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An Examination of Factors Affecting Catch in the Inshore Cod Fishery of Labrador and Eastern Newfoundland

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August 1986

Canadian Technical Report of Fisheries and Aquatic Sciences No. 1469

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Technical Report of Fisheries and Aquatic Sciences

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Fisheries and Aquatic Sciences 1469

August 1986

AN EXAMINATION OF FACTORS AFFECTING CATCH IN THE INSHORE COD FISHERY OF LABRADOR AND EASTERN NEWFOUNDLAND

by

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This is the ninety-fifth Technical Report from

Fisheries Research Branch, St. John's, Newfoundland.

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Cat. No. Fs 97-6/1469E ISSN 0706-6457

Correct citation for this publication:

Lear, W. H., J. W. Baird, J. C. Rice, J. E. Carscadden, G. R. Lilly, and S. A. Akenhead. 1986. An examination of factors affecting catch in the inshore cod fishery of Labrador and eastern Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1469: iv + 71 p.

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Lear, W. H., J. W. Baird, J. C. Rice, J. E. Carscadden, G. R. Lilly, and S. A. Akenhead. 1986. An examination of factors affecting catch in the inshore cod fishery of Labrador and eastern Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1469: iv + 71 p.

The inshore cod fishery of Labrador and eastern Newfoundland (NAFO Div. 2J, 3K and 3L) has a long history of variability in landings and local abundance. During 1981 and 1985, the fishery was very poor and catches were only about 77,000 t, down from an average of about 98,000 t during 1980-84. The present study attempts to consolidate biological and hydrographic information during 1975-84 and uses principal component analysis to determine the interrelationships of these factors and their contribution to short- and long-term variability on the inshore fixed gear fisheries for cod. Several hypotheses to explain variability in the inshore fishery are discussed and recommendations are presented for future research and data collections toward the future testing of these hypotheses.

RÉSUMÉ

Lear, W. H., J. W. Baird, J. C. Rice, J. E. Carscadden, G. R. Lilly, and S. A. Akenhead. 1986. An examination of factors affecting catch in the inshore cod fishery of Labrador and eastern Newfoundland. Can. Tech. Rep. Fish. Aquat. Sci. 1469: iv + 71 p.

La variabilité des débarquements et des niveaux d'abondance locale de la pêche côtière de la morue du Labrador et de l'est de Terre-Neuve (Div. de l'OPANO 2J, 3K et 3L) est connue depuis longtemps. Les pêches de 1981 et de 1985 ont été très mauvaises, les prises ne s'élevant qu'à 77,000 t environ comparativement à la moyenne d'environ 98,000 t notée au cours de la période 1980-84. Les auteurs regroupent les renseignements biologiques et hydrographiques obtenus de 1975 à 1984 et font appel à l'analyse par composante principale pour déterminer la variabilité à long terme de la pêche côtière de la morue par engins fixes. Ils traitent de diverses hypothèses permettant d'expliquer la variabilité de cette pêche et font des recommandations portant sur les recherches à effectuer et les données à recueillir pour la vérification de ces hypothèses.

1. INTRODUCTION

The inshore cod fishery of Labrador and eastern Newfoundland (NAFO Div. 2J, 3K and 3L) (Fig. 1) has a long history of variability both in terms of annual landings and in local abundance. This problem has become acutely realized in recent years. The fishery was late in starting during 1985, mainly because pack ice on the Newfoundland east coast persisted until early July. Figures supplied by the Fisheries Statistics and Systems Branch indicate that the 1985 catch (about 77,700 t) was about 20% below that of 1984 and only slightly above that of 1981 (Table 1). The 77,000 t of cod landed in 1981 was considered to constitute a major failure of the inshore fishery.

As a result of the late start of the inshore cod fishery in 1985 and the low landings to the end of September, the Fishermen's Union declared the northeast coast inshore cod fishery to be a natural disaster.

The present authors were called upon to consolidate existing biological and hydrographic information pertaining to cod abundance and availability inshore. The aim of this report is to provide a Branch viewpoint on biological and oceanographic changes and their contribution to short- and long-term variability of inshore fixed gear fisheries for cod.

A reassessment of the 2J3KL cod stock complex was outside the mandate of this working group. The working group adopted as its working hypothesis that the present status of the 2J3KL cod stock is reflected in an estimated average 4+ biomass of 1,250,000 t during 1984 based on a fishing mortality rate of 0.23 (Baird and Bishop 1985; Anonymous 1985). Since an estimated biomass of about 1,000,000 t during 1982 yielded an inshore catch of about 115,000 t in the same year, then it is reasonable to assume that an estimated biomass of about 1,250,000 t should have been sufficient to sustain a successful inshore cod fishery during 1985 and in the case of failure other possible causes need to be investigated.

2. THE INSHORE FISHERY - DEFINITION AND STATISTICS

The nearshore fishery off eastern Newfoundland and Labrador operates in two distinct depth ranges: shallow water warmed by the sun each spring and deep water which is relatively warm all year. The intermediate cold (<-0.5°C) water of the Labrador Current does not support a fishery (Templeman and Fleming 1956; Templeman 1966). The fishery in shallow water is prosecuted with traps (poundnets), gillnets, hook and line (jiggers, handlines, longlines), and small otter trawls. The deep water fishery was originally prosecuted primarily with longlines but more recently almost entirely by gillnets.

The inshore fishery is defined statistically as that involving fixed gear operated by vessels less than 65 feet in length. This results in the unfortunate circumstance that cod caught 50 km NE of Cape Bonavista in greater than 300 m are included in the inshore fishery, whereas cod caught by small otter trawlers less than 5 km from land in less than 50 m off the southern Avalon are not included.

The manner in which statistics are collected presents three problems which hinder examination of factors affecting the success of the fishery.

1) There is no information on effort.

2) The lack of depth records for gillnets means that shallow-water and deep-water gillnets cannot be distinguished, so the success of gillnet fisheries shoreward and seaward of the core of the Labrador Current cannot be independently assessed. These fisheries will likely be affected by different factors, and some factors might influence the two fisheries in opposite ways.

3) The absence of otter-trawl catches in inshore statistics results in the recorded catch being less than the actual catch, and lowers one's perception of availability of cod in inshore waters.

3. POSSIBLE CAUSES OF VARIABILITY IN INSHORE CATCH

Factors which may affect total catch may be grouped into three broad categories: availability of fish, catchability of fish, and fishing effort.

3.1. Availability of fish

The quantity of fish available to inshore gears is clearly a function of the quantity of fish of the appropriate size- and age-group present in the ocean.

- The quantity of fish present in the 2J3KL stock on January 1 of each year is a function of recruitment, growth and mortality in previous years, and has been estimated for the period 1962-84 by Baird and Bishop (1985).

- The quantity of fish potentially available to the inshore fishery is that present on January 1 minus that taken "offshore" in winter, spring and summer (see Section 6).

  - Annual variation in the total offshore catch might cause variability in the quantity potentially available to the total inshore fishery (see Section 6).

  - Geographic variation in offshore catch might cause regional variability in quantity potentially available in a given year. In addition, the pattern of offshore fishing could vary among years, causing among-year variability in the regional pattern (see Section 10).

The proportion of fish migrating inshore may vary annually.

- The proportion migrating to shallow inshore water may vary with the temperature or thickness of the core of the Labrador Current. The proportion should increase with increasing temperature and decreasing thickness of the cold layer (see Section 8).

- The proportion migrating inshore may vary with prey availability and distribution.
    - The proportion moving inshore and remaining inshore may increase with an increase in the quantity of mature capelin moving inshore to spawn (see Section 8.2).
    - The proportion moving inshore may decrease with an increase in the quantity of immature capelin (2-year-olds may be the most important component) (see Section 8.2).
    - The proportion remaining inshore in summer and autumn may increase with the abundance of prey other than capelin (e.g. squid).
- Spawning. If spawning is delayed (by cold water offshore, for example), then the tendency to feed may be less. Cod may not make contact with the migrating capelin and therefore remain offshore (see Section 11).

The distribution of fish inshore may vary geographically.

- Water column structure might vary, so that the proportion moving toward the heads of bays varies, or the proportions on eastern and western sides of bays vary.
- Migration routes may vary between years (e.g. in response to annual variability in ice cover).
- Availability of prey (e.g. capelin, squid) may vary geographically within and among years.

3.2. Catchability of fish

The depth at which fish occur and the degree to which they are concentrated may affect catch rates.

- The vertical distribution of fish may depend on the thickness and depth of the zone of suitable temperature (see Templeman 1966).

  This will depend on:

  wind direction
  wind strength
  air temperature
  sunlight
  current direction and strength.

- Vertical distribution might vary with light intensity, which varies with:

  cloud cover
  fog.

The availability of prey may affect the tendency of fish to take baited hooks.

The presence of "slub" may make fixed gear more visible to fish or cause the gear to behave in such a fashion that fish are less likely to be caught (see Section 12).

3.3. Fishing effort

Fishing effort will vary with many factors, including:

catch rates
price
markets for fish.

- Plants may refuse to buy fish or may take less than fishermen can provide because:
    - Processing capacity of plants is exceeded (cod "glut").
    - Plants are processing other species (e.g. capelin).
    - Plants have poor markets.
- In some areas fishermen cannot sell fish because there is no plant or collector boat.
- Availability of vessels for "direct sales" is highly variable in space and time within a year, and has increased in recent years.

There may be changes in technology, such as introduction of synthetic gillnets, automatic baiters, fish finders and inshore draggers.

There may be saturation of fishing locations.

- Total effort can ultimately be limited by available space.
- Best fishing locations are taken first, so catch/effort should decline with increasing effort independently of fish availability and catchability.

Competition with fisheries for other species may occur (e.g. capelin, squid).

Unfavourable environmental conditions may exist, such as:

wind
high seas
ice cover
icebergs
"slub"
interference by marine mammals and sharks
unfavourable drying weather for salt fish.

Materials may be unavailable, for example:

fishing gear (loss or damage by storms, ice, etc.)
bait
salt.

Fish may not be marketable:

minimum size limit is variable;
flesh may have unpleasant odour (e.g. "blackberry");
parasites (codworm).

Fishermen may refuse to catch and sell fish (strike).

Social programs may interfere with fishing activity. (Some fishermen may stop fishing in autumn when catch rates decline to keep benefits from Unemployment Insurance Program from declining. This is not true at present since U.I.C. benefits are based on best weeks fishing rather than most recent.)

Gear competition may exist. Catch by a given gear is affected when:

fishermen switch to a different gear;
different fishermen deploy different gears in same area. (There are often interactions between mobile gear and fixed gear.)

Only a few of the above factors will be examined or discussed in more detail in this report. This does not mean that the other factors are considered unimportant.

4. HISTORICAL PERSPECTIVE

Historical catches of cod from the inshore fishery of Newfoundland-Labrador during the past 100 years have been highly variable. Catches by selected decades were obtained on an annual basis from export figures and from Fisheries Reports in the Journals of the House of Assembly. The estimates of Labrador and insular Newfoundland are based upon reports by Gosling (1910), Browne (1909), Hatton and Harvey (1883), Packard (1891) and Prowse (1895). Conversions to round weight were made using conversion factors presented in NAFO SCS Doc. 80/VI/6. The estimates are intended only to give a general impression of the variability of the inshore cod fishery in NAFO Div. 2J, 3K and 3L. Within a decade (e.g. 1910-19), the range of annual catch is about 100,000 t (Fig. 2). Similar ranges are exhibited in other decades with the exception of 1960-69 when catches were smaller and the range decreased (Table 1) although the proportional change remains about the same. The decade of 1910-19 has been singled out to illustrate the annual variability in inshore catch for the following reasons:

1) 1917 was a year of record catch (estimated at 336,000 t) in inshore 2G, 2H, 2J, 3K and 3L.

2) There was no offshore cod fishery north of the Grand Bank.

3) No commercial fishery for capelin existed.

4) The gears employed were passive, for example, cod trap, line trawl, gillnet, handline and jigger.

5) There were no regulatory constraints on effort or catch.

The catches in the 1910-19 decade varied from a low of 179,000 t in 1915 to a high of 336,000 t in 1917. In most years there was a fishery failure along some section of the coast. In Labrador, in 1910, the fishery started in May (the earliest on record up to then) but was the worst fishery on record. In 1911, the Labrador catch was below average but above the 1910 catch. The fishery from Cape Race to Lamaline was a blank from June to October 1, but fish were plentiful from October to November. In 1912, there was a good fishery overall. In 1913, the cod trap fishery was a failure in northern and eastern Newfoundland while from Cape St. Francis to the southeast side of St. Mary's Bay the cod trap fishery was fairly good.

In 1914, the cod trap fishery was almost a complete failure in Notre Dame and White bays while the fishery in Labrador was excellent. The catch in 1915 was fair although it was generally good in Labrador. The fishery in 1916 was good for cod traps in eastern Newfoundland as far north as Fogo but from Fogo north the trap fishery was considerably below average. The year 1917 was a banner year with an excellent catch all around except that the cod didn't migrate into the deep-water bays. The fish were obtained only at headlands and in the outer portions of the coast. In spite of the lack of migration into the bays, this was one of the best all around catches that Newfoundland ever recorded up to 1917.

In 1918, an excellent overall catch was obtained but the catch from Bonavista Bay to White Bay was below average. In 1919, the cod trap fishery from Cape Race to Bonavista was below average while that in Conception Bay was exceptionally poor. The fishery in Labrador was successful.

What was true of the decade 1910-19 was equally true for other decades, emphasizing the great variability in abundance and/or availability of cod to the inshore fisheries of 2J, 3K and 3L.

5. TOTAL INSHORE AND OFFSHORE LANDINGS BY DIVISION (1962-84)

Offshore landings from NAFO Div. 2J, 3K and 3L reached a peak of 706,435 t in 1968 and declined steadily thereafter to a low of 57,104 t in 1978

(Table 1). The 2J3KL stock came under quota control in 1973 but for the years 1973-76, the TAC was never caught. Only during 1977-78 did the catch match the ever declining TAC's which reached their lowest level at 135,000 t in 1978. The decreased TAC's and catches were mainly due to a stock depleted by an excessive level of exploitation during the 1960's. The stock of 4+ cod is estimated to have reached a low of 300,000 t in 1976 (Fig. 3). Since then the stock has increased and has been about 1,000,000 t since 1982.

Inshore catches of cod reached a low of 35,181 t in 1974 and increased steadily to 96,523 t in 1980 (Table 1). The fishery of 1981 resulted in a low catch of 77,187 t but increased dramatically to 115,621 t during 1982 and was somewhat lower during 1983 and 1984 at 106,124 and 96,773 t, respectively. The 1985 catch was about 77,700 t, somewhat above the 1981 catch.

6. RELATIONSHIP BETWEEN INSHORE CATCH AND AVAILABLE BIOMASS

The quantity of fish potentially available to the inshore fishery in a given year is the quantity present on January 1 minus that taken offshore prior to the start of the inshore fishery. (Growth, natural mortality, and offshore catches later in the spring and summer are ignored in this simplified analysis. A more detailed approach adopted by Pinhorn (1984) for a shorter time period revealed trends similar to those reported below.) The January 1 4+ biomass declined from a peak in 1962 to a minimum in 1976 and subsequently increased (Table 2). The offshore winter (January-April) catches generally increased from a moderate level in 1962 to a peak in 1969, declined to a minimum in 1978, and subsequently increased (Table 2).

6.1. Relationship between inshore catch and biomass following the winter fishery

Between 1962 and 1974, there was a general decline in inshore catch as available biomass declined (Fig. 4). The inshore fishery took 4.8-7.1% of the available biomass (Fig. 5). Inshore catches improved from 1974 to 1977, despite the continuing decline in available biomass. That is, the proportion taken inshore increased dramatically (Fig. 5). Since 1977, there has been a gradual increase in catches but also great variability, most notably a decline in 1981, a recovery in 1982, and a subsequent decline in 1983 and 1984. The inshore catch expressed as a proportion of available biomass has declined since 1977, the most notable changes since 1978 being the "failure" in 1981 and the good catch of 1982.

As noted by Pinhorn (1984) and implied in Section 3, the proportion of available biomass taken inshore is the product of the proportion migrating inshore and the proportion of those inshore actually caught in the inshore fishery. The latter is influenced by both effort and catchability. Without information on effort, an interpretation of the relationships in Fig. 4 and 5 will be difficult. Nevertheless, the changing long-term patterns in the relationship between inshore catch and available biomass must be explained if we hope to investigate the influence of other factors, such as temperature and capelin abundance.

6.2. Influence of offshore catch on inshore catch

It is clear from the pattern of tag returns that the groups of cod fished offshore in winter and spring contribute to the inshore fishery in late spring, summer and autumn (see Section 10). Thus, the intensity of offshore fishing in a given year will affect the quantity of fish potentially available to the inshore fishery later in the same year. This expected relationship was examined by plotting total inshore catch against offshore catch in the period January-April of the same year, both variables expressed as a percentage of 4+ population biomass at the beginning of the year (Fig. 6).

During the period 1962-74, the proportion of the January 1 biomass taken offshore increased from about 5% to about 28%, while the proportion taken inshore declined from about 6.5% to about 4%. After 1974, there was a dramatic increase in the proportion taken inshore while the proportion taken offshore declined slowly at first and then very rapidly. Since 1978, the proportion taken offshore has remained low and relatively constant, while the proportion taken inshore has steadily declined (with the exception of the good catch in 1982).

We conclude that the dramatic changes in January 1 4+ biomass (Table 2) and the changing patterns in the proportion of "May 1 biomass" caught inshore (Fig. 5) make it very difficult to determine the extent to which offshore catches affect inshore catches in the same year. In other words, we cannot determine what proportion of fish caught offshore in winter-spring might otherwise be caught inshore in that year had there been no offshore fishery to remove these fish from the stock.

7. LANDINGS BY GEAR AND AREA (1975-84)

The catches by cod trap from Areas A to G and O (see Fig. 7 for areas) increased from 15,709 t in 1975 to 39,944 t during 1978 but dropped to 26,834 t in 1979, increased to 34,281 t in 1980, decreased to 20,861 t in 1981 (a disastrous year for cod traps) and more than doubled to 48,170 t in 1982. During 1983 and 1984, cod trap catches were about 40,000 t annually. The cod trap catches were particularly low in all areas except Labrador during 1981 (Table 3).

Catches by gillnets increased steadily from 20,045 t in 1975 to 40,370 t in 1980 with a decrease to 34,534 t in 1981 and a large catch of 51,903 t in 1982 and declining catches during 1983 and 1984 (Table 4). Catches by longlines increased during 1975-81 and have decreased since from 20,561 t in 1981 to 5845 t in 1984 (Table 5).

Catches by handlines increased from 5060 t in 1975 to 15,435 t in 1979 and have fluctuated between 9395 t and 22,466 t since then (Table 6).

The actual success of the inshore fishery in terms of catch per unit effort by gear type could not be measured as data on units of gear fished are not collected. The assumption that effort is equal over all years is probably highly violated in view of the changing patterns of gear used within the cod fishery and shifts among fisheries for other species, such as capelin, squid, herring and mackerel.

