ambient water temperatures. Correlation analyses were conducted to determine if there was

any relationship between cod growth and capelin biomass, cod biomass and water temperature.

To provide annual mean lengths for ages 4-8, length frequencies from the inshore cod trap fishery of Div. 2J3KL, collected in July (mainly) and August, 1970-77, were applied to age-length keys of the inshore fishery. Estimates of growth for each of Div. 2J, 3K and 3L were calculated by subtracting individual cohort mean lengths from the succeeding year. The values were averaged to provide an index of annual growth for each area and for the Div. 2J3KL stock for 1970-78 (Table 1).

The average growth over the eight year series is 6.25 ( $\pm 48$ ) cm/year. There was no significant difference between mean growth indices of cod from Div. 2J, 3K and 3L. However, the annual growth indices were not correlated in all cases (Table 1). The growth indices of cod from Div. 2J and 3L were correlated, but the growth index of cod from Div. 3K was significantly different from the indices in both Div. 2J and Div. 3L. Thus although the mean growth over the time period considered was similar in all areas, the pattern of annual growth was different between areas. As a result, cod growth in relation to the other variables was examined using both separate (2J, 3K, 3L) and combined indices (2J3KL).

Since the growth index was indicative of cod growth ages 4-7, the total cod biomass for these age groups (Wells and Bishop 1980) was also used (Table 1). Both total and mature capelin biomass from the two series of estimates (Carscadden and Miller 1980, Carscadden and Winters 1980) were used (Table 1). The index of water temperature (TEMPSUM) was derived by summing the monthly water temperatures at 25 metre intervals, from surface to bottom, from July-June at Station 27 near St. John's (Table 1). The July-June period was considered to correspond to the period from which growth indices were derived.

Correlation analysis was conducted using all indices of cod growth and all other indices, singly, in pairs and all together. None of the relationships was statistically significant ( $P < 0.05$ ) (Table 1).

#### INSHORE COD FISHERY

There is persistent anecdotal evidence that the availability of cod to inshore gears, especially trap nets, is dependent on the appearance of capelin. The obviously heavy feeding on capelin by cod taken in inshore gears suggests

that the cod are following the capelin in a feeding migration.

Correlation analysis was conducted relating cod trap catches and total inshore cod landings to mature capelin biomass, cod biomass and water temperature. Only mature capelin biomass (both indices-Carscadden and Miller 1980, Carscadden and Winters 1980) was used since cod move inshore and feed on capelin during the capelin spawning migration (Table 2). Cod biomass for ages 4-7 (Table 2) was used when related to cod trap landings because this is the age range usually taken in traps. Cod biomass for ages 4-13 (Table 2) was used when the relationship between cod biomass and total inshore cod landings was examined. The index of water temperature was derived by summing the monthly water temperatures at 25 metre intervals, surface to bottom, from June to September at Station 27. This time period corresponds approximately to the inshore cod fishery.

Trap landings and total inshore landings were regressed against each other and were regressed separately against each of the 4 variables (Table 2) for the years 1972-79 inclusive. The trap catches were positively correlated with the total inshore catches ( $r = .83$ ;  $P < .02$ ). Neither trap catches nor total inshore catches were correlated with any of the other 4 variables. Temperature explained 49% of variance in total inshore catches, just below the level of significance. Multiple regression analyses yielded no significant correlations for trap or total inshore catches with combination of the other variables.

It was postulated that the changing availability of cod to the inshore fishery was a function of the capelin biomass and temperature. The index of availability of cod to the inshore fishery was calculated as follows: a) trap landings divided by the cod biomass of ages 4-7 and (b) total inshore landings divided by the cod biomass of ages 4-13. On average this fraction was .035 for traps and .050 for the total inshore fishery. The trap index and one mature capelin biomass (Carscadden and Winters 1980) index were positively correlated ( $r = 0.92$ ) (Fig. 3). There was no significant correlation between trap index and temperature or the other capelin index. There was a significant positive correlation between the total inshore cod fishery index of availability and one mature capelin biomass (Carscadden and Winters 1980) index ( $r = .81$ ) and the addition of temperature to the regression increased the  $r$  to 0.91 (Fig. 4).