8. TEMPERATURE AND CAPELIN ABUNDANCE

The inshore migration of cod in late June and July is undoubtedly a feeding migration tuned to take advantage of the concentration of mature capelin in a narrow band near the coast. To reach the shallow inshore waters warmed in spring by the sun, the cod must pass the cold intermediate layer of the Labrador Current, either by breaking through the cold water some distance offshore and migrating shoreward in the surface layers or by migrating along the bottom through the cold water, possibly for many kilometers. It is not known whether cod actively follow capelin schools toward shore or simply follow a migration instinct which brings them to the coast at the appropriate time.

The following evidence has been presented in support of the hypothesis that cod actively pursue capelin schools in the surface layer (Templeman 1951; Templeman and Fleming 1956, 1962):

1) If the cod moved shoreward along the bottom, they would have to pass through very cold water (as cold as -1.5 or -1.6°C) for many kilometers, and at these temperatures cod would be expected to die. In contrast, it is only a short vertical distance through the cold layer to the warmer surface layer.

2) Few or no cod are caught, either by baited hook or otter trawl, in sets at temperatures of -1.0°C.

3) Cod tagged on the northwestern edge of the Grand Bank on June 4-5, 1948, were recaptured just a few weeks later on the western side of the Avalon Peninsula during the capelin spawning period. These cod approached shore so quickly that they probably followed the pelagic capelin.

4) The earliest large catches in parts of the St. John's area, such as Cape Broyle, are in May from baited longlines suspended at a depth of 10-20 fathoms (18-37 m) over deep water.

5) The cod, when they come shoreward in June, follow the capelin to very shallow water.

8.1. The Labrador Current as a barrier

There is as yet no direct evidence that the bulk of the cod migrating inshore do so in the surface layer but, whatever the route, the cold intermediate layer of the Labrador Current must be passed. The thickness of this intermediate layer and the minimum temperature in the core vary annually (see, for example, Templeman 1975). It is postulated that the proportion of the cod moving across the barrier decreases as the thickness of the core increases or the temperature decreases. Thickness and minimum temperature are probably highly correlated (see Templeman 1975, Fig. 2, 3).

Thickness of the core may be defined as the distance from the upper to the lower isotherms of a temperature thought to be important as a barrier to cod movement (for example, -0.5 or -1.0°C). Thickness could be measured only at sites in deep water near shore, such as Station 45 on the Cape Bonavista line. However, the only long-term data available for June is from Station 27 off St. John's, where only the upper isotherm is available because of the shallowness of the water. During the period 1975-84, the position of the -1.0°C isotherm changed irregularly over time within years, and was considered an unreliable index of the depth of the cold layer. We therefore chose core temperature as an index of the strength of the barrier. The coldest water at standard depths at Station 27 in the summer is usually at 100 m or 125 m (Templeman 1975). The index chosen was the average temperature from 100 m to 150 m in June and July (Table 7).

It should be noted that if cold water reduces the proportion of cod migrating to shallow water, there may be a tendency for more fish to accumulate on the seaward side of the cold core. Thus, cold water might result in reduced catch rates in shallow water but increased catch rates in deep water. As noted earlier (Section 2), the deep-water and shallow-water gillnet catches cannot be separated, so hypotheses regarding the effect of core temperature on gillnet catches and total catches cannot be addressed adequately.

8.2. Influence of capelin abundance

There is as yet no direct evidence that cod literally pursue capelin schools from offshore to inshore. If they do, then the proportion of the cod stock migrating inshore should increase with the abundance of mature capelin. Even if the inshore cod migration is cued by factors other than the sight of capelin, the tendency for cod to remain inshore once they have arrived might increase with increasing abundance of mature capelin.

However, cod in offshore areas in spring feed on immature capelin as well as mature capelin (Fig. 8). If cod literally follow capelin, then a high abundance of immatures, which do not migrate inshore, might tend to decrease the inshore migration of cod. If the cod inshore migration is innate and cued by factors other than the sight of capelin, the tendency to respond to the cues might be reduced if the cod are already feeding well on immature capelin.

It is therefore postulated that inshore catch is positively correlated with abundance of mature capelin and negatively correlated with the abundance of immature capelin.

We cannot at present assess the possibility of annual variation in the proportion of immature to mature capelin in the diet of offshore cod just prior to the time of inshore migration. The intensity of sampling of cod stomachs during spring groundfish surveys was low in 1978-82, surveys were not conducted in 1983-84 and stomachs collected in 1985 have not been examined.

8.3. Indices of abundance of capelin by year-class

Data were available from two capelin stocks, Div. 2J3K and Div. 3L. Only data from the Div. 2J3K capelin stock were considered because these data are much more extensive than those from Div. 3L. Furthermore, there seems to be parallelism in year-class strengths of capelin (although this has not been clearly documented). Thus trends in indices of abundance in one stock should reflect trends in another stock.

Indices of abundance for the Div. 2J3K capelin stock could be derived from four data sources: catch per unit effort of the USSR commercial fishery 1972-84, sequential capelin abundance models (SCAM) 1971-79, Soviet acoustic surveys 1973-84, and Canadian acoustic surveys 1981-84. There are problems with all of the data sources including shortness of the time series (for SCAM and Canadian acoustic surveys), inability to precisely estimate age compositions from the published material (for Soviet acoustic surveys), missing data in the series (Soviet acoustic surveys, Canadian acoustic surveys), and concerns about the comparability of recent data to historical data (CPUE data from USSR fleet (Carscadden et al. 1985). Indices of abundance by age group were calculated for each data series by standardizing to the highest value in each series. Trends in abundance were compared for all series and although no statistical tests were performed it was obvious that with few exceptions trends in abundance were similar in all data series.

Two catch rate at age series were originally used in this analysis; that series derived from the catch per unit effort data (Table 4, Carscadden et al. 1985) and that derived from Soviet acoustic surveys. There are doubts about the reliability of the data from both series. As discussed in Carscadden et al. (1985), the changes in the offshore fishery may be affecting catch per unit effort estimates which are used to derive the catch at age indices. There has been a substantial decline in catches and a change in geographical distribution of this fishery in recent years and this change must raise some concern as to the comparability of catch/effort data before and after 1979. For instance, STACFIS (Anon. 1981) decided that the catch rate in 1980 was not a reliable indicator of stock abundance because the fishery was concentrated in a small area with fewer vessels for a shorter time period and was able to sustain a relatively high catch rate.

In the case of the Soviet survey series, numbers at age were derived from estimates of abundance and age composition data as contained in Soviet ICNAF and NAFO Research Documents. In some cases, precise age composition data were not provided in tabular form and estimates had to be read from crude histograms. In other cases, age composition data were not available in the original document but were available in summary tables in documents in recent years. In years when data were available in both the original document and the summary table, the age composition did not agree, thus raising questions about which data were correct.

It was decided that the catch per unit effort series was more reliable, with the exception of the 1980 datum. The 1980 point for 2-year-old capelin was calculated by regressing the CPUE data for 1975-79 and 1981-84 on the USSR survey data, and estimating the value for 1980 from this regression. The regression was highly significant ($F = 38.76$, df = 1,7; $P = 0.0004$; $r^2 = 0.85$). The catch per unit effort data series from the Soviet commercial fishery was finally chosen as an index of abundance for this analysis (Table 7).

The index for age 3 capelin was not taken directly from the catch per unit effort data, because the proportion of age 3 capelin suffering spawning mortality prior to the fishery might vary among years. Therefore, the index of abundance of age 2 capelin in year t was used for the index of abundance of age 3 capelin in year t + 1.

9. PRINCIPAL COMPONENT ANALYSIS OF THE INSHORE FISHERY AND THE ENVIRONMENT, 1975-84

9.1. Introduction

Total effort in the inshore fishery has varied over the past decade, and the distribution of effort among the various gears has also varied. Without doubt, some of the variation in landings of the inshore fishery reflects this variation in amount and type of effort. However, we lack any useful data on inshore effort, so we cannot extract any of the variance in catch attributable to variation in effort. Moreover, some of the variation in amount and type of fishing effort is, without doubt, amplified as a consequence of variation in fish available inshore. Hence, variation in landings which might be attributed to variation in effort in a standard regression analysis, might actually be variation in stock, which is simply mirrored by variation in effort.

This discussion of a possible relationship between inshore landings to inshore effort highlights a problem with the fishery and environmental data that are available. The data on landings by gear may show relationships with a variety of environmental attributes, but the environmental attributes are likely to be interrelated among themselves. For example, if water temperatures affect inshore capelin abundance and cod movements inshore are blocked by temperature and capelin abundance, regressing cod landings on either temperature or capelin alone will be misleading. For that reason, we have used principal components analysis (PCA) to extract patterns of interrelationships among landings for various areas, and among landings and attributes of the environment.

Principal components analysis has the desirable attribute of simply identifying interrelations among a series of variables, rather than attributing variation in one variable to one or another of several intercorrelated "independent" variables. The individual component loadings have many similarities with correlations, and their squared values can be interpreted as the amount of variance in the attribute (area landing or environmental variable) accounted for by the component. This variance-explanatory property of the component structure is useful.

PCA is not without drawbacks, however. Like standard regression techniques, it picks out only linear relationships among variables. Also, if there are no strong patterns in the data, PCA is prone to treat the occasional "outlier" or odd point as evidence of an important trend. For that reason, it is desirable to have substantially more cases than variables to insure that extracted factors reflect true trends. We do not have many more years of data than variables we want to relate. Hence, the PCA results can be used only to suggest promising lines of further research. Lacking many more years of data, the PCA results cannot be considered conclusive evidence of any interdependencies of the inshore fishery and various characteristics of the environment. We do analyze landings for three different gears, however, and when PCA results coincide for different gears, our confidence in the validity of the pattern is enhanced.

9.2. What patterns exist among areas?

Landings for each of the three inshore gears (longlines and handlines were combined) were tabulated for the period 1975-84, by Statistical Areas A to G, and the Labrador fishery (Area O) (Tables 3-6). Each of the three data sets (one for each gear) was examined by PCA with rigid quartimax rotation.

9.2.1. Trap fishery

The data contains significant interrelationships among areas across years (Bartlett's test Chi-square = 57.77, df = 28, $P < 0.001$). Three distinct regions emerge from the PCA results: a general east and northeast coast fishery (Areas B to F), the Labrador-Great Northern Peninsula fishery (Areas A and O), and the fishery in St. Mary's Bay (Area G). Trap catches within each region are interrelated over the past decade, but each region varies independently of the others. Bonavista Bay (Area C) has a moderate negative association with the St. Mary's Bay fishery; as much variance (38%) is attributable to Component 3 as to Component 1 - the east-northeast. In all other areas, at least 75% of the variance in landings is explained by a single component.

9.2.2. Gillnet fishery

The Bartlett's test again indicated significant structure in the landings tabulated by year and area (Chi-square = 61.01; df = 28, $P < 0.001$). In this case, two components (regions), rather than three, were present. The first was again the east-northeast coast fishery, from Area B to F. The second component combines the Labrador-Great Northern Peninsula fishery with St. Mary's Bay (Areas A, O and G). In this case, variance in Area E (Conception Bay) is split between the two components.

9.2.3. Longline/handline fishery

In this fishery, there is a single component capturing the significant variations (Bartlett's test Chi-square = 86.06, df = 28, $P < 0.001$). As was observed with the trap and gillnet data, the Labrador (O), Great Northern Pensinsula (A) and St. Mary's Bay (G) are more loosely associated with this component than are the other regions, but no systematic pattern is present other than the first, general one.

9.2.4. Summary

Three regions (B to F, A and O, and G) are clearly present in the trap data. Evidence for the three regions is present in the gillnet and longline data, but more weakly. In the subsequent analyses relating landings to environmental attributes, the three regions will be used, rather than the eight statistical areas. This treatment is conservative, providing maximum sensitivity for separate relationships of the A and O, and G fisheries to various environmental attributes.

9.3. How do ice conditions, water temperatures, and capelin influence inshore catch by region?

We investigated these interrelationships with two data sets for each year. One contained our set of environmental measures (last day of ice at Cape Freels and Cape Bauld; surface temperature and cold-core temperature at Station 27; Soviet CPUE indices of 2-year-old and 3-year-old capelin; the ratio of 2-year-old to 3-year-old capelin from the Soviet CPUE indices) (Table 7) and the gross catch inshore by region (Tables 3-6). The other set contained the same environmental measures but with the inshore catch by gear expressed as a proportion of the estimated biomass of the 2J3KL cod stock from VPA. For the trap data, biomass of age 4-7 cod was used and, for the other gears, the total 4+ biomass was used (Table 7). The first data set (gross catch) relates variation in apparent success of the fisheries to environmental factors, but is also influenced by the known changes in available biomass over the past decade. Hence, there was a need for the second data set (proportional catch) to relate variation in the effectiveness of the fishery to environmental factors after a correction for the apparent stock levels.

Each data set contains different information about the fishery (both would be greatly enhanced by information on inshore effort). When analyses of each data set imply similar relationships, confidence in the validity of the patterns is enhanced. In the following analyses, gross catch refers to the total inshore catch for a gear type or region while proportional catch refers to the gross catch divided by the cod biomass.

9.3.1. Trap fishery

9.3.1.1. Gross catch

PCA produces three components (Fig. 9), but the low Bartlett's test value (Chi-square = 37.42, df = 45, P = 0.78) indicates little genuine structure in the data. However, the consistency of these patterns with other data sets makes it worthwhile to interpret the major components. The B to F fishery is almost exclusively related to the first component. The environmental attributes contributing to this component emphasize core temperature and last ice dates, but catch varies inversely with the environmental attributes. Gross catch was high in years of late ice and cold core temperatures.

The A and O fishery is also slightly influenced by this factor, but is primarily associated with Component 3. This component reflects surface temperature and ice at both Capes; warm surface water corresponds to a good northern trap fishery.

The G fishery is reflected in the second component. Its variation is negatively related to the index of abundance of 2-year-old capelin and with the index of amount of 3-year-old capelin.

9.3.1.2. Proportional catch

When the long-term trend in cod biomass is removed, four components are found (Bartlett's Chi-square = 114.36, df = 45, $P < 0.001$). All four components influence the B to F fishery. The strongest influence (35% of variation in the proportional catch) is both a high absolute abundance and especially a high relative abundance of 3-year-old capelin (relative to 2-year-old capelin) - Component 3. Component 2 reflects 25% of the variation in the B to F fishery, implying reasonable fisheries when both 2- and 3-year-old capelin indices were low, and a poor fishery when 2-year-old capelin were abundant. The B to F fishery also responds to both core (Component 4) and surface temperatures (Fig. 10) (Component 1), with warm core and cold surface temperatures corresponding to good fisheries.

The A and O fishery is largely influenced by the absolute and relative amounts of 3-year-old capelin (Component 3), but again has some association with surface temperature (Component 1).

The G fishery is almost exclusively related to Component 2; varying inversely with 2-year-old capelin, and to a lesser extent with 3-year-old capelin.

9.3.2. Gillnet fishery

9.3.2.1. Gross catch

The structure present in these data (Bartlett's Chi-square = 125.81, df = 45, $P < 0.001$) produces four factors. Influences on the B to F fishery are spread among two components. Seventy-four percent of the variation in that fishery is related positively to absolute amounts of both 2- and 3-year-old capelin (Component 4); another 17% is related to core temperature (Fig. 11) (Component 1). As with gross catch with traps, cold core water apparently corresponds to enhanced catches. Most of the variation in the G fishery is reflected by Component 1 as well. The A and O fishery is equally reflected in Components 1 (cold core) and 2. Again, warm surface temperatures and early ice-free conditions at both Capes correspond to a good northern fishery.

9.3.2.2. Proportional catch

These data are as systematic as the gross catch gillnet data (Bartlett's Chi-square = 120.73, df = 45, $P < 0.001$), and again the order in the data is captured in four components. With proportional catch data, variation in the B to F fishery is split among two components. Core temperatures influence the B to F fishery strongly, warm temperatures enhancing catch (Component 4). A negative association with 2-year-old capelin (Component 2) also is present. Three-year-old capelin influence the B to F fishery weakly (Component 3) (Fig. 12).

Both the A and 0 and the G fishery are primarily related to Component 2 influences; a weak fishery corresponds to times of abundant 2-year-old capelin.

The northern fishery (A and 0) also shows some relationship to Component 1. Again, warm temperatures and early ice-free conditions correspond to an enhanced fishery in the A and 0 region.

9.3.3. Handline/longline fishery

9.3.3.1. Gross catch

Again there is meaningful structure in the data (Bartlett's Chi-square = 138.04, df = 45, $P < 0.001$). Although four components are present, most variation in gross catch of fisheries in all three regions is captured in Component 1. The environmental attributes associated with this component are surface temperature and ice conditions; warm water and early ice-free conditions correspond to enhanced catches. Good B to F and A and 0 fisheries are also weakly associated with cold core temperatures (Fig. 13).

9.3.3.2. Proportional catch

The data structure (Bartlett's Chi-square = 137.33, df = 45, $P < 0.001$) was resolved into three components. Relationships of catch as proportion of biomass to environmental influences were much clearer than in the analysis of gross catch. All three fisheries emphasized Component 1, related closely and inversely to the indices of abundance of 2- and 3-year-old capelin. Another 25% of the variation in the G line fishery is present in Component 2, associated with core temperature and the index of relatively large 2-year-old capelin stocks. All three fisheries show weak association with surface temperatures (Component 3) (Fig. 14).

9.3.4. Summary

Similar relationships between regional catches and the diverse environmental attributes appear for all gears. The sensitivity of the northern fishery to surface temperature and ice conditions was seen for gross catch for all three gears. Both core temperature and amount of 3-year-old capelin are related to the east-northeast (B to F) fishery, particularly for the trap and gillnet fisheries. The long-term trend in biomass of cod makes the temperature relationship appear inverse for gross catch data. However, when the trend is accounted for, proportional catch is higher when core temperatures are warm. Lower proportional catches were generally associated with high indices of 2-year-old capelin, regardless of gear or region.

The relationships of the fisheries in St. Mary's Bay to environmental measures are less consistent. Both gross and proportionate catch can be repressed by high abundance of 2-year-old capelin. Colder core temperatures are associated with low gillnet landings, whereas warm surface temperatures enhance handline/longline catches.

Given the consistency of patterns across gears for the northern and eastern fisheries, we have moderate confidence in those patterns. Influences on the St. Mary's Bay fishery are less clear.

9.4. How well does the pattern of factor scores across the past decade match the pattern of catches for three regions?

We have been interpreting the PCA results as having fairly direct correspondence to variations in the regional fisheries. In support of that interpretation we see similar trends over the past decade in regional catches and appropriate components. In PCAs where a particular fishery is related to two different components, comparing trends over the past decade often clarifies separate environmental influences on a fishery.

9.4.1. Trap fishery

9.4.1.1. Gross catch

The B to F fishery loaded almost solely on Component 1. Both the component scores (Fig. 15) and standardized catch (Fig. 16) show a general increase from 1975 to 1978, followed by a decline which reached its low point in 1981. Both component scores and B to F catch have rebounded strongly since then. The A and O fishery loaded on Component 3. Both catch and component scores are low but increasing from 1975 to 1978. In 1979, catch declined markedly, whereas the component score dropped only slightly, implying the suitability of environmental conditions did not deteriorate as badly as the fishery declined. Both catch and the component scores rebounded strongly in 1980, and remained high but variable since then. The decline in component scores in 1983 and 1984 matches the recent lower relative catches.

The G fishery loads negatively on Component 2. As Component 2 scores dropped from 1975 to 1977 and then increased very slowly, the G region catch increased and stayed relatively high. The precipitous drop in the fishery in 1981 corresponds to the rise in scores of Component 2. The catch recovered slightly in 1983, possibly corresponding to the drop in Component 2 score in that year. Generally, however, the relatively low catches in the 1980's correspond well to the persistent high scores on Component 2. These patterns suggest that consistent catch and environmental patterns persisted across the past decade.

9.4.1.2. Proportional catch

The PCA resolved the regional fisheries catch as a proportion of our index of available biomass into four separate components. The patterns of PCA scores and the regional catch data across 1975-84 correspond well. The B to F (Fig. 17 and 18) fishery loaded moderately on all four components. Standardized B to F landings show an early peak in 1976, and low values to 1981. Components 3 and 4 both show the 1976 peak; the generally declining trend through the late 1970's appears in all component scores. Catch increased in 1982, but has not reached earlier high levels. Components 1 and 3 show that pattern as well. Together these patterns imply the proportional fishery in B to F in the mid-1970's was enhanced by favourable core temperatures and good 3-year-old capelin stocks; the ensuing decline was brought about by the combined influence of several unfavourable factors; and the recent improvement was facilitated by favourable surface temperatures and improved mature capelin stocks. The A and O fishery corresponds to Component 3. Both those scores and standardized A and O catch show generally average or high values from 1975 to 1982, with troughs in 1979 and 1981. Both scores and catches have decreased in 1983 and 1984. The G fishery corresponds to Component 2. High Component 2 scores from 1976 to 1980 correspond to generally high catch over that period. A continuing decline in Component 2 scores from 1980 matches a sharp drop in catch from 1981 on. Component 2 scores have remained low since 1981, with a slight peak in both scores and catch in 1983. Variation over years in catches follows the patterns of variation in the appropriate component scores for both gross and proportional catch.

9.4.2. Gillnet fishery

9.4.2.1. Gross catch

Scores for Component 1 from PCA of the gross gillnet catch data (Fig. 19) generally show the consistent increase from 1975 to 1980 seen in the standardized catch data by region (Fig. 20). After 1980, the two prominent features of the component scores are reflected in the corresponding catch values. Component 1 had an extremely low value in 1981, and the catch in Region G (loading exclusively on Component 1) was also extremely low. The B to F fishery loaded primarily on Component 4 with catch values increasing in the early 1980's, and remaining high. The other marked feature of the component scores in the 1980's is the sharp drop in Component 2 in 1984. The A and O fishery which loads heavily on that component shows a similar drop in that year.

9.4.2.2. Proportional catch

For proportional catch, the A and O fisheries' negative association with Component 1 is reflected in a general inverse correspondence between component scores (Fig. 21) and standardized proportional catch (Fig. 22). The decline in the fishery since 1982 is most clearly captured in the PCA. Relatively good catches in the late 1970's correspond to high scores on Component 2, and for 1980, the additional effect of the low score on Component 1. The B to F proportional catch data correspond well with scores of Component 4 for the early years, with high values in 1976 and lower values from 1977 to 1981. The improvement in 1982 and subsequent decline are present in both the B to F catch values and scores of Components 2 and 4. The G fishery took proportionately more fish in 1975 than the relationship with Component 2 would suggest. The rest of the patterns coincide fairly well, particularly the sharp drops in both figures in 1981, and the low catches and component scores which have been experienced in 1983 and 1984.

9.4.3. Handline/longline fishery

9.4.3.1. Gross catch

The fisheries of all three regions load on Component 1 (Fig. 23). The gross catches also show the same general pattern for all three regions (Fig. 24). In both figures, a steady increase is apparent from 1975 to 1979 or 1980. Thereafter, values have been variable, but slightly lower in both graphs. The deep trough in scores for Component 2 in 1981 correspond to poor catches in B to F and A and O in that year. This suggests the poor fishery in 1981 was related to different environmental influences (core temperature) than was the longer-term trend through the 1970's (ice and surface temperature).

9.4.3.2. Proportional catch

The A and O proportional catch loads almost equally on Components 1 and 3 (Fig. 25). The scores on Component 1 and the A and O proportional catch data (Fig. 26) show some similarities: low values in 1975 and 1976, and low values through the 1980's. The peaks in A and O proportional catch in 1979 and 1983 are seen in the scores for Component 3. From 1980 to 1982, the two components indicate conflicting influences on the fishery: Component 1 unfavourable, Component 3 favourable. The Component 1 influence appears stronger in the catch data. Scores on Component 2 are erratic until 1981 when there is a sharp rise and then dramatic decline. The G fishery loads heavily on this component. Aside from missing low proportional catch values in 1975 which is shown by Component 1, the curves correspond well, particularly the peak in 1981. Recent low catch values in G correspond to the low scores on Component 1. The B to F fishery data also loads on Component 1. Both the catch and the component scores indicate low values in 1975, moderately good catch (fairly high consistent Component 1 scores) from 1976 to 1980, and poor catches (low Component 1 scores) from 1982 to 1984.

9.4.4. Summary

In the majority of cases, the patterns of the regional catch data over years and patterns of the appropriate component scores over years both correspond well. This suggests that the environmental features which load along with regional catches on specific components have some real association with those catches. The association need not be direct (i.e. causal) however; principal components analysis is a correlational procedure. Also, some of the correspondence of matched catches and component scores is tautological; the catch values were used, along with the environmental values, in calculating the scores.

In a few cases, component scores and catches did not correspond well. This generally occurred when a regional fishery had fairly high loadings on two separate components. In some of those cases, scores of one component matched standardized catch values for part of the time series, and scores of the other component corresponded to other catch values (for example the B to F fishery proportional trap data). In other instances, scores of both components were fairly similar for most years, and catches corresponded well. In a few years, however, the component scores make conflicting suggestions regarding catch. No consistent pattern was seen about what actual catch would be in those instances. The proportional catch in the G line fishery, for example, was intermediate in 1982, when one component suggested favourable conditions and another component suggested unfavourable conditions. We can conclude that different independent environmental factors may influence a fishery, but we lack enough data to assess how such potential interactions among environmental influences are resolved.

10. TAGGING AND ACOUSTIC SURVEYS AND ACOUSTIC TRACKING OF COD

10.1. Results of tagging cod from prespawning concentrations

During February-March 1978-81, about 25,000 Atlantic cod (>45 cm) were tagged from the prespawning concentrations on Hamilton Bank, Belle Isle Bank, Funk Island Bank and northern Grand Bank (Lear 1984). There is evidence of a consistent annual pattern of migration to inshore waters during summer and to offshore areas during winter for each group of cod tagged. The Hamilton Bank component contributes to the southern Labrador and northeast Newfoundland coastal fisheries mainly from Notre Dame Bay northward. The Belle Isle Bank component migrates during summer mainly to southern Labrador, Strait of Belle Isle entrance and northeastern Newfoundland as far south as Notre Dame Bay. The pattern of movement is similar to that of the Hamilton Bank component except for a greater proportion in the Strait of Belle Isle. Cod on the northern and northeastern slopes of Funk Island Bank migrate during summer to eastern and southeastern Newfoundland, with smaller proportions going to southern Labrador and the Strait of Belle Isle than for the taggings on Belle Isle Bank. Cod from the southwestern slope of Funk Island Bank contribute mainly to the summer inshore fishery of Notre Dame Bay and Bonavista Bay and in a smaller degree to the fishery in Trinity Bay, Conception Bay and the eastern part of the Avalon Peninsula. Cod which overwinter on northern Grand Bank migrate southwards across the bank to the Virgin Rocks and to the eastern slope of the bank. This component contributes mainly to the inshore fishery from Trinity Bay southward to St. Mary's Bay, with little effect on the fishery north of Cape Bonavista.

The evidence from tagging on winter concentrations is that each component contributes to the inshore fishery in specific, although wide, overlapping areas. Excessive exploitation of any one component of the stock complex could have adverse effects on the inshore fishery in the areas frequented by the summer migrants. It is desirable, therefore, that the offshore fishery in winter should be managed so that the inshore fishery in summer and autumn would not be affected detrimentally by excessive exploitation of a particular component of the stock complex in Div. 2J, 3K and 3L (Lear 1984).

10.2. Cod concentrations during June 1984 and 1985 based on acoustic and trawl surveys

During June 1984, a cruise employing acoustic survey techniques and bottom trawling was conducted in Div. 3L from Cape St. Mary's to the Virgin Rocks and northwards, both inshore and offshore, to the Funk Island Bank.

A small concentration of mainly small cod was observed on the North Cape of the Grand Bank at depths of 190-220 m and temperatures of 0 to 1.4°C. Highest catches were about 200 kg per 30-minute set.

A larger concentration of large cod was observed on the northwest slope of Wolfall Bank in depths of 150-160 m and bottom temperatures of -0.6 to -0.9°C. Largest catches ranged from 650 to 1300 kg per 30-minute set.

A dense concentration of cod was observed north of Cape Bonavista, at the entrance to Bonavista Bay and along the north side of Trinity Bay. The dense concentrations were in depths of 260-310 m and in water temperatures higher than -0.5°C while the densest concentrations were in temperatures of 1 to 4°C. These concentrations sometimes extended from the bottom up to 50 m off the bottom but generally always remained where the temperature was higher than -0.5°C (i.e. below the cold core of the Labrador Current). Occasionally, individual cod were observed, up to 80 m off bottom and in temperatures as low as -0.8°C.

At the time of observation (June 5-10) only occasional, small schools of capelin were observed in the vicinity of the cod concentration. The capelin schools remained at the surface during the night and descended at dawn and early morning and ascended during the evening. The cod did not pursue the capelin into the cold water (-1.0 to -1.7°C) during the night even though the cod were feeding heavily on the capelin during the day, apparently when the schools were near the bottom.

During June 1985, a similar survey was conducted covering approximately the same area. Concentrations of cod were found offshore north of the Virgin Rocks and on the southwestern slope of Funk Island Bank (Fig. 27). North of the Virgin Rocks, the largest catch of cod per 30-minute tow was 2006 kg in a depth of 79 m and temperature of -0.3°C. On southwestern Funk Island Bank, the largest catch was 533 kg in 290 m and 2.2°C.

Good concentrations of cod were observed in deeper water (250-340 m) along the northeast coast off Newfoundland from the deep waters in Trinity Bay, off

Cape Bonavista, Funk Island and north of Fogo Island and the entrance to Notre Dame Bay. The bottom water temperatures here ranged from -0.7°C to 1.7°C. Cod in these concentrations were not always on the bottom but ranged from close to the bottom and were almost equally distributed from there up to 80 m off the bottom or up to the lower edge of the cold water (generally up to the 0°C temperature water). During this period the cod, even though they were abundant, would probably not be caught in bottom gillnets.

Off Cape Bonavista, the largest catch of cod was 4311 kg in a depth of 307 m and a temperature of 2.1°C.

Northeast of Fogo, the largest catch was of 2129 kg in a depth of 246 m and a temperature of -0.7°C.

Across the mouth of Conception Bay, cod were very scarce. The bottom water temperatures across the mouth of Conception Bay ranged from -1.4 to -1.6°C.

10.3. Results of tagging of cod prior to inshore migration during June 1984 and 1985

During June 1984, 3391 cod were tagged from a concentration off Cape Bonavista at a depth of about 300 m. During the inshore fishing season of 1984, 355 recaptures (10%) were reported from the inshore fishery mainly from Bonavista and Notre Dame bays. About 45% of the recaptured tags from the inshore fixed gear fishery were from deep water (260-450 m) below the cold core of the Labrador Current during the summer and autumn. There was a tendency for the cod to move northward from the tagging area during the summer. During the winter fishery of 1985, there were 40 tags reported from offshore, mainly the eastern edge of Funk Island Bank, although three were reported from the Nose of the Grand Bank. Up to September 30, there were 65 tags reported from the inshore fishery in 2J3KL mainly from the deep water around Funk Island and around Fogo Island.

During June 1985, cod were tagged from concentrations on the central Grand Bank, off Cape Bonavista and off Fogo Island.

Of the 1033 cod tagged on the central Grand Bank (north of the Virgin Rocks) during June 1985, there have been 70 (7%) recaptured to the end of October 1985 of which 43 (67%) were from the shallow-water area around the Virgin Rocks. The remainder were from the inshore fishery mainly around the southeast Avalon Peninsula with only two being recaptured north of Cape Bonavista.

Of the 2159 cod tagged in deep water (300 m) off Cape Bonavista during June 1985, there have been 180 (8%) recaptured to the end of October 1985 of which 86 (35%) were taken by deep-water gillnets (250-400 m). This indicates about the same proportion of cod migrated inshore (<50 m) during 1985 as in 1984. Of 972 cod tagged in deep water (250 m) off Fogo during June 1985, only 26 (3%) have been recaptured, all from the inshore fishery, and almost all from the area around Fogo Island. Clearly, there was a large component of this concentration that did not migrate inshore.

10.4. Results of tracking cod with acoustic tags in the inshore area

During June-July 1984, the movement of individual cod was monitored using acoustic tags and tracking equipment. Results from monitoring individual cod indicate that during late June to early July, the cod, which are in shallow water (10-50 m), tended to move within the same general area and generally remained within a range of 1° to 4°C and depths of 10-45 m. Occasionally, the cod wandered for short periods of time in water as cold as -1°C and as warm as 5-6°C but returned to the depths in which temperatures were mainly around 1 to 4°C.

11. MATURITY STAGE OF COD AS A POSSIBLE SOURCE OF DELAY OF THE INSHORE COD MIGRATION

Templeman (1966) cites the possibility of the delayed spawning of cod during 1961 as being an unfavourable factor leading to decreased abundance of cod in the inshore fishery in that year. It was postulated that spawning was evidently delayed by cold water on the cod wintering grounds. It was further postulated that the schools of cod must complete spawning in time to pursue and feed upon the capelin schools as they move shoreward. A considerable delay in spawning may mean an appreciable number of cod fail to make contact with the shoreward-moving schools of capelin.

During the cod migration cruises during May 26-June 12, 1984 and June 1-16, 1985, catches of cod were examined for length, sex and maturity stages on the Grand Bank and off eastern Newfoundland to determine if cod off the coast just prior to migration were in the spent, spawning or developing condition.

During both 1984 and 1985 off eastern Newfoundland, particularly in the deep water off Cape Bonavista, about 45-60% of the female cod were in the prespawning stage. Off Fogo Island during mid-June 1985, about 65% of the cod had not spawned. It is not known if this is the normal situation for these areas at this time of year or if this represents delayed spawning and the possibility of delayed migration to inshore shallow water.

12. PRESENCE OF ORGANISMS CAUSING "SLUB" ON NETS AND AFFECTING CATCHABILITY

Mahoney and Buggeln (1983) report that the mucus fouling of nets, locally called "slub", is caused by the discarded houses of the larvacean genus *Oikopleura*. This organism is found in the cold water of the Labrador Current. During periods when the Labrador Current water is upwelled inshore from the interaction of local wind, tide and current patterns, the presence of "slub" on nets generally becomes a serious problem. The fishing efficiency of nets decreases markedly either from saturation of the gear with the mucus-laden houses, in which case the net actually goes adrift with the current or the nets have to be removed from the water for cleaning, or the mucus-laden nets are readily visible to cod which would then avoid the nets. In each case the effective fishing effort is reduced.

During June-July 1985, the problem of net fouling in eastern Newfoundland and Labrador was well documented by the media and it is quite conceivable that the presence of the cold-water organisms which cause slub were a contributing factor to reduced fishing efficiency of gear, reduced effort and loss of catch.

13. RESEARCH SURVEY AND COMMERCIAL CATCH RATES

Research vessel surveys have been conducted during the fall by the GADUS ATLANTICA in NAFO Div. 2J and 3K since 1977 and 1978, respectively. Biomass estimates from these surveys are given in Tables 8 and 9. Spring surveys were conducted in Div. 3L from 1971 to 1982 by the A. T. CAMERON and in 1985 by the WILFRED TEMPLEMAN (Table 10). This survey could not be conducted in 1983 and in 1984 a survey of only limited coverage (<180 m) could be completed. As part of a seasonal survey program, research vessel surveys have been conducted in the fall for the years 1981-84. These surveys were conducted by the A. T. CAMERON in 1981-82 and by the WILFRED TEMPLEMAN in 1983-84. Biomass estimates from these surveys, along with estimates from a winter survey conducted by the WILFRED TEMPLEMAN in 1985, are shown in Table 11. Biomass estimates increased in Div. 2J from 1977 to 1983 with a drop in 1984. Estimates for Div. 3K have been variable with the 1984 point the second highest in the series. Estimates for both spring and fall Div. 3L surveys have shown some increase over the time series.

Commercial catch rates (t/day) for cod in offshore areas of Div. 2J3KL by month and quarter during 1984 are given in Tables 12 and 13. Catch rates for 1985 by month up to July are given in Table 14. The best catch rates during 1984 were in the Funk Island Bank area in the first quarter. Other good catch rates were observed on Belle Isle Bank during the first and second quarters, on Hamilton Bank during the fourth quarter and on the Northern Grand Bank during the first quarter. The best catch rates observed during 1985 up until July were on Funk Island Bank during February and Belle Isle Bank in April. Catch rates on Funk Island Bank appeared quite good for the first six months of 1985. In general, these catch rates were quite variable over time and area for both years presented. The good catch rates during June-September 1984 and for July 1985 on Funk Island Bank (in excess of 20 t/day) indicate that there was a large concentration of cod offshore during this time which presumably did not migrate inshore. Similarly high catch rates for Belle Isle Bank during June-July 1985 (20 and 15 t/day, respectively) and for Hamilton Bank during July (20 t/day) indicate an offshore component or a late migration of cod to inshore areas.

14. SUMMARY

1) The inshore cod fishery in Labrador and eastern Newfoundland in 1985 has been a relative failure. The total inshore catch to the end of October, estimated from production figures, was about 77,700 t, about 20% below

that of 1984, but about the same as that of 1981, which was also considered a failure.

2) The aim of this paper was to analyze various factors which may have contributed to the high variability in inshore availability or abundance of cod during the decade 1975-84 with an aim of identifying factors which led to the poor inshore cod fishery during 1985.

3) It is assumed that the present estimated stock level of 1,250,000 t of cod of age 4 years and older was sufficient to sustain a successful inshore cod fishery during 1985.

4) The inshore cod fishery is defined statistically as that involving fixed gear operated by vessels less than 65 feet in length. This definition includes, in the inshore catch, cod caught 50 km NE of Cape Bonavista in greater than 300 m but excludes those cod catches by small otter trawlers less than 5 km from land in less than 50 m off the southern Avalon.

5) The factors which may affect the total inshore catch of cod may be grouped into three broad categories:

   a) availability of cod
   b) catchability of cod
   c) fishing effort.

6) Inshore catches of cod from Labrador and eastern Newfoundland have been highly variable. Catches have shown a high degree of variability among regions both within and among years.