#### DISCUSSION

Numerous studies of the food of cod in NAFO Div. 2J3KL have shown that at certain times and in certain areas cod feed on capelin. Estimates for the Newfoundland area in general suggest that capelin comprise about 30% of the cod's diet. Furthermore, capelin is the major prey of cod taken by the inshore trap fishery. Such information has resulted in the general hypothesis that cod are dependent upon capelin, and that a reduction in capelin stocks, such as might result from a fishery, will have a detrimental effect upon the cod and the inshore cod fishery. Since no studies have been directed specifically at these problems, a correlational approach has been adopted, using annual growth as an indicator of the cod's well-being and inshore catch as an indicator of the intensity of the cod's inshore migration. From this analysis, there was no correlation between cod growth and capelin abundance, cod abundance and water temperature. However, there was a positive correlation between cod trap availability index and mature capelin biomass as well as between total inshore cod fishery index availability and mature capelin biomass and temperature. Because of uncertainties in the data (discussed below) we suggest that these statistically significant relationships should be taken not as unequivocal proof that such relationships do exist in nature, but that they should be used in determining the direction of future experimental research.

This correlational approach is not ideal for there are many uncertainties in the available data: Differences in the estimates of capelin abundance remain unresolved; annual determinations of cod length-at-age were made during the feeding and growth period rather than at the end; the index of inshore migration is catch rather than some measure of catch per effort; and the mean temperatures at Station 27 may not faithfully reflect the temperature encountered by the cod, especially as they approach the shallow inshore areas. Even if more appropriate data were available and the real relationships are close, it is likely that the estimates of growth, biomass and extent of inshore migration will contain high observational variance, so that significant correlations could be determined only after many more years of observation than the present 8 (cf. Gulland 1965). Furthermore, the available data on cod growth relate to a period of reduced cod abundance. The importance of capelin may become more apparent as the cod stock recuperates.

The present analysis provides no useful evidence for testing the importance

of capelin to cod. Determination of the contribution of capelin to the cod's diet on an annual basis requires seasonal feeding information from the entire distribution of the cod stock. Since the acquisition of such information for a series of years may be prohibitively expensive, it may be considered sufficient to monitor the cod's somatic and gonadal growth at the end of each year, and to relate this to the abundance of capelin. However, the cod is known for its broad and variable food spectrum. It may therefore be necessary to determine the amount of feeding on other moderate-sized pelagic organisms, including Arctic cod, sand lance and squid, and to determine the extent to which reduced availability of the larger pelagic prey can be compensated for by predation on shrimp, crabs and plankton, especially hyperiid amphipods and euphausiids. These crustacea comprise a large portion of the cod's diet, and it is possible that their stocks may be sufficiently large to provide adequate forage during a short period of reduced capelin abundance. Without detailed annual information on the cod's food spectrum and the availability of various prey, it may be impossible to interpret any annual differences observed in the cod's growth, reproduction and mortality.

It is of interest to note that on the Flemish Cap a separate cod stock exists in the absence of capelin. There are only two species of abundance on Flemish Cap, cod and redfish. Changes in the availability of small redfish from recent large redfish year-classes has been tentatively identified as responsible for very large changes in the growth of Flemish Cap cod (Lilly 1980).

A lack of detailed data also hinders examination of the importance of capelin to the inshore cod fishery. Although cod and capelin tend to arrive in inshore waters at about the same time, suggesting that the cod may actively follow the capelin toward shore, there is also anecdotal evidence that either species may arrive inshore unaccompanied by the other, and that the arrival of the cod is also closely related to the warming of inshore waters. Elucidation of these relationships require a site-specific study of the inshore migration, in which the abundance and movement of both cod and capelin can be related to changes in hydrography.

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Table 1. Annual growth increments of cod caught by the inshore trap fishery, NAFO Div. 2J3KL, and associated capelin biomass, cod biomass and temperature, 1970-79.