7) During 1962-74, the inshore-cod fishery took 4.8-7.1% of the available 4+ biomass. Between 1974 and 1977, the proportion taken inshore increased dramatically to 23% in 1977. The inshore catch expressed as a proportion of available biomass has declined since 1977, the most notable variations since 1978 being the failure of 1981 and the good catch of 1982.

8) During the period 1962-74, the proportion of the January 1 biomass taken offshore increased from about 5% to about 28% while the proportion taken inshore declined from about 6.5% to about 4%. After 1974, there was a dramatic increase in the proportion taken inshore while the proportion taken offshore declined slowly at first and then very rapidly. Since 1978, the proportion taken offshore has remained low and relatively constant, while the proportion taken inshore has steadily declined (with the exception of the good catch in 1982). The dramatic changes in 4+ biomass and the changing patterns in the proportion of "May 1 biomass" caught inshore make it very difficult to determine the extent to which offshore catches in the winter-spring of a given year affect inshore catch in the same year.

9) The several hypotheses that have been proposed to explain variability in the inshore cod fishery are as follows:

a) The inshore migration of cod in late June and July is a feeding migration in which cod actively pursue mature migrating capelin towards the coast. It is postulated that inshore catch is positively correlated with mature capelin biomass.

b) The inshore migration of cod is postulated to be negatively correlated with the biomass of immature capelin which are mainly offshore and which would provide an adequate food supply and reduce the necessity to migrate inshore.

c) It is postulated that the proportions of cod moving across the thermal barrier in the intermediate layer of the Labrador Current decrease as the thickness of the core increases or the temperature decreases.

d) The inshore cod catch (especially in cod traps and other shallow-water gear) is influenced by the surface temperatures near the coast in the vicinity of cod traps and other fixed shallow-water gear.

10) To extract patterns of interrelationships among inshore cod landings from various areas, and among landings and attributes of the environment, principal component analysis (PCA) was used rather than regression analysis because of the possible interrelationships among the environmental attributes. Regression analyses in these circumstances would have possibly given misleading results.

11) For the trap fishery catches, there were interrelationships among areas across years. Three distinct regions emerged:

a) a general east and northeast coast fishery (Areas B to F)
b) the Labrador-Great Northern Peninsula fishery (Areas A and O)
c) the St. Mary's Bay fishery (Area G).

12) For the gillnet fishery (deep- and shallow-water components are inseparable), two regions emerged:

a) east and northeast coast (Areas B to F)
b) the Labrador-Great Northern Peninsula and St. Mary's Bay fisheries (Areas A, O and G).

13) For the longline/handline fishery, only one region emerges, i.e. no special regional patterns are evident.

14) For the PCA analyses in which the environmental and biomass indices are related to inshore landings, three regions (B to F, A and O, and G) were used rather than the eight statistical areas. This treatment is conservative providing maximum sensitivity for separate relationships of the A and O and G fisheries to various environmental attributes.

15) The proportional trap catch in the B to F fishery is influenced by the absolute and the relative abundance of 3-year-old capelin (relative to 2-year-old capelin) implying reasonable fisheries when both 2- and 3-year-old capelin indices were low and a poor fishery when 2-year-old

capelin were abundant. The B to F fishery also responds to both core and surface temperatures, with warm core and cool surface temperatures corresponding to good fisheries. The A and O fishery is largely influenced by the absolute and relative amount of 3-year-old capelin and to some extent with surface temperature.

The St. Mary's Bay fishery (G) varies inversely with 2-year-old capelin and to a lesser extent with 3-year-old capelin.

16) For the proportional gillnet catch, the variation in the B to F fishery is split among two components. Warm core temperatures enhance the fishery while a negative association exists with 2-year-old capelin and 3-year-old capelin exerting only a weak influence. Both the A and O and the G fisheries are primarily related to 2-year-old capelin in which an abundance of 2-year-old capelin leads to a poor fishery.

Warm temperatures and early ice-free conditions correspond to an enhanced fishery in the A and O region.

17) In the handline/longline fishery (proportional catch), all three fishery regions were related closely and inversely to the indices of abundance of 2- and 3-year-old capelin. About 25% of the variation in the St. Mary's Bay line fishery is associated with core temperature and the index of relatively large 2-year-old capelin stocks. All three fisheries (A and O, B to F and G) showed weak association with surface temperatures.

18) In general, there is a good correspondence between the patterns of the regional catch data over years and patterns of the appropriate component scores over years. This suggests that the environmental features which load along with regional catches on specific components have some real association (although not necessarily causal) with those catches. In a few cases, component scores and catches did not correspond well. Also, in a few cases the scores of one component matched standardized catch values for part of the time series, and scores of the other component corresponded to other catch values. For example, the proportional trap fishery in B to F in the mid-1970's was enhanced by favourable core temperatures and relatively high stocks of mature capelin; the ensuing decline was brought about by the combined influence of several unfavourable factors; and the recent improvement was facilitated by favourable surface temperatures and improved mature capelin stocks. In general, we can conclude from the results of the principal component analysis (PCA) that different independent environmental factors may influence a fishery, but we lack enough data to assess how such potential interactions among environmental influences are resolved.

19) The results of tagging adult cod on winter concentrations has demonstrated that there are several major components which contribute to the inshore cod fishery in NAFO Div. 2J3K and 3L. It is possible that excessive exploitation on any component may have adverse effects on the inshore fishery in that area to which a particular stock component contributes. It is also possible that the various environmental attributes discussed

previously impact in different ways upon the migration behaviour of the various components.

20) In support of the cold thermal barrier hypothesis, recent observations during June 1984 and 1985 off eastern Newfoundland confirm that adult cod are densely concentrated at 250-320 m below the cold core of the Labrador Current and generally in water of temperatures higher than -0.5°C. The concentrations of these cod below the Labrador Current suggest that, in some years, a significant proportion of these cod do not migrate into the shallow-water area but remain in deep water outside the range of cod traps, handlines and other shallow-water gear. The presence of large numbers of cod up to 50 m off the bottom would also put them above the range of the deep-water gillnets and result in a low catch rate.

21) Results of tagging these cod off the eastern Newfoundland coast during June 1984 and 1985 confirmed that many of these cod did not appear to break through the cold core since about 45% of the returns during summer and autumn 1984 were from deep water (260-450 m) below the cold core of the Labrador Current. The return of tags from the 1985 tagging confirm an even lower proportion of the tagged cod migrated to the inshore area during summer.

This lends support to the hypothesis that cod may migrate towards the coast but may fail to migrate to the shallow-water area and are hence not available to cod traps and other shallow-water inshore gears.

22) The monitoring of individual cod by acoustic tags during June-July 1984 indicates that, during late June to early July, the cod which are in the shallow water (10-50 m) tended to migrate within the same general area but generally remained within a range of 1-4°C. Occasionally these cod wandered into water as cold as -1°C and as warm as 5-6°C but returned to the depths in which temperatures were mainly around 1-4°C. This lends support to the hypothesis that changes in the depth of the thermocline, generally from wind-induced flooding or upwelling, will change the distribution of cod in cod trap depths as the cod migrate to remain in a relatively stable thermal regime.

23) It has been postulated that the delayed spawning of cod may be an unfavourable factor leading to decreased abundance of cod in the inshore fishery in a particular year. This delay in spawning may mean that an appreciable number of cod fail to make contact with the shoreward-moving schools of capelin. The high proportions (45-60%) of prespawning stages among mature female cod during 1984 and 1985 in deep water off eastern Newfoundland may possibly represent such a delayed spawning and may result in a delayed inshore migration. It is not known, however, if this represents a normal situation for cod in this area at this time for a particular segment of this component or if this represents delayed spawning/migration behaviour.

24) The presence of net-fouling cold-water organisms (Oikopleura), commonly called "slub", in the waters of eastern Newfoundland and Labrador during June-July 1985 may also have been a contributing factor to reduced fishing

efficiency of gear, reduced fishing effort and reduced catch in some areas.

25) The good offshore catch rates in excess of 20 t/day by Newfoundland vessels on Funk Island Bank during June-September 1984 and July 1985 indicate that there was a large concentration of cod offshore during that period and that these cod presumably did not migrate inshore. Similarly high catch rates for Belle Isle Bank during June-July 1985 (20 and 15 t/day, respectively) and for Hamilton Bank during July 1985 (20 t/day) indicate an offshore component or a late migration of cod to inshore areas.

15. RECOMMENDATIONS

The following are recommendations arising from the Working Group which examined the factors which affect the catch variability in the inshore cod fishery of Labrador and eastern Newfoundland.

1) The collection of quantitative information on catch and effort indices from the inshore cod fishery by gear type is essential and of paramount importance.

2) A procedure should be developed to quantify shallow-water (<100 m) and deep-water (>100 m) cod catches (especially gillnet catches).

3) We should obtain, on a regular basis, the collection of hydrographic data to provide a continual index of the core of the Labrador Current from a deep-water station, preferably off the northeast coast (e.g. Cape Bonavista).

4) A consistent procedure should be implemented to ensure consistency in the recording of cod catches in the different kinds of line fishery, e.g. jigger, handline, linetrawl and longline.

5) We should develop abundance indices of capelin during spring by year-class for the stock areas (Div. 2J, 3K and 3L) which would be comparable to the cod stock areas used in the inshore cod fishery study. This would be preferable to the autumn indices of capelin abundance used in the present analysis. Also, there should be a directed effort to develop the best historic index of capelin and to determine ways to combine the various indices of abundance now available.

6) The proportion of immature to mature capelin in the diet of offshore cod just prior to the inshore migrations should be monitored. A minimum program would involve intensive collections of cod stomachs from specified areas in Div. 3L during annual spring bottom-trawl surveys.

7) Inshore migration. There is a need to know more about the behaviour of cod and capelin with respect to cold water, particularly as it may be modified by migration instinct and feeding. Do cod approach the coast in surface waters or along the bottom? Do cod actively pursue capelin toward

the coast? This would possibly involve studies in the Avalon Channel or off Cape Bonavista during spring to observe the pulse of capelin moving inshore and see where and when the cod follow.

Laboratory studies can provide information on thermal preferences and resistance by both cod and capelin to low temperature. Site-specific studies could monitor the behaviour of capelin and cod as they approach the coast. The site-specific studies might monitor the commercial fishery in deep water and shallow water; occupy transects on a frequent basis, obtaining sounder records and temperature profiles for at least the period mid-May to mid-July; and conduct experimental fishing.

8) Inshore catchability. There is a need to know more about the behaviour of cod with respect to water column structure in the inshore area. This involves testing aspects of Templeman's (1966) hypotheses. The study would be similar to No. 7, but would take place in relatively shallow water.

9) The pattern in the relationship between inshore catch and biomass of fish in the ocean (Fig. 4 and 5) has changed several times in the period 1962-84. There should be a more detailed investigation of factors which might have caused such changes. This could include an examination of the accuracy of the cohort analysis, an examination of the influence of changing size-composition in the available biomass, and an attempt to document major changes in effort, such as the number of inshore fishermen and changes in technology.

10) Effort should be directed toward examining the degree and patterns of variability of inshore cod landings over intermediate spatial scales (50-200 km) along a coast. Effort data in this study are essential if we are to learn anything of real value. The degree of variability of landings and effort (especially in terms of catch/effort by gear type) would be documented, and consideration must be given to factors which could create this variability. For example, are there geographic differences in temperature patterns, current patterns, or prey availability?

11) Effort should be directed to monitor and assess offshore cod catches and catch rates of the various cod stock components and the effects of these catches on inshore areas to which these cod stock components contribute. This should be done with a view to future allocation by major stock component to prevent over-exploitation of any offshore spawning or over-wintering component to the detriment of the inshore cod fishery which derives from and depends on a particular stock component.

12) The data on maturity and spawning times of cod in NAFO Div. 2J, 3K and 3L should be analyzed to determine if there are regional and annual variations in spawning times and if the maturation rates and spawning times are related to environmental variables, and further if delayed spawning in a particular year signals a late start for the inshore cod fishery.

13) The existing data bases on ice conditions (sea ice and ice bergs) should be assembled and the influence of ice conditions on inshore and offshore cod landings and catch/effort determined and documented.

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Table 1. Historical catches of cod from NAFO Divisions 2J3KL for the years 1959-84.

Year	2J			3K			3L			2J3KL Offshore Not Specified	Total Inshore	Total Offshore	Total	TAC
		Offshore			Offshore			Offshore						
	Inshore	Can.	Other	Inshore	Can.	Other	Inshore	Can.	Other					
1959	17533	-	39405	56264	-	83003	85695	4515	43097	30060	159492	200080	359572	-
1960	15418	1	164036	47676	53	69855	94192	7355	60213	-	157286	301513	458799	-
1961	17545	1	243144	31159	-	60574	70659	4675	70318	3	119363	378715	498078	-
1962	23424	-	226841	42816	-	45554	72271	4383	87463	-	138511	364241	502752	-
1963	23767	1	187925	47486	-	75344	73295	4446	78620	9020	144548	355356	499904	-
1964	14787	13	180232	40705	30	110887	75806	10158	129135	41832	131298	472287	603585	-
1965	25117	-	227206	26467	21	46146	58943	7353	119529	44872	110527	445127	555654	-
1966	22645	39	221004	32208	13	57543	55990	8253	117231	7381	110843	411464	522307	-
1967	27721	28	212327	24905	114	76900	49233	13478	195494	10335	101859	508676	610535	-
1968	12937	4592	323280	40768	1849	114123	47330	15784	202998	43809	101035	706435	807470	-
1969	4328	30	356543	24923	56	74397	67973	18255	142954	58974	97224	651209	748433	-
1970	1963	-	196823	21511	93	69396	53113	14471	128975	29868	76587	439626	516213	-
1971	3229	84	146903	21111	31	58404	38115	11976	140664	11979	62455	370041	432496	-
1972	1725	-	148038	14054	7	132122	46273	4380	107991	3580	62052	396118	458170	-
1973	3619	1123	52985	13190	110	159651	24839	1258	97734	-	41648	312861	354509	666000
1974	1804	-	119463	10747	19	149189	22630	880	67918	-	35181	337469	372650	657000
1975	3000	410	78578	15518	13	112854	22695	670	53770	-	41213	246295	287508	554000
1976	3851	94	30691	20879	646	79665	35209	2187	40998	-	59939	154281	214220	300000
1977	3523	525	39584	28818	1039	26788	40282	5362	26799	-	72623	100097	172720	160000
1978	6638	4682	17546	29623	5859	7541	45194	9213	12263	-	81455	57104	138559	135000
1979	8445	9194	6536	27018	15190	23275	50359	14184	12690	-	85822	81069	166891	180000
1980	17210	13592	7435	37015	21920	6828	42298	15523	13961	-	96523	79259	175782	180000
1981	11582	24794	4760	22770	23344	3847	42835	21746	15070	-	77187	93561	170748	200000
1982	15330	57483	8923	42410	8614	4072	57881	25788	9273	-	115621	114153	229774	230000
1983	10638	37341	3640	40803	31565	2352	54683	39423	9768	-	106124	124089	230213	260000
1984	12689	11005	1203	34996	47850	9647	49088	49633	13118	-	96773	132456	229229	266000

Table 2. Beginning of the year population biomass (4+), total inshore catch, and January to April offshore catch of cod in NAFO Division 2J3KL for the period 1962-84.

Year	4+ Beginning of the year population biomass	Total inshore catch	Jan.-Apr. offshore catch
1962	2338000	138511	107514
1963	2156600	144548	121834
1964	2031800	131298	147942
1965	1901500	110527	176547
1966	1859600	110843	152661
1967	1989700	101859	151201
1968	1959300	101035	293170
1969	1693500	97224	337851
1970	1409300	76587	252240
1971	1387000	62455	213946
1972	1318500	62052	272527
1973	1081700	41648	206471
1974	848900	35181	240300
1975	537600	41213	159600
1976	388700	59939	99468
1977	389500	72623	73834
1978	598900	81455	35889
1979	706100	85822	46662
1980	820200	96523	40598
1981	891300	77187	50906
1982	1050500	115621	75233
1983	1166500	106124	70827
1984	1308600	96773	77701

Table 3. Inshore cod Landings (t) by Area. Trap.
1975-84

Year	A	B	C	D	E	F	G	O	Total
1975	2095	2661	1083	3487	2261	2263	973	886	15709
1976	2720	4604	1123	6201	4562	5482	1132	1853	27677
1977	4445	7330	1346	4511	4214	8066	2862	1757	34531
1978	7051	5765	1129	4645	5059	8471	4033	3791	39944
1979	1469	2358	1126	4142	4065	8289	3159	2226	26834
1980	11137	4073	936	3129	2717	3762	2333	6194	34281
1981	4125	625	1112	2361	1719	4391	602	5926	20861
1982	10944	7214	2324	6347	5186	9576	832	5747	48170
1983	4108	6898	3455	5537	5290	9063	2348	4637	41336
1984	4843	5623	4503	5668	4401	7473	1020	5839	39370

Table 4. Inshore cod Landings (t) by Area. Gillnets.
1975-84

Year	A	B	C	D	E	F	G	O	Total
1975	2500	6601	2755	1735	877	859	1151	3567	20045
1976	4026	7162	2978	2371	1245	1350	1168	3612	23912
1977	4106	8576	2490	2701	933	722	1684	3182	24394
1978	5226	7720	2725	2789	763	774	1968	5211	27176
1979	5083	7044	3538	3924	1144	1109	3913	9046	34801
1980	7457	8865	3520	2623	1230	984	2847	12844	40370
1981	3600	7719	4813	3355	827	2039	1066	11115	34534
1982	8192	12550	5854	5167	1841	3298	3835	11166	51903
1983	6226	13713	5617	5392	1053	1661	2605	7550	43817
1984	3871	10631	5103	3842	1383	1623	2847	6334	35634

Table 5. Inshore cod Landings (t) by Area. Longlines. 1975-84

Year	Area A	B	C	D	E	F	G	O	Total
1975	424	174	254	124	235	535	493	10	2249
1976	316	400	264	301	378	1522	439	134	3754
1977	761	570	368	365	474	1597	787	306	5228
1978	1546	2136	498	506	576	2188	1328	442	9220
1979	4320	4541	570	512	696	2896	1931	1181	16647
1980	2541	6000	1058	980	1322	3896	2148	1568	19513
1981	1920	4891	1149	823	1505	3884	4049	2340	20561
1982	1766	4565	668	640	955	1945	1414	1626	13579
1983	1597	1188	746	230	677	1160	890	714	6401
1984	1266	1038	395	343	463	1374	839	127	5845

Table 6. Inshore cod Landings (t) by Area. Handlines. 1975-84

Year	Area A	B	C	D	E	F	G	O	Total
1975	685	988	999	341	515	1106	152	274	5060
1976	965	1516	1169	602	796	1860	407	291	7606
1977	1513	3032	1426	864	729	3108	720	493	11237
1978	907	2306	1887	882	893	3496	630	640	11641
1979	1493	2249	1861	870	1267	4708	332	2655	15435
1980	1093	1741	2245	830	1020	4230	475	1329	12963
1981	734	1369	2051	629	874	3995	94	313	10059
1982	939	1236	1815	522	466	3364	40	1013	9395
1983[a]	2831	6932	2085	1096	932	3712	1176	3702	22466
1984[a]	2995	5356	1967	778	951	2940	758	1002	16747

[a]1983 and 1984 have jigger and handline catches combined.

Table 7. Biomass in 2J3KL cod stock and environmental indices during the period 1975-84.

	Cod biomass[a] (tons x 10^{-2})		Capelin abundance index		Mean[d] temperature		Ice-free date[e]	
Year	Ages 4-7	Ages 4-13+	Age 2[b]	Age 3[c]	Surface	Core	Cape Freels	Cape Bauld
1975	2560	4059	0.76	0.19	1.90	-1.24	122	156
1976	2212	3006	0.08	0.76	4.80	-1.11	130	144
1977	3957	4619	0.02	0.08	5.60	-1.58	151	153
1978	4836	5399	0.06	0.02	3.50	-1.37	134	159
1979	6775	7371	0.36	0.06	4.90	-1.34	123	144
1980	7394	8342	0.10	0.36	6.70	-1.44	96	138
1981	6532	8589	0.89	0.10	6.20	-1.10	64	120
1982	7664	10316	1.00	0.89	5.10	-1.39	94	168
1983	8096	11413	0.93	1.00	5.40	-1.46	125	135
1984	9317	12584	0.92	0.93	2.00	-1.46	144	175

[a]Mid-year biomass of 2J+3KL cod stock (Baird and Bishop 1985).

[b]Catch at age per unit effort in 2+3K USSR commercial fishery (Carscadden, et al. 1985), standardized to a maximum of 1.0.

[c]The index of abundance at age 2 in year t was used as the index of abundance at age 3 in year t + 1.

[d]Mean temperatures were calculated by integrating over depth after linear interpolation, then dividing by the depth range involved. The operation was repeated with respect to time. Surface temperature is the mean for June in the depth range 0-20 m. Core temperature is the mean for June-July in the depth range 100-150 m.

[e]Last date when ice might have prevented fishing (including deep water fishing) in the inshore area, as deduced from examination of ice conditions as reported in charts prepared by the Department of the Environment.

Table 8. Cod biomass estimates (t) from research vessel surveys in NAFO Division 2J.

Depth Range (mtrs)	Stratum Number	Stratum area (mi^2)	Gadus 3 1977	Gadus 15 1978	Gadus 29 1979	Gadus 44 1980	Gadus 58 1981	Gadus 71 1982	Gadus 86-88 1983	Gadus 101-102 1984
101-200	201	1427	12377	4847	3256	11319	15998	18085	16764	12033
	205	1823	2761	16200	2669	1676	10126	39216	17742	25093
	206	2582	5328	2074	2671	3849	13153	8533	11442	39133
	207	2246	16809	8209	4192	7738	12284	12612	12608	18136
Total		8078	37275	31330	12788	24582	51561	78446	58556	94395
201-300	202	440	3074	525	749	12964	6292	5681	3798	2948
	209	1608	15336	5384	43569	12810	22275	18351	53925	7678
	210	774	10481	5572	5771	5810	823	10428	97578	9448
	213	1725	6525	31627	31100	34068	5622	8073	14748	9401
	214	1171	24370	20791	13231	25095	9669	10993	6944	33853
	215	1270	31757	55780	19546	64301	96161	60996	12584	10471
	228	1428	3930		12374	16972	23904	4357	2215	3012
	234	508	2857	1030	553	3699	1192	4614	5370	3657
Total		8924	98330	120709	126893	175719	165938	123493	197162	80468
301-400	203	480	1930			7467	230	3141	1369	2054
	208	448	1962	438	3341	631	908	3750	3153	454
	211	330	1738	10285	5685	9384	4747	6490	3016	954
	216	384	0		484	10204	454	86	24	908
	222	441	43	2029	653	2780	281	0	105	22
	229	567	1009	319	7394	3150	1144	467	516	106
Total		2650	6682	13071	17557	33616	7764	13934	8183	4498
401-500	204	354	308				3149	316	1506	2192
	217	268	0				0	0	0	-
	223	180	0				0	0	0	0
	227	686	131				0	36	129	0
	235	420	75				347	315	1584	121
Total		1908	514				3496	667	3219	2312
101-200		8078	37275	31330	12788	24582	51561	78446	58556	94395
201-300		8924	98330	120709	126893	175719	165938	123493	197162	80468
301-400		2650	6682	13071	17557	33616	7764	13934	8183	4498
401-500		1908	514				3496	667	3219	2312
Total			142801	165110	157238	233917	228759	216540	267120	181674
Total			142961	165109	157237	233916	228894	216679	267120	181731
Upper limit			199808	222301	253553	314419	424737	288880	1175017	241662
Lower limit			86113	107917	60921	153412	33051	144478	640777	121800

Table 9. Cod biomass estimates (t) from research vessel surveys in NAFO Division 3K.

Depth Range (mtrs)	Stratum Number	Stratum area (mi^2)	Gadus 15 1978	Gadus 29 1979	Gadus 44 1980	Gadus 58,59 1981	Gadus 71,72 1982	Gadus 86-88 1983	Gadus 101-102 1984
101-200	618	1455							9363
	619	1588							3004
Total									12367
201-300	620	2709	32708	55286	33699	33603	9851	33248	41781
	621	2859	25889	63106	5939	10935	11764	6750	14149
	624	668	29936	40531	1742	7973	5365	1586	959
	632	447	873	3896	10165	7566	5721	13992	
	634	1618	6907	29309	29404	40573	23579	22967	11703
	635	1274	3702	2551	7902	10271	7249	3236	5457
	636	1455	2248	5040	11959	8428	14144	6335	7065
	637	1132	3540	10613	7871	9829	13256	17317	34548
Total		12162	105803	210332	108681	129178	90929	105431	115662
301-400	623	1027	11293	7522	15746	2175	4849	12071	20190
	625	850	1825	5538	4626	2640	4817	3499	1397
	626	919	6976	1940	3242	4781	2076	3932	1653
	628	1085	2729	6206	2739	3848	1480	3841	2112
	629	495	1136	1062	337	150	1255	1167	832
	630	544		1019	1174	939		847	708
	633	2179	6947	6379	8073	8406	8482	6558	10861
	638	2059	4210	13362	7161	17706	10143	23310	5511
	639	1463	2204	5734	1949	3225	8335	9295	2684
Total		10621	37320	48762	45047	43870	41437	64520	45948
401-500	622	632				1297	561	289	646
	627	1194				267	330	601	318
	631	1202				451	0	1489	72
	640	198				0	0		119
	645	204				0	54	42	176
Total		3430				2015	945	2419	1331
101-200									12367
201-300			105803	210332	108681	129178	90929	105431	115662
301-400			37320	48762	45047	43870	41437	64520	45948
Total			143123	259093	153728	175023	133310	172458	175307
Upper limit			215048	421005	201839	237798	159091	216590	228070
Lower limit			71198	97181	105619	112247	107529	128325	122544

Table 10. Cod biomass estimates (t) from research vessel surveys in NAFO Division 3L (spring).

Depth range (fath)	Stratum number	Stratum area (mi^2)	ATC 262 1977	ATC 276 1978	ATC 290 1979	ATC 304-5 1980	ATC 317-8 1981	ATC 329 1982	WT 28-30 1985
31-50	350	2,071	5,187	2,106	13,637	7,124	2,539	4,775	31,785
	363	1,780	5,399	3,919	11,237	4,182	7,082	6,721	14,881
	371	1,121	535	1,490	2,439	8,148	0	789	15,647
	372	2,460	1,685	7,006	8,342	7,448	7,155	3,978	44,792
	384	1,120	10	19	3,521	2,480	462	231	284
Total		8,552	12,996	14,540	39,176	29,382	17,238	16,494	107,389
51-100	328	1,519	38		518		0	893	74
	341	1,574	3,916	1,006	2,468	3,291	2,038	8,495	4,735
	342	585	1,196	3,010	409	961		871	429
	343	525	438	1,789	1,190	2,936	946	4,768	795
	348	2,120	1,701	3,546	7,128	7,855	1,966	5,709	7,904
	349	2,114	10,746	8,879	8,800	7,282	321	10,182	16,005
	364	2,817	1,101	928	7,884	7,154	1,533	3,938	9,837
	365	1,041	1,112	532	2,953	2,442		6,056	2,160
	370	1,320	330	367	1,046	3,807	0	99	7,054
	385	2,356	422	80	1,118	6,278	413	0	2,084
	390	1,481	505	795	2,125	2,798	500	217	261
Total		17,452	21,505	20,932	35,639	43,804	8,717	41,228	51,338
101-150	344	1,494	7,784	20,366	19,398	10,172	50,712	19,583	648
	347	983	1,128	8,492	7,705	16,019	9,043	21,435	3,416
	366	1,394	6,211		11,509	5,912	81,497	21,817	45,178
	369	961	2,050	999	2,448	7,406	9,378	4,959	19,297
	386	983	1,228	251	2,881	2,361	4,593	1,279	3,877
	389	821	1,343	1,063	1,098	6,923	478	1,664	6,169
	391	282	634	356	1,048	2,064	1,212	95	429
Total		6,918	20,378	31,527	46,087	50,857	155,913	70,832	79,014
151-200	345	1,432	13,271	10,687	4,844	11,674	29,493	6,060	2,939
	346	865	990		2,137	2,154	4,307	1,223	341
	368	334	404		239	796	1,761	809	1,536
	387	718	122	184	459	256	243	2,353	21,491
	388	361	1,181	181	349	108	190	1,321	346
	392	145	30	66	189	0	128	256	2,237
Total		3,855	15,998	11,118	8,217	14,988	36,122	12,022	28,890
31-50		8,552	12,996	14,540	39,176	29,382	17,238	16,494	107,389
51-100		17,452	21,505	20,932	35,639	43,804	8,717	41,228	51,338
101-150		6,918	20,378	31,527	46,087	50,857	155,913	70,832	79,014
Total			70,877	78,118	129,117	139,030	218,214	140,578	266,628
Upper limit			93,640	100,261	154,966	166,965	405,205	171,826	337,779
Lower limit			48,114	55,974	103,267	111,094	31,224	109,329	195,476

Table 11. Cod biomass (t) from stratified random cruises in NAFO Division 3L (fall, 1981-84; winter, 1985).

Depth Range	Stratum No.	Stratum Area	ATC 323-325 1981	ATC 333-334 1982	W. Templeman 7-9 1983	W. Templeman 16-18 1984	W. Templeman 22-24 1985
31-50	350	2071	6244	3849	8463	16498	3084
	363	1780	852	2009	17993	20017	4497
	371	1121	137	1363	6126	11210	489
	372	2460	20737	6882	44364	27045	7067
	384	1120	-	1090	5941	27463	193
	Total	8552	29970	15193	82887	102233	15330
51-100	328	1519	-	-	-	299	114
	341	1574	2146	901	1949	1760	447
	342	585	834	951	263	736	23
	343	525	1419	-	661	2261	926
	348	2120	2651	4249	3125	11537	9518
	349	2114	3604	3174	2266	8257	7964
	364	2817	1932	1800	1946	4536	5903
	365	1041	17904	3702	961	3624	5699
	370	1320	300	446	1184	7891	3263
	385	2356	38	43	1019	1886	11322
	390	1481	9	58	852	1130	5347
Total		17452	30837	15324	14226	43917	50526
101-150	344	1494	3869	7701	1682	6121	1457
	347	983	4550	4805	3167	5731	2236
	366	1394	9313	11920	8999	7101	2260
	369	961	7755	2290	5849	3962	29179
	386	983	1414	1430	-	2546	46147
	389	821	-	3428	-	2737	35844
	391	282	-	487	159	79	2710
Total		6918	26901	32061	19856	28277	119833
151-200	345	1432	4703	7686	6443	3673	430
	346	865	12012	4212	7746	3003	35605
	368	334	5948	3604	-	1222	12498
	387	718	1334	8216	-	7465	54145
	388	361	-	461	-	616	22162
	392	145	-	220	109	68	2182
Total		3855	23997	25399	14298	16047	127022
31-50		8552	29970	15193	82887	102233	15330
51-100		17452	30837	15324	14226	43917	50526
101-150		6918	26901	32061	19856	28277	119833
151-200		3855	23997	25399	14298	16047	127022
Total			109706	87997	131267	191701	318563
Upper limit			153131	105967	175407	226108	421863
Lower limit			66281	70027	87127	157294	215263

Table 12. Cod catch rates (t/day) in January-December 1984 from offshore areas by Newfoundland vessels, based on main species (cod).

Area	Stat. Area	Months											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Hawke Channel	202				32.7			6.0	0.9				
Belle Isle Bank	203			45.7	40.8	60.3	14.0	18.3	4.6				1.4
	204			43.0	35.2	22.4							2.9
Hamilton Bank	206	12.9			25.7								9.0
	207							9.2					40.1
Hamilton Bank	210												10.4
	211												11.4
Hamilton Inlet	208							8.1					
Funk Island Bank	343	60.8				14.5	19.4	20.4	9.1				
	344		62.4		19.5	17.6	8.6						13.6
	345	20.4	21.7	25.0	25.5	15.1				13.0	22.1	3.5	15.2
	346	25.6	37.2	20.1	19.3	11.5			13.1	9.6	15.2		16.0
	347	41.8	47.3	42.5	21.6	40.5	24.3	20.7					5.6
N. Grand Bank	329		1.8	11.2	8.4	7.5	7.3	7.2				10.6	
	330	25.8	32.7	16.3	16.2	20.0		0.9	9.8	11.9	12.3	8.3	14.6
	331	31.2	1.9	39.1	29.1	20.7	0.6	2.7			33.1	2.1	3.0
	332			1.8	3.9	21.7	14.2	14.7			2.3	0.0	
E. Grand Bank	325		8.5	6.3	3.0	42.6			1.5				
	326	9.2	5.1	16.4	16.6		3.5						
	327	0.0	2.0	1.4		7.1	10.1	10.4	10.4	13.1		2.9	
Virgin Rocks	328	15.6		3.5	11.0	12.2	9.7	7.2	10.4	8.5	4.0	15.5	15.5
Off Cape Race	333	27.4	13.5	11.6	5.8	6.5	11.2	3.0				31.9	25.6
St. Mary's	334	22.1	22.9	8.7	16.0		3.5	5.7					36.1
Funk Island	339				16.0	32.4	22.4						
St. Anthony	342						23.0	44.0					

Table 13. Cod catch rates (t/day) in 1984 from offshore areas by Newfoundland vessels, based on main species (cod).

Area	Stat. Area	Months Jan.-Mar.	Apr.-May	June-Sept.	Oct.-Dec.
Hawke Channel	202	-	32.7	4.9	-
Belle Isle	203	45.7	41.6	13.3	1.4
Bank	204	43.0	31.6	-	2.9
Hamilton	206	12.9	25.7	-	9.0
Bank	207	-	-	9.2	40.1
	210	-	-	-	10.4
	211	-	-	-	11.4
Hamilton Inlet	208	-	-	8.1	-
Funk Island	343	60.8	14.5	19.5	-
Bank	344	62.4	17.9	8.6	13.6
	345	24.6	23.6	13.0	14.9
	346	33.4	19.2	10.3	14.8
	347	42.3	28.0	24.1	5.6
Funk Island	339	-	27.6	22.4	-
St. Anthony	342	-	-	28.6	-
N. Grand Bank	329	7.8	7.9	7.3	10.6
	330	27.4	16.7	11.4	13.2
	331	32.6	25.8	1.5	3.8
	332	1.8	18.5	14.3	1.2
E. Grand Bank	325	8.1	20.6	1.5	-
	326	15.4	16.6	3.5	-
	327	1.4	7.1	10.5	2.9
Virgin Rocks	328	11.6	12.0	8.8	15.3
Off Cape Race	333	14.8	6.1	9.5	25.7
St. Mary's Bay	334	20.6	16.0	4.6	36.1

Table 14. Cod catch rates (t/day) in January-July 1985 from offshore areas by Newfoundland vessels, based on main species (cod).

Area	Stat. Area	Months						
		Jan.	Feb.	Mar.	Apr.	May	June	July
Belle Isle Bank	203		0.9	7.3	0.6		19.8	15.3
	204				53.1			
Hamilton Bank	206							5.6
	207							20.4
Funk Island Bank	343		52.1				1.5	23.7
	344						6.9	24.1
	345	12.8	57.0	26.3	19.1	12.9	14.1	11.7
	346	40.2	46.0	27.1	32.7	29.8	15.2	
	347	42.2	39.4	42.0	43.5	40.1	32.3	
N. Grand Bank	329					12.4	6.4	4.8
	330	12.0			29.6	19.2	2.8	
	331			1.1		13.2		
	332					5.9	2.1	
E. Grand Bank	325				4.2	15.8		
	326			0.6	24.9	30.1	4.7	
	327					8.6	7.6	27.1
Virgin Rocks	328		28.0	32.3	8.9	9.8	9.7	9.3
Off Cape Race	333		18.7	27.5	4.2	5.6	9.2	16.4
St. Mary's Bay	334		21.9		13.7	1.9	0.9	

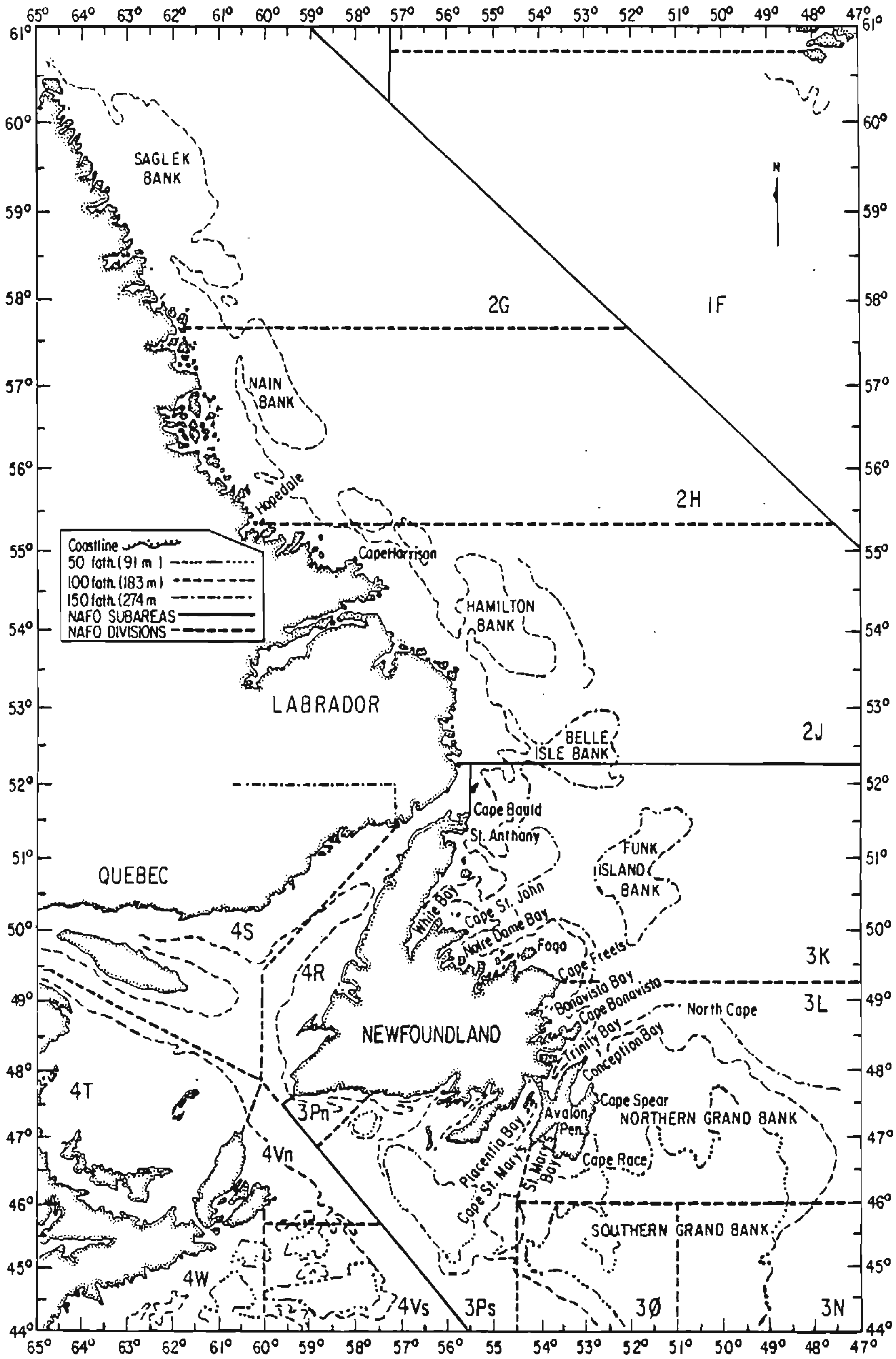

Fig. 1. Area map of Newfoundland and Labador, showing NAFO Divisions and place names mentioned in the text.