Period	Cod growth increments (cm)				Capelin biomass ( $\times 10^{-3}$ m tons)				Cod biomass	July-June
	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_3$	$\bar{X}_4$	Mature		Total		ages 4-7 ( $\times 10^{-3}$ m tons)	TEMPSUM
					1	2	1	2		
	$\bar{X}_1$	$\bar{X}_2$	$\bar{X}_3$	$\bar{X}_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$
1970-71	-	7.4	4.6	6.0					1285	54.50
1971-72	5.0	3.1	5.8	4.6	1679	234	4261	720	1177	49.20
1972-73	6.7	4.0	5.9	5.5	2181	223	4581	837	900	-4.29
1973-74	5.4	6.7	4.5	5.5	1978	254	4591	913	650	27.61
1974-75	9.2	9.0	7.5	8.6	1904	362	6123	1336	399	-1.25
1975-76	5.5	6.8	5.9	6.1	2251	526	7310	1256	398	52.66
1976-77	10.9	5.8	7.6	8.1	3375	342	5641	781	751	42.92
1977-78	4.4	7.2	5.2	5.6	3405	218	3713	556	1006	39.13

Correlation Matrix for Periods 1971-72 to 1977-78

	$X_2$	$X_3$	$X_4$	$X_5$	$X_6$	$X_7$	$X_8$	$X_9$	$X_{10}$
$X_1$	.24	.89	.89	.24	.26	.41	.30	-.38	-.30
$X_2$		.21	.65	.19	.42	.41	.54	-.74	-.20
$X_3$			.84	.17	.38	.50	.37	-.32	-.20
$X_4$				.27	.44	.55	.52	-.64	-.30
$X_5$					-.05	-.15	-.49	.15	.29
$X_6$						.97	.76	-.79	.29
$X_7$							.85	-.84	.09
$X_8$								-.90	-.29

<sup>1</sup> Estimated biomass at January 1 of second year in cod growth period. Estimate 1 from Carscadden and Miller (1980); Estimate 2 from Carscadden and Winters (1980).

<sup>2</sup> Estimated biomass at January 1 of second year in cod growth period. Calculated from Table 7 and 10 of Wells and Bishop (1980).

Table 2. Cod landings by the trap and total inshore fishery (NAFO Div. 2J3KL), mature capelin biomass, cod biomass and temperature, 1972-79.

Year	Cod landings (tons $\times 10^{-3}$ )		Mature capelin biomass <sup>1</sup> ( $\times 10^{-3}$ m tons)		Cod biomass <sup>2</sup> ( $\times 10^{-3}$ m tons)		June- Sept.
	Trap	Total inshore	1	2	Ages 4-7	Ages 4-13	TEMPSUM
	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>
1972	32.5	62.1	1679	234	1177	1593	0.92
1973	16.7	41.6	2181	223	900	1304	1.13
1974	15.6	35.2	1978	254	650	1017	0.39
1975	15.7	41.2	1904	362	399	672	0.99
1976	26.5	59.9	2251	526	398	556	1.63
1977	33.8	72.6	3375	342	751	874	1.08
1978	37.4	81.5	3405	218	1006	1185	1.44
1979	25.5	84.6	548	209	1402	1573	1.61

Correlation Coefficients

Trap Landings

	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>7</sub>
X <sub>1</sub>	.46	-.05	.40	.44

Total Inshore Landings

	X <sub>3</sub>	X <sub>4</sub>	X <sub>6</sub>	X <sub>7</sub>
X <sub>1</sub>	.08	-.15	.35	.70

<sup>1</sup> Estimated biomass on January 1. Estimate 1 from Carscadden and Miller (1980), Estimate 2 from Carscadden and Winters (1980).

<sup>2</sup> Estimated biomass on January 1, from Wells and Bishop (1980).