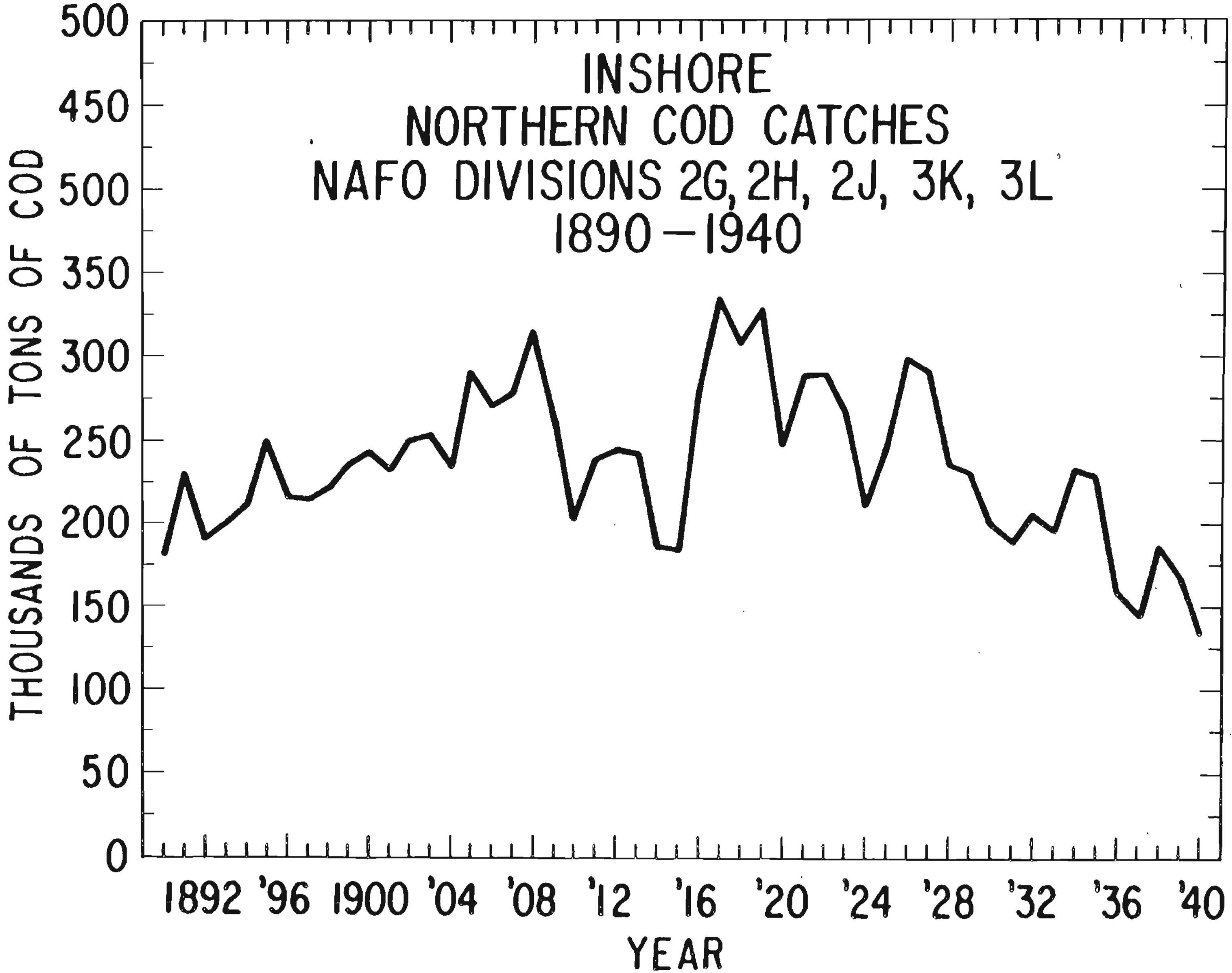

Fig. 2. Inshore catches of cod from coastal Labrador (NAFO Divisions 2G, 2H and 2J) and eastern Newfoundland (NAFO Divisions 3K and 3L) during 1890-1940.

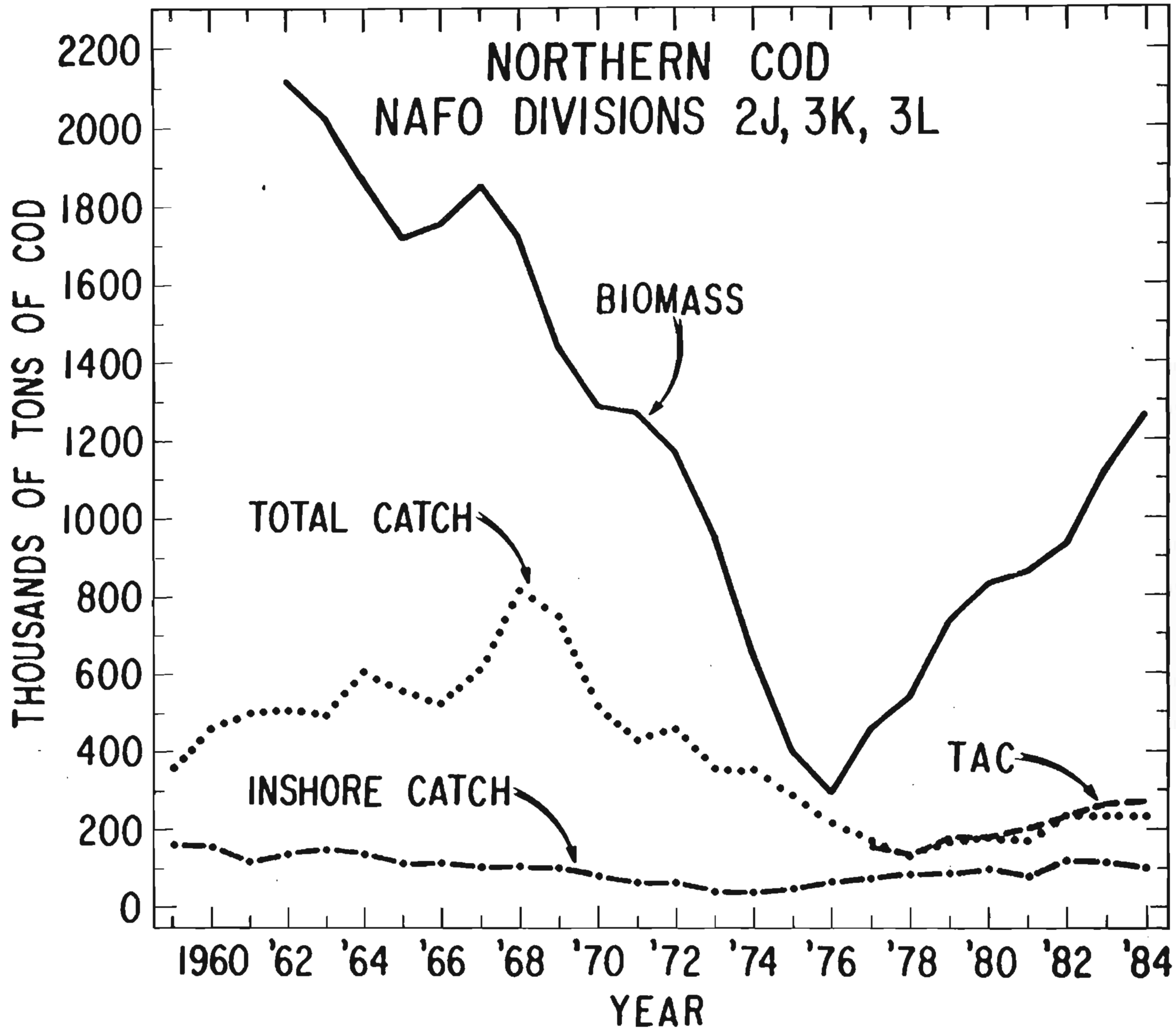

Fig. 3. Estimated biomasses of cod 4 years of age and older (1962-84), total catches and inshore catches of cod (1960-84) and total allowable catches (TAC's) during 1977-84.

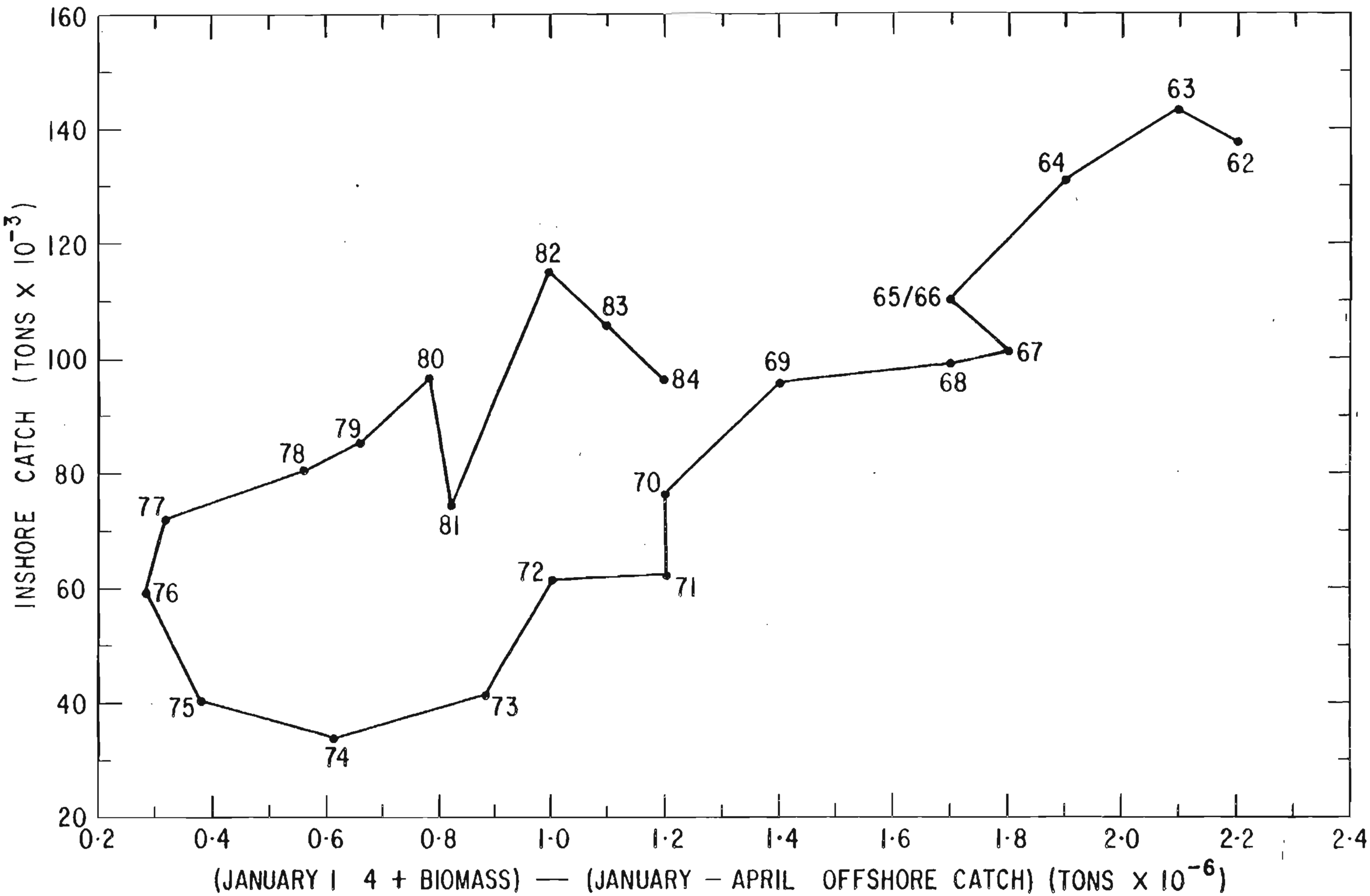

Fig. 4. Relationship between the inshore catch of cod in NAFO Divisions 2J, 3K and 3L and the offshore stock available to move inshore that year (January 1, 4+ biomass minus the January-April offshore catch).

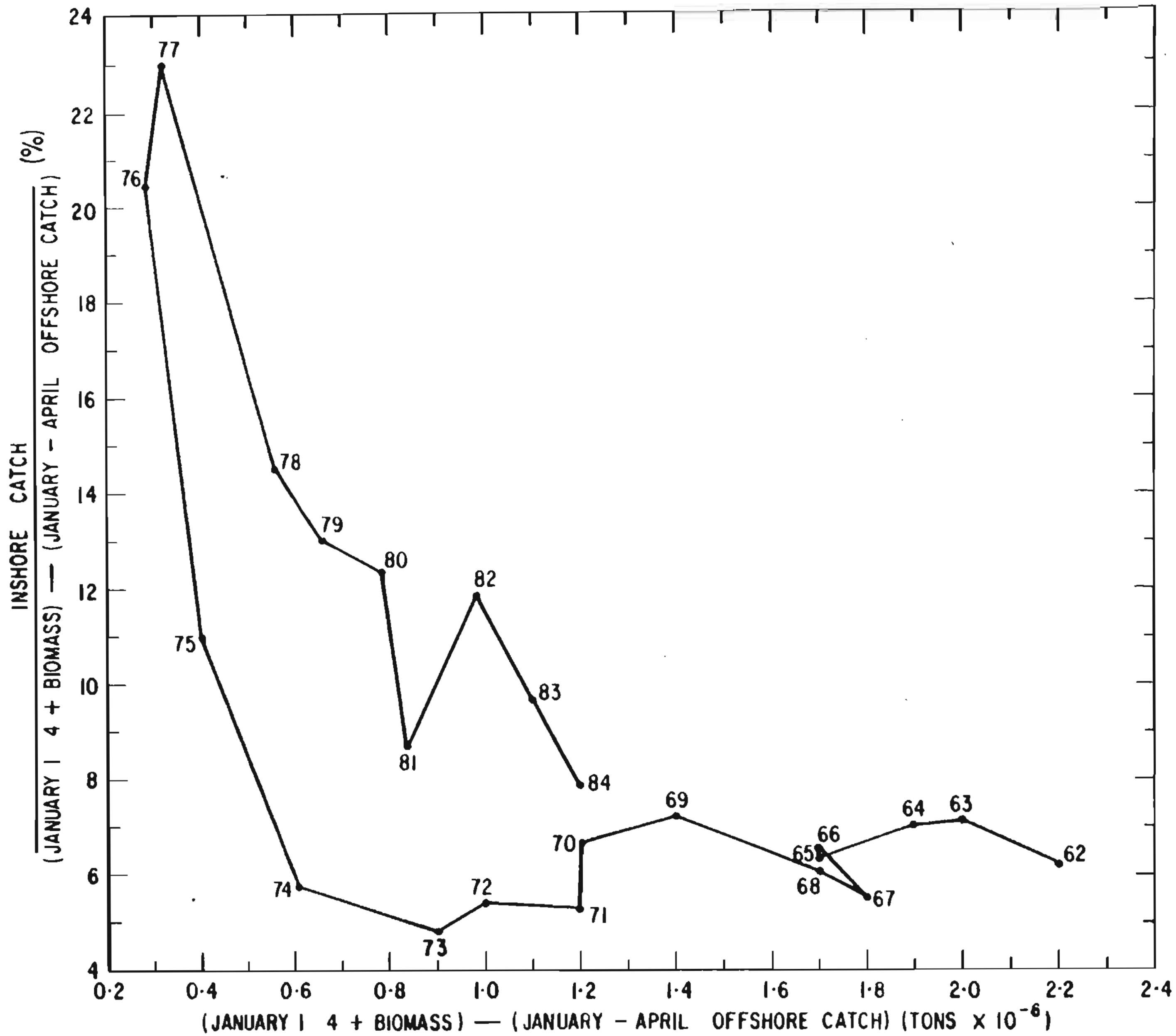

Fig. 5. Relationship between the proportional inshore catch of available biomass and the actual offshore cod stock available of NAFO Divisions 2J, 3K and 3L.

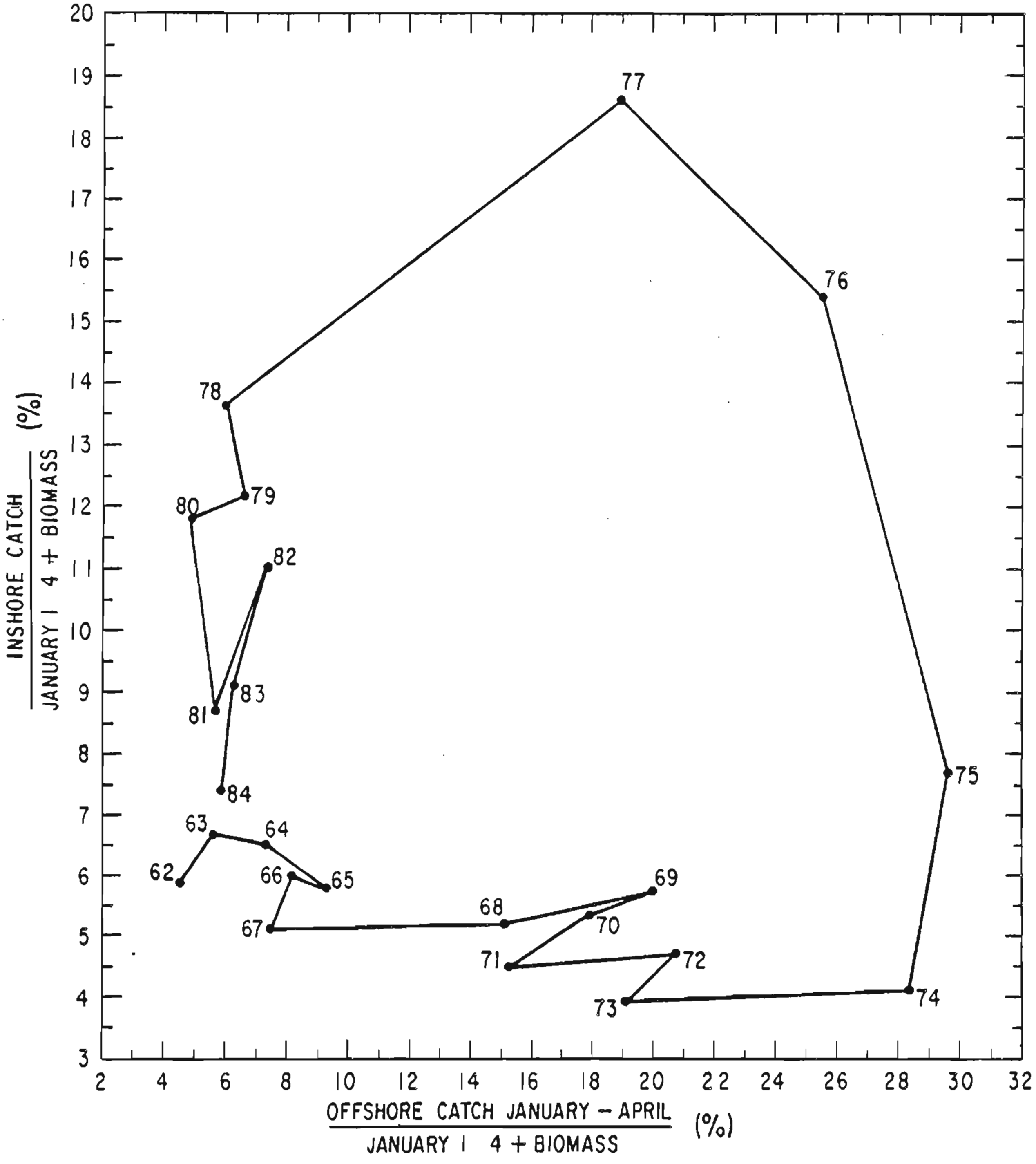

Fig. 6. Relationship between the proportional inshore catch of January 1, 4+ biomass and the proportional offshore January-April catch of January 1, 4+ biomass of cod of NAFO Divisions 2J, 3K and 3L.

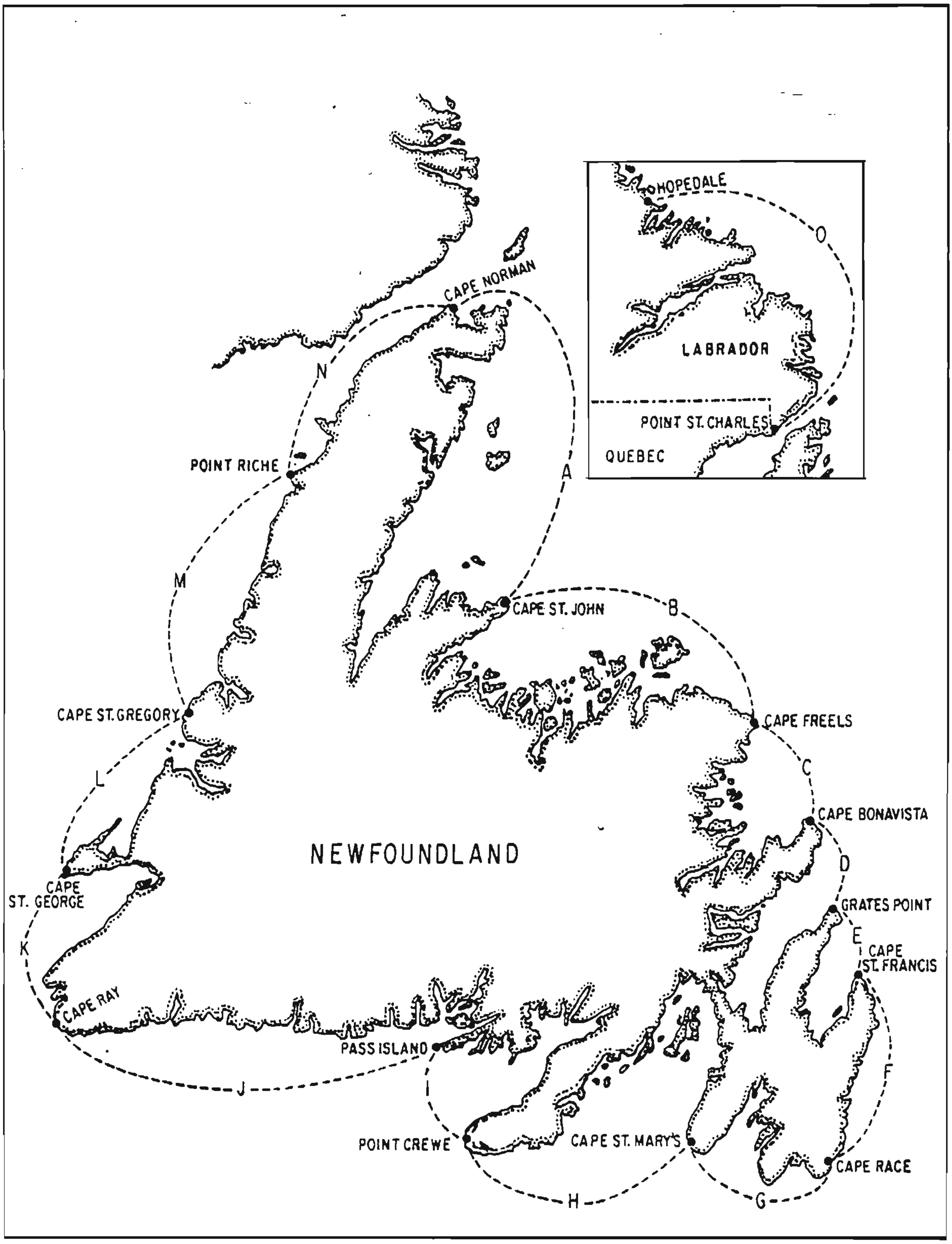

Fig. 7. Area map of Newfoundland and Labador (inset) showing Sea Fisheries Areas referred to in the text.

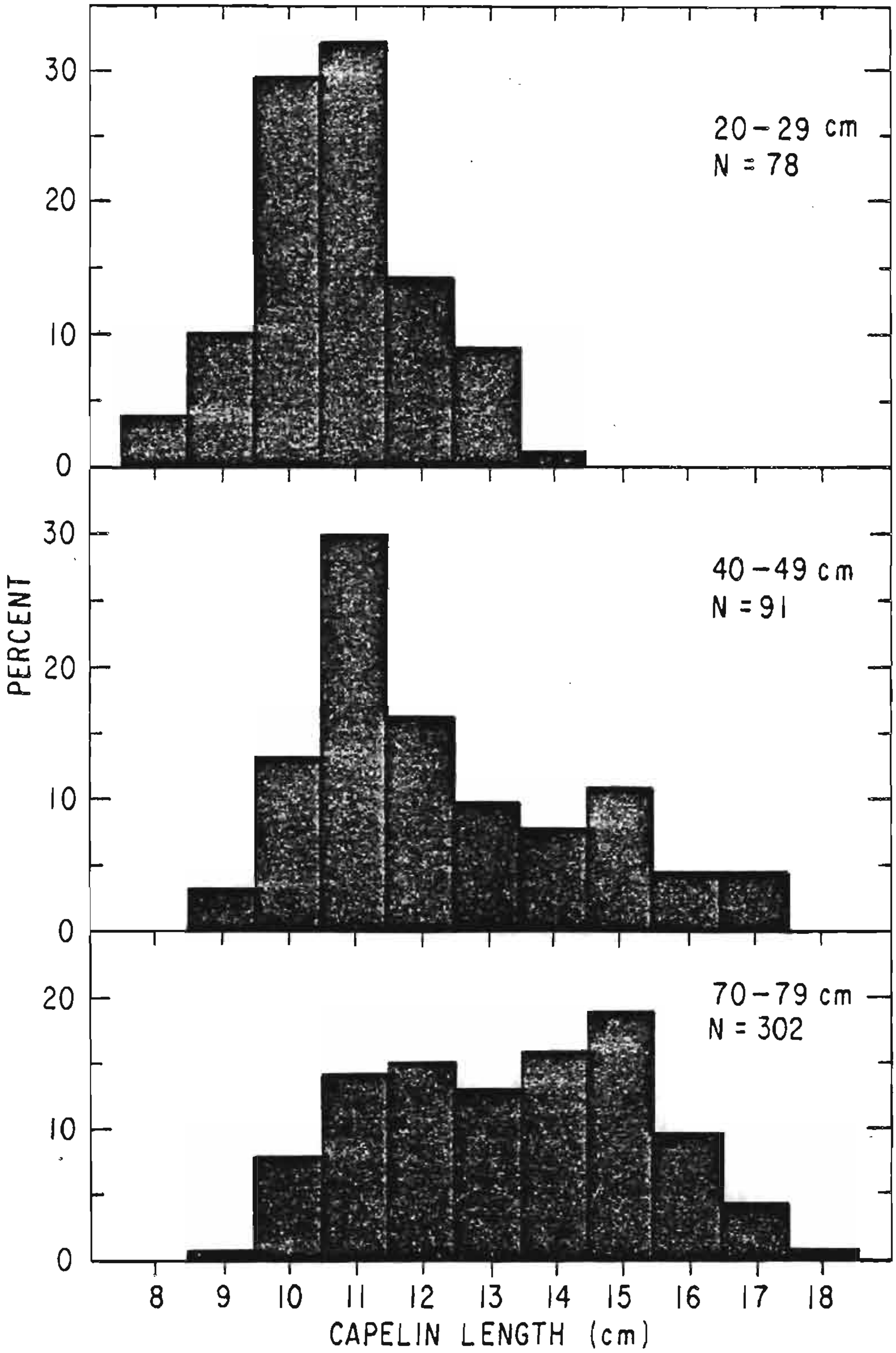

Fig. 8. Length frequencies of capelin from stomachs of cod (10-cm length-groups) caught by bottom otter trawl (GADUS ATLANTICA, Trip 49) in northwestern NAFO Division 3L, April 1981.

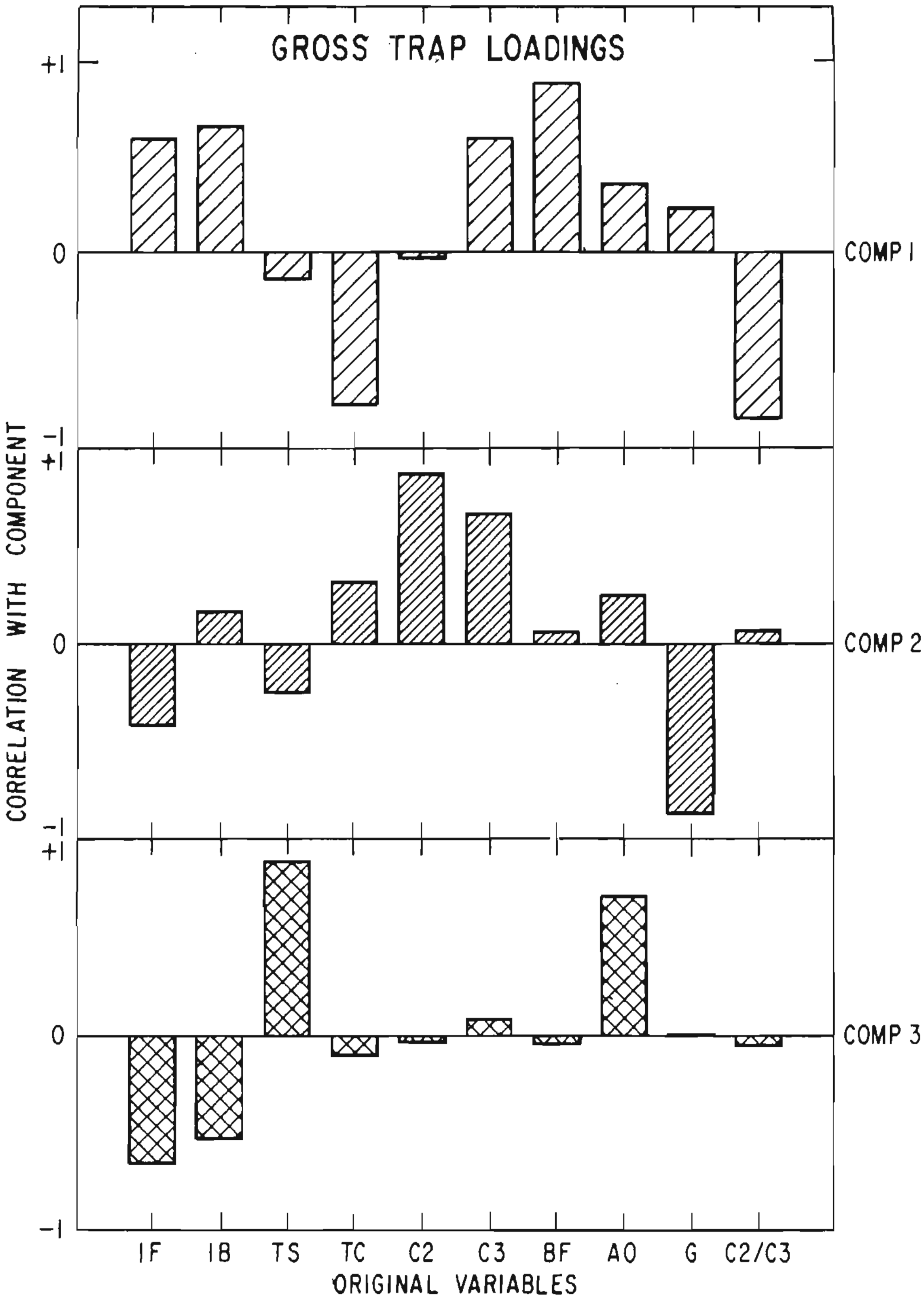

Fig. 9. Correlations of original variables with principal Components 1, 2 and 3 for gross cod trap loadings for 1975-84.

In this and succeeding figures, the following abbreviations are used for the various factors:

IF = Last date when ice might have prevented fishing at Cape Freels.
IB = Last date when ice might have prevented fishing at Cape Bauld.
TS = Mean surface temperature at 0-20 m for June.
TC = Mean core temperature for June-July in depth range 100-150 m.
C2 = Index of abundance of age 2 capelin.
C3 = Index of abundance of age 3 capelin.
BF = Cod catch in Areas B to F.
AO = Cod catch in Areas A and O.
G = Cod catch in Area G.
C2/C3 = Proportion of 2-year-old capelin to 3-year-old capelin.

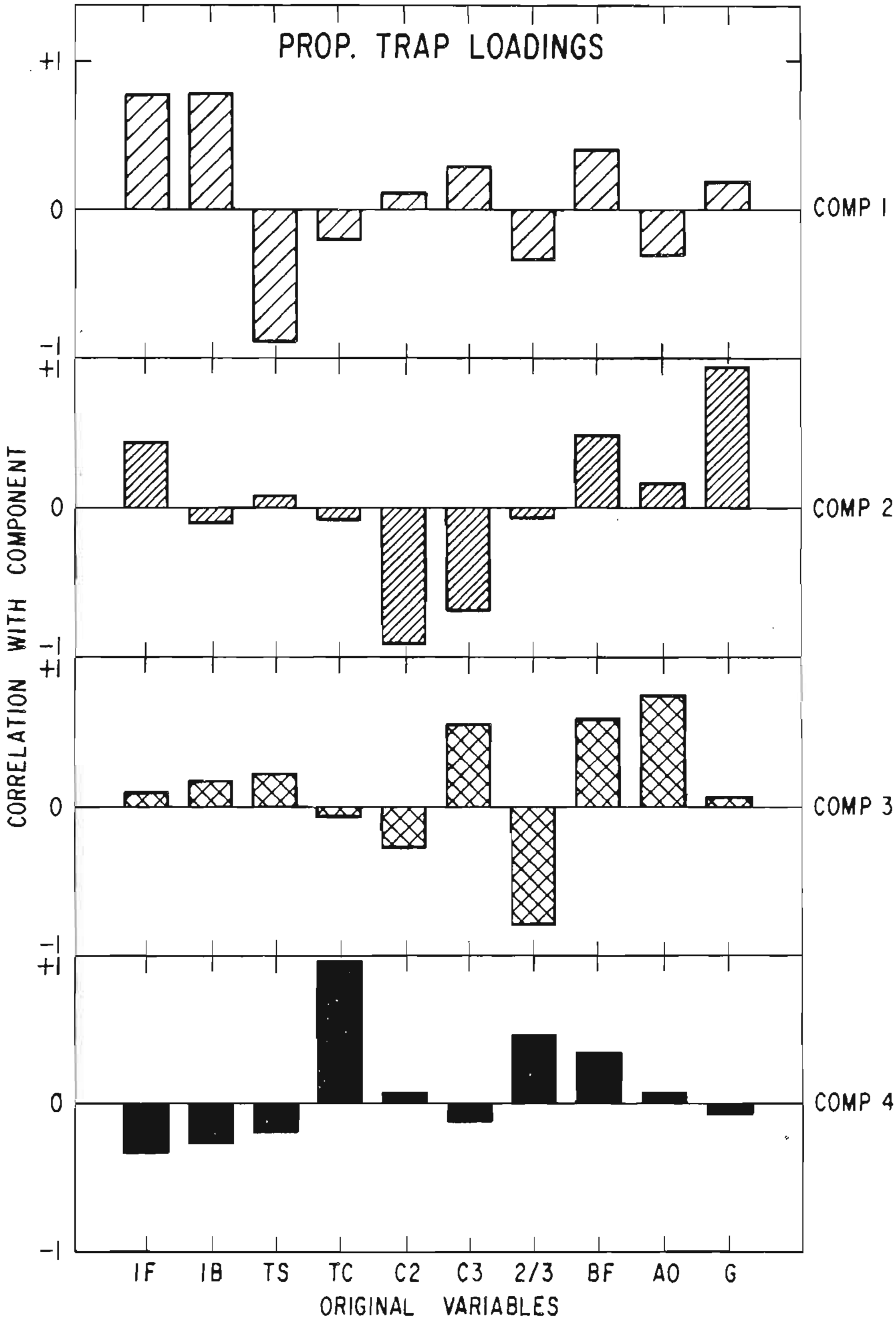

Fig. 10. Correlations of original variables with principal Components 1, 2, 3 and 4 for the proportional cod trap loadings during 1975-84.