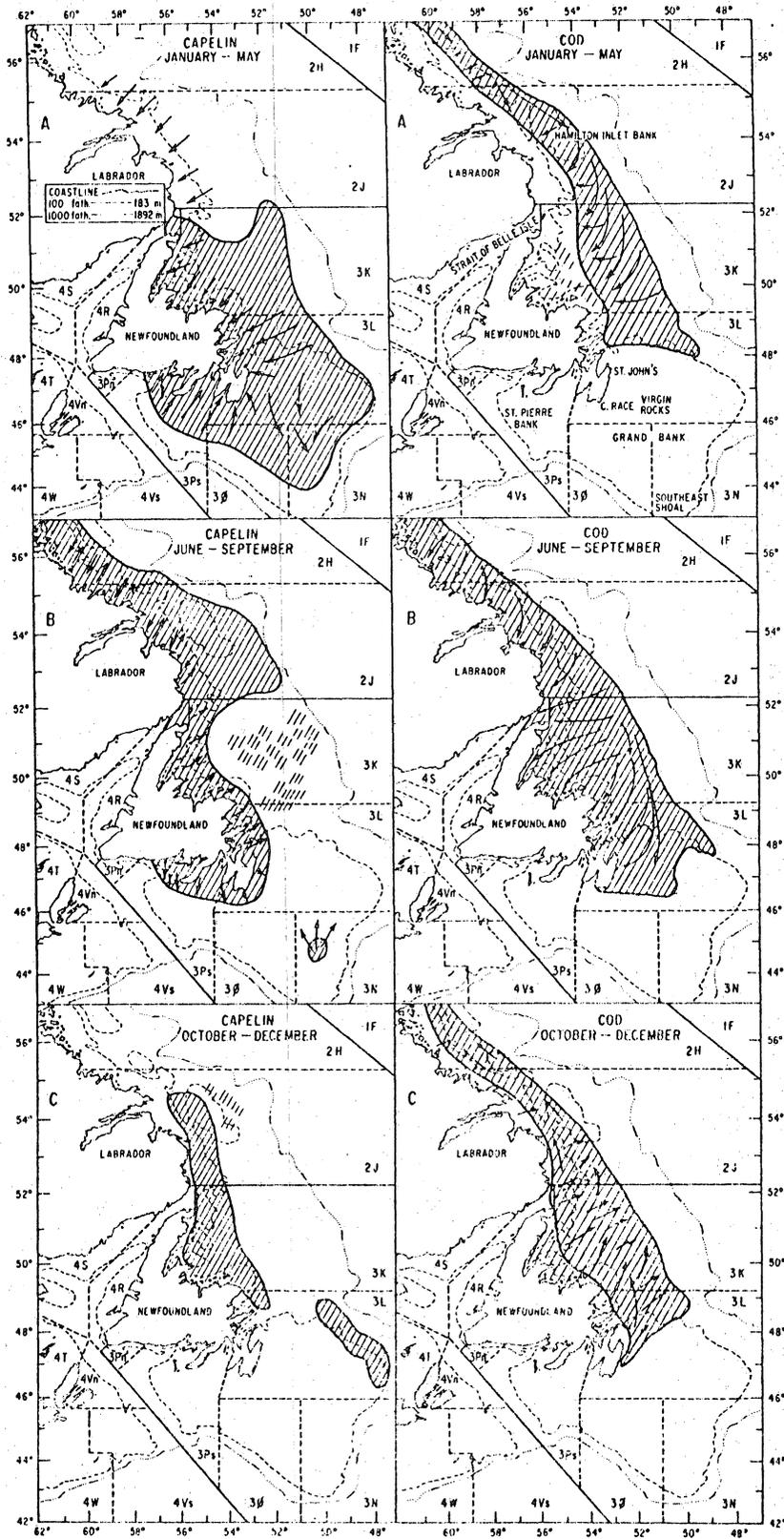


Fig. 1. General distribution of cod (Div. 2J3KL stock) and capelin (Div. 2J3K, 3L, 3NO, 3P stocks) for three periods of the year. A. January-May. B. June-September. C. October-December.

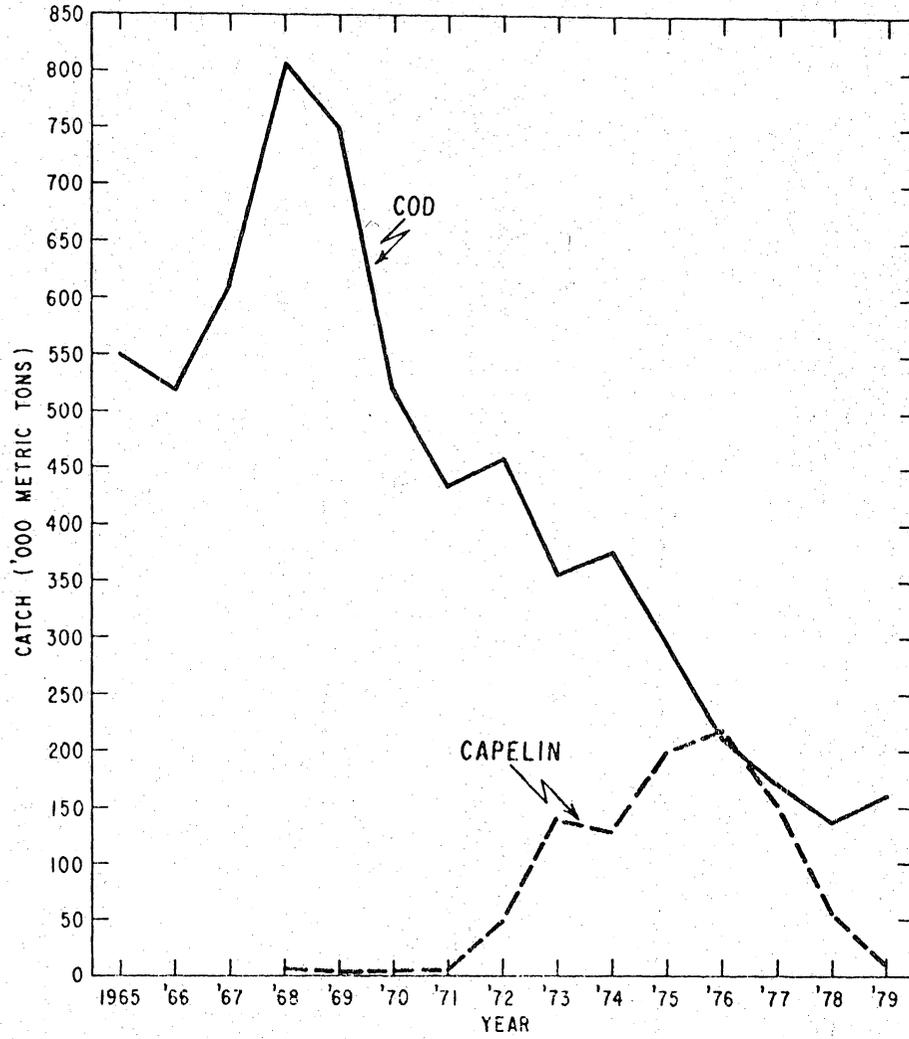


Fig. 2. Catches of Div. 2J3KL cod, 1965-1979, and Div. 2J3K capelin, 1968-1979.

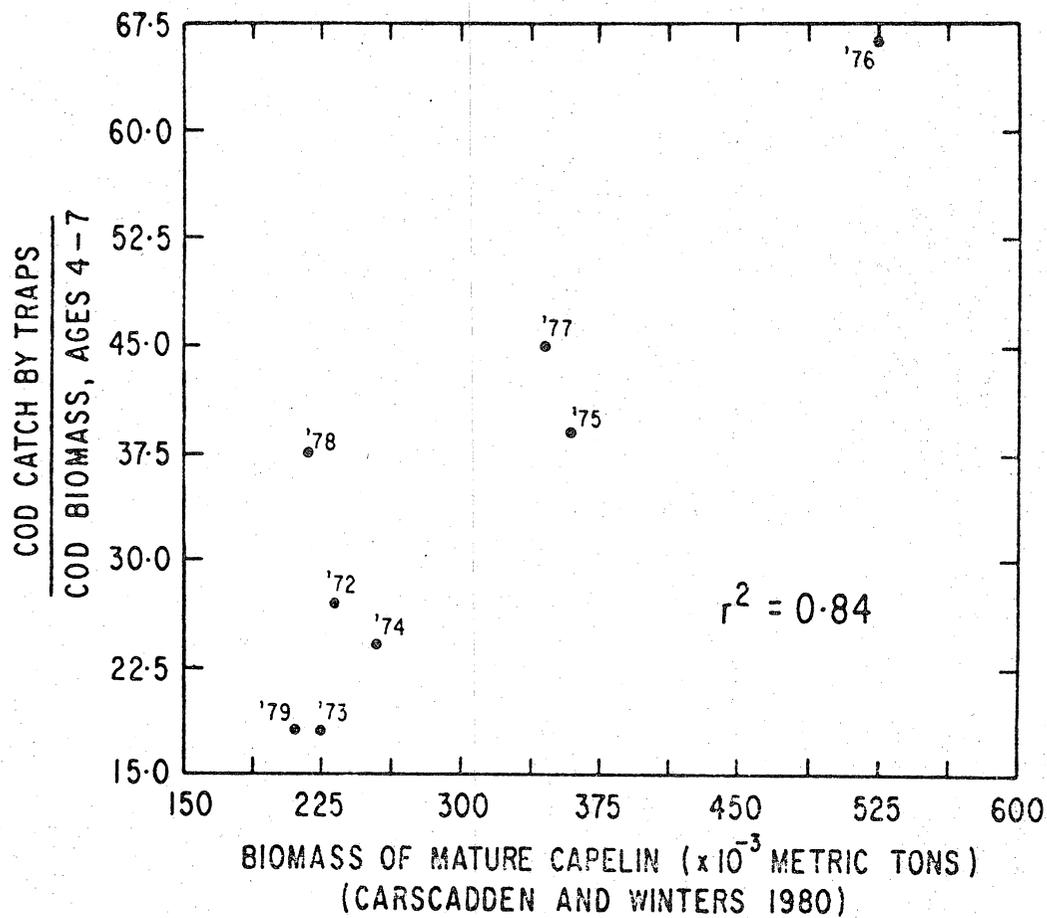


Fig. 3. Relationship between availability of cod to the trap fishery and biomass of mature capelin (Carscadden and Winters 1980), 1972-1979.

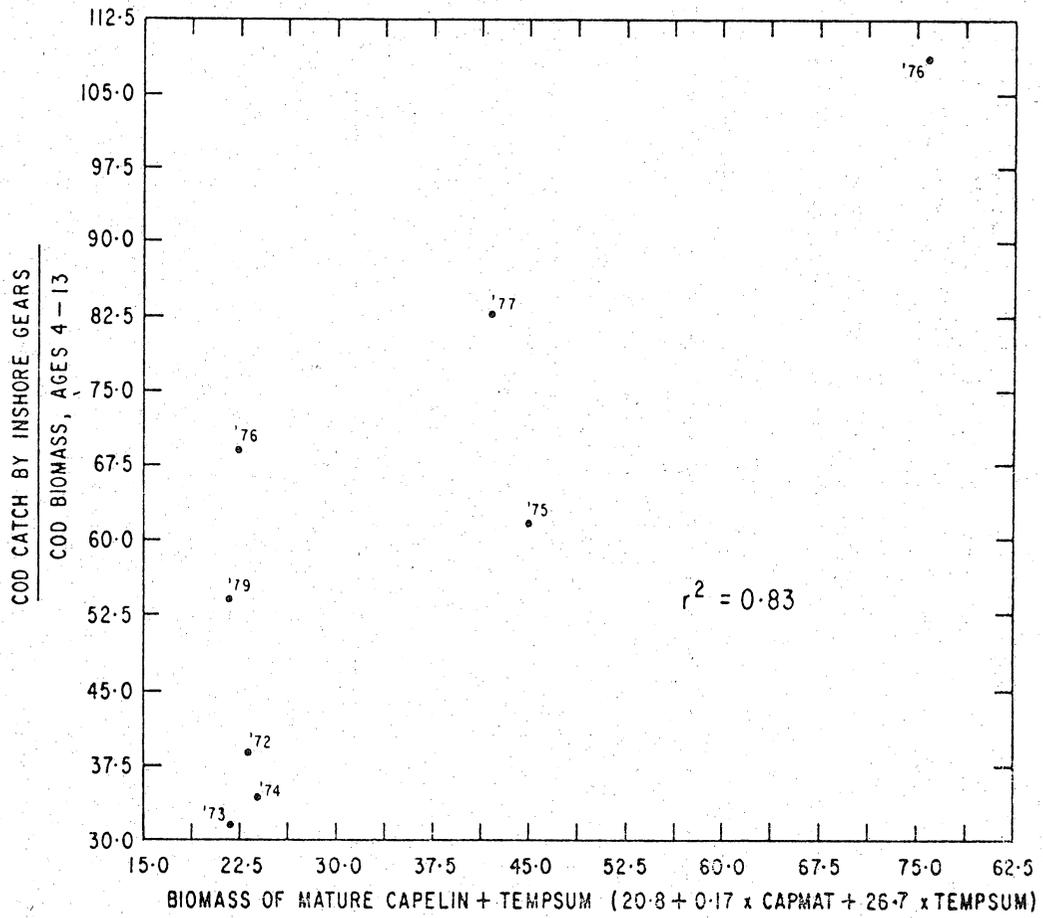


Fig. 4. Relationships between availability of cod to the inshore fishery and biomass of mature capelin (Carscadden and Winters 1980) and TEMPSUM, 1972-1979.