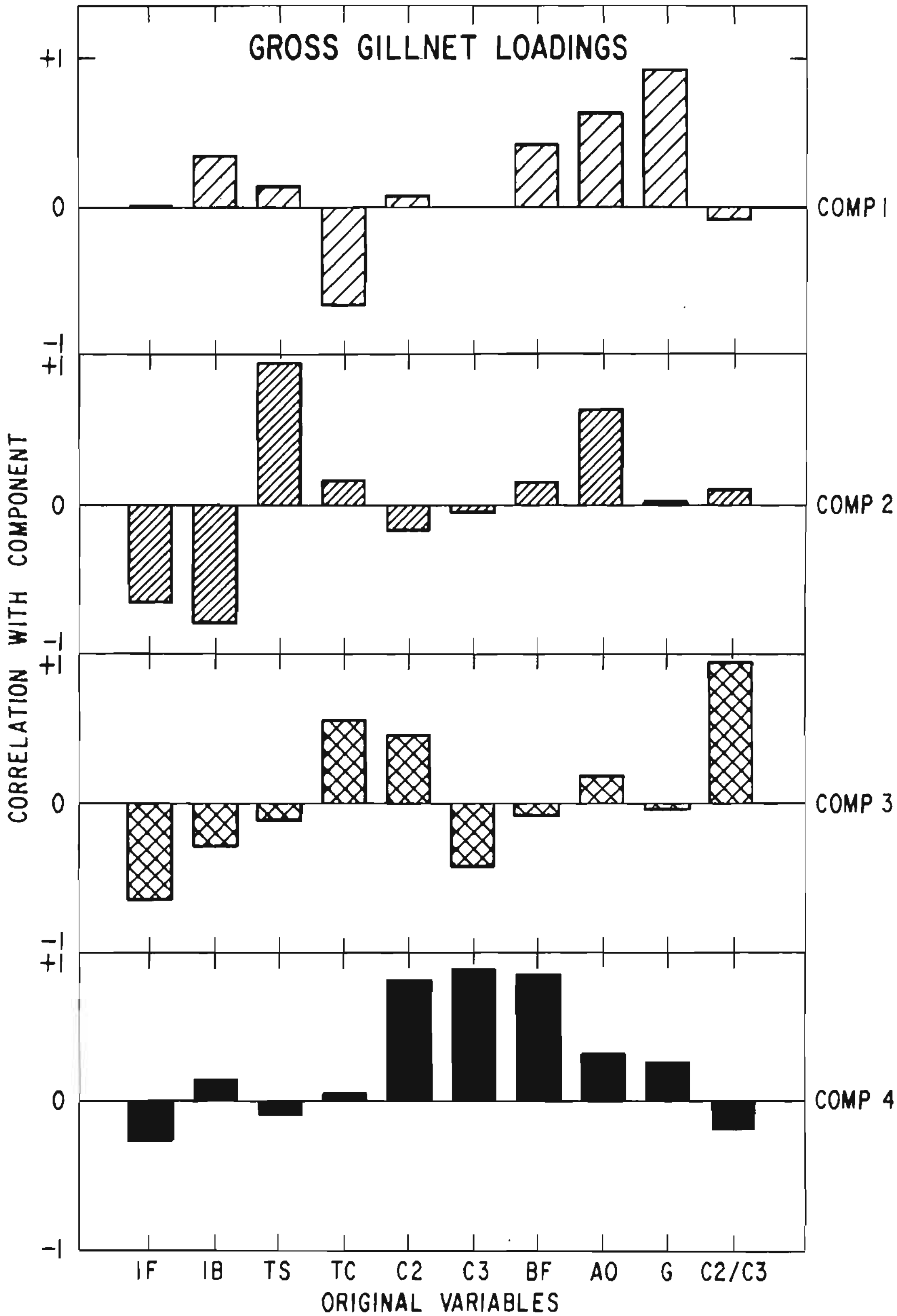

Fig. 11. Correlations of original variables with principal Components 1, 2, 3 and 4 for the gross gillnet loadings during 1975-84.

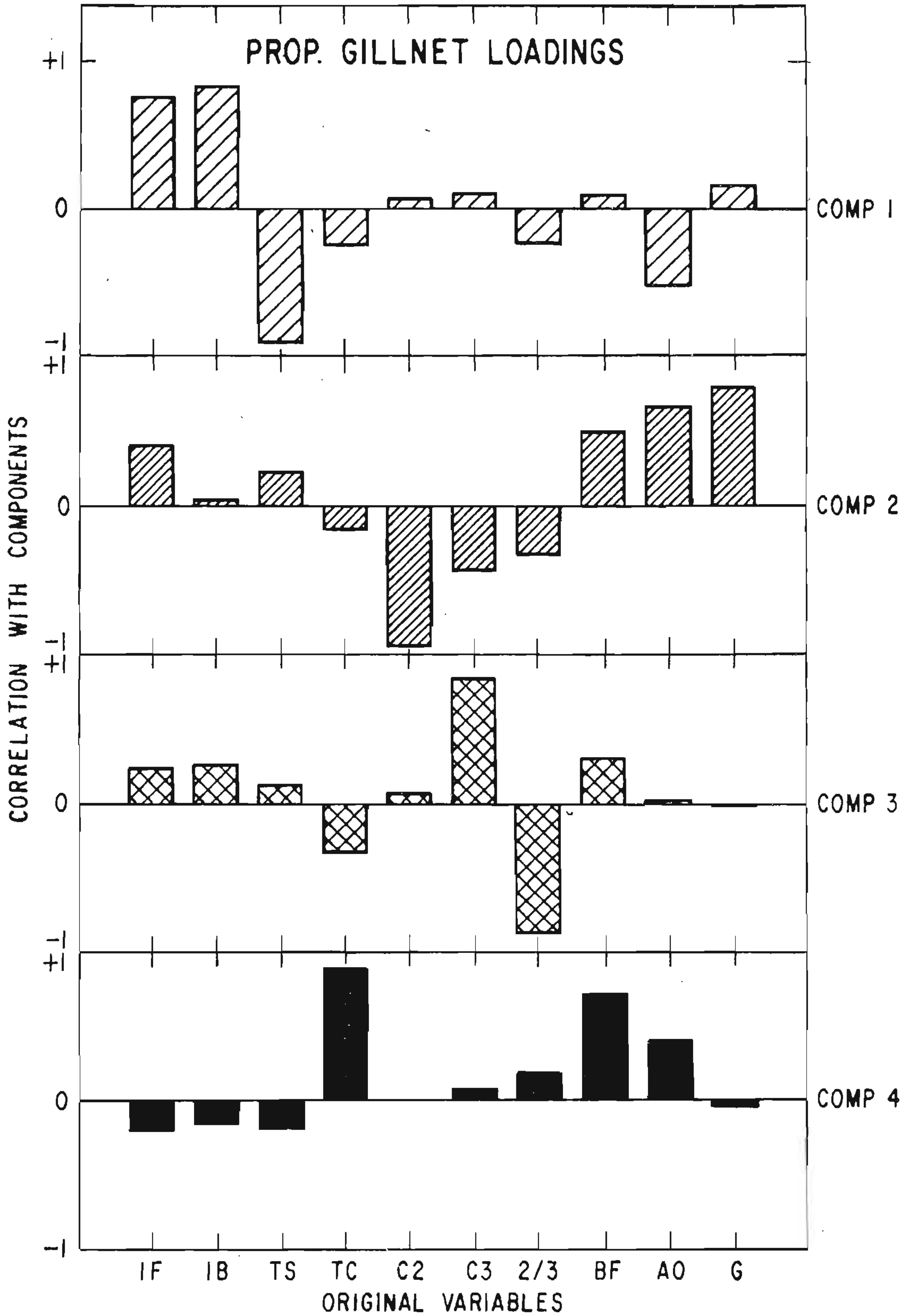

Fig. 12. Correlations of original variables with principal Components 1, 2, 3 and 4 for the proportional gillnet loadings during 1975-84.

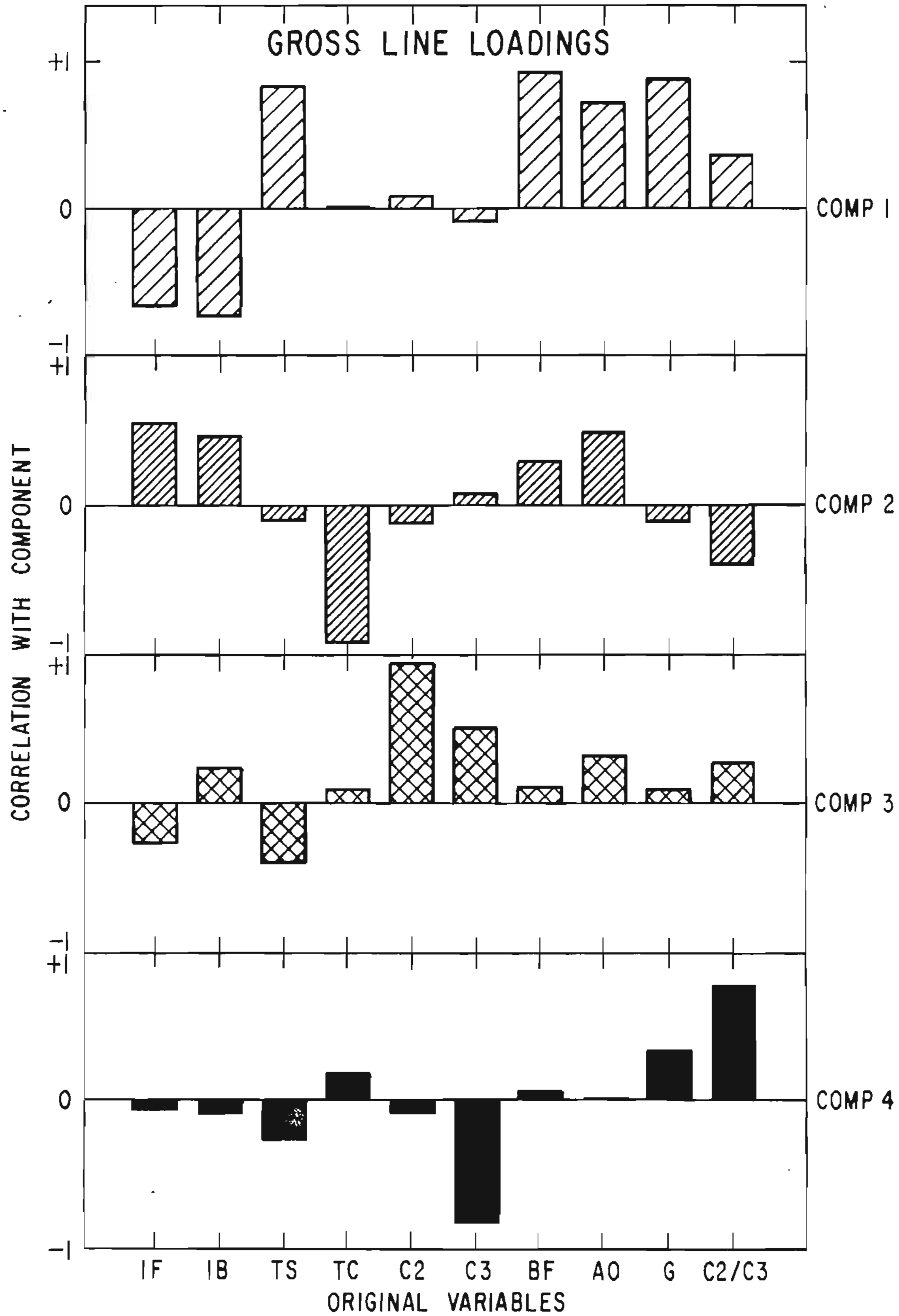

Fig. 13. Correlations of original variables with principal Components 1, 2, 3 and 4 for the gross handline and longline loadings during 1975-84.

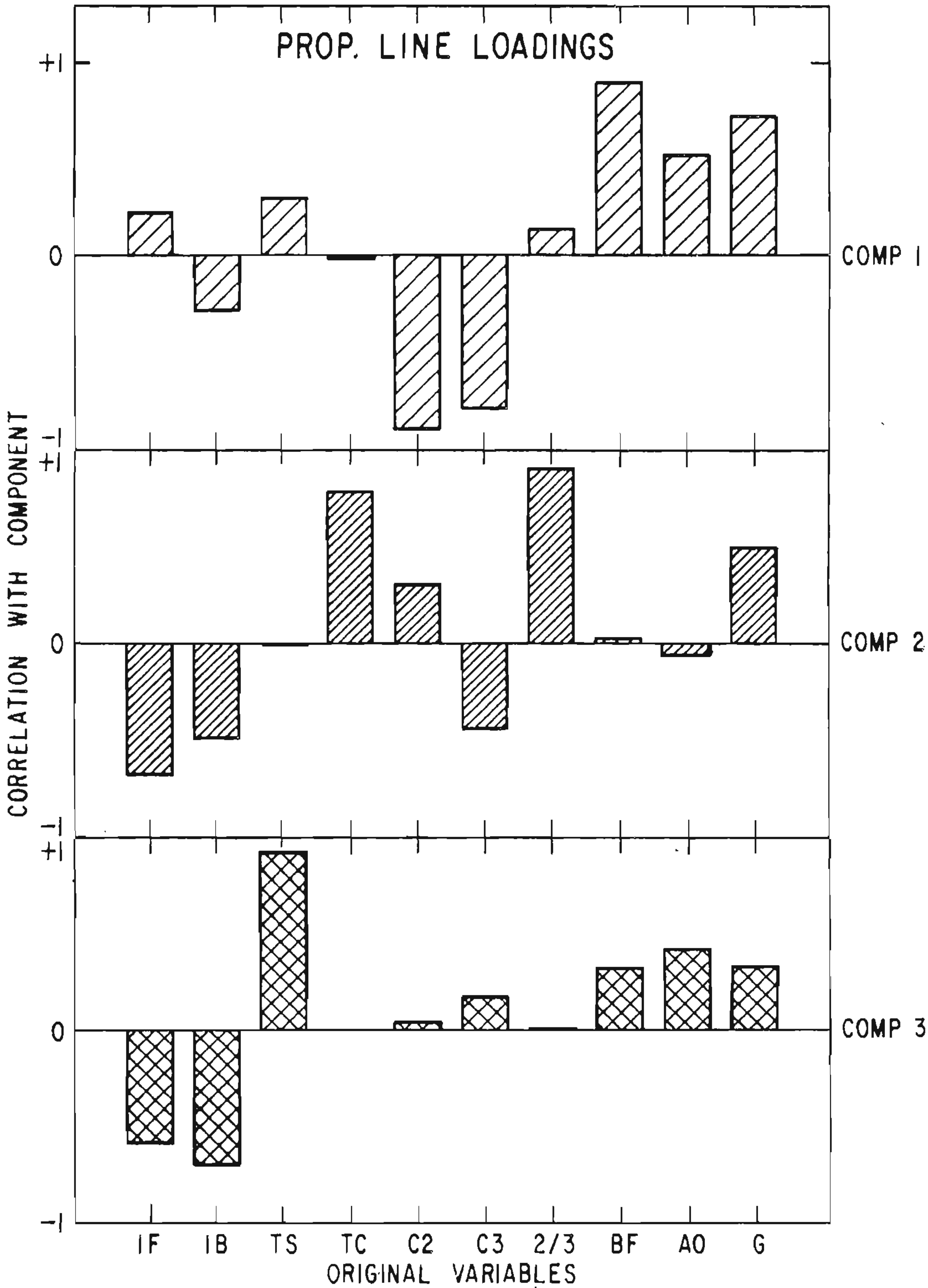

Fig. 14. Correlations of original variables with principal Components 1, 2, and 3 for the proportional handline and longline loadings during 1975-84.

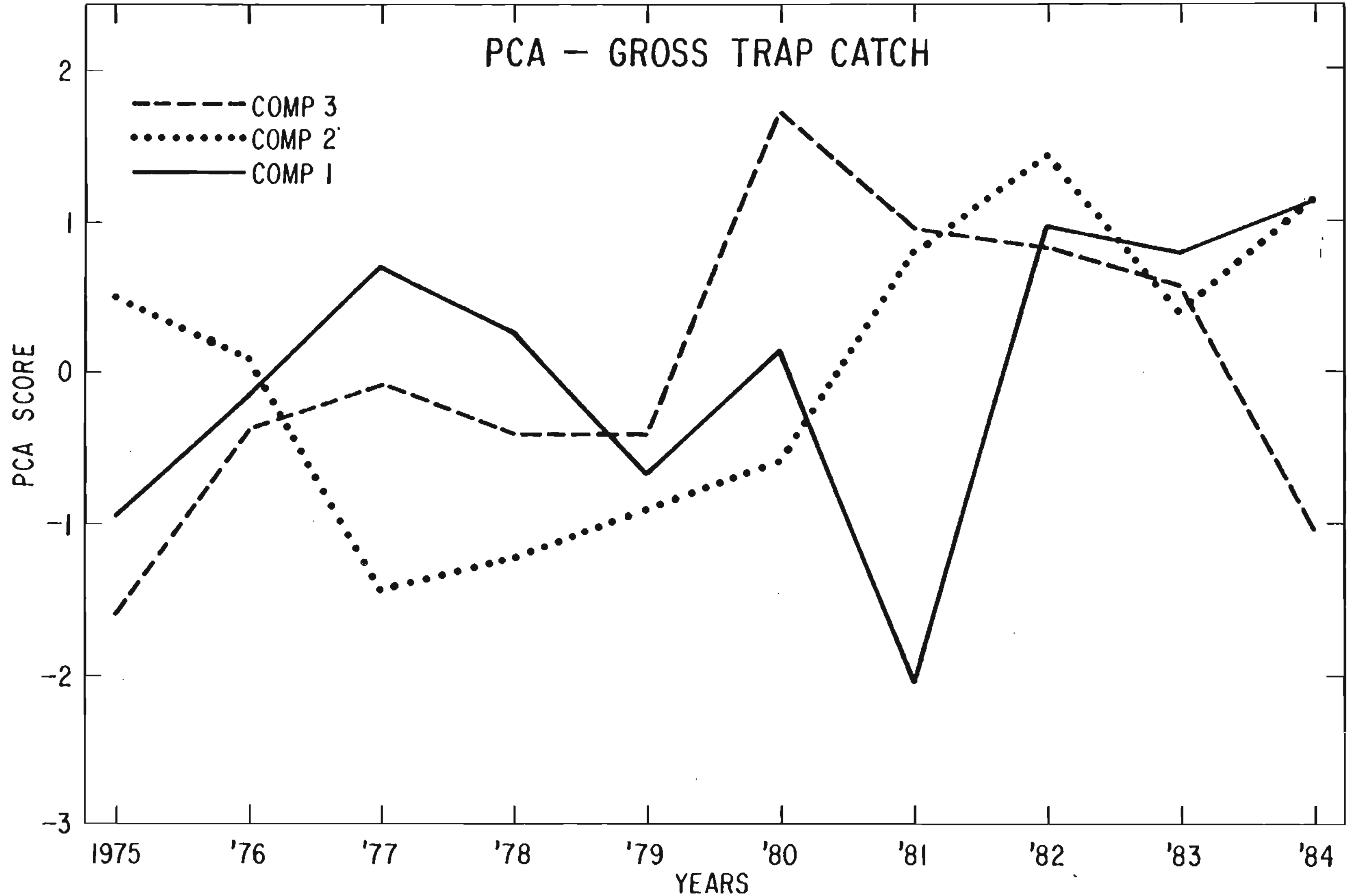

Fig. 15. PCA scores for Components 1, 2, and 3 for the gross cod trap catches during 1975-84.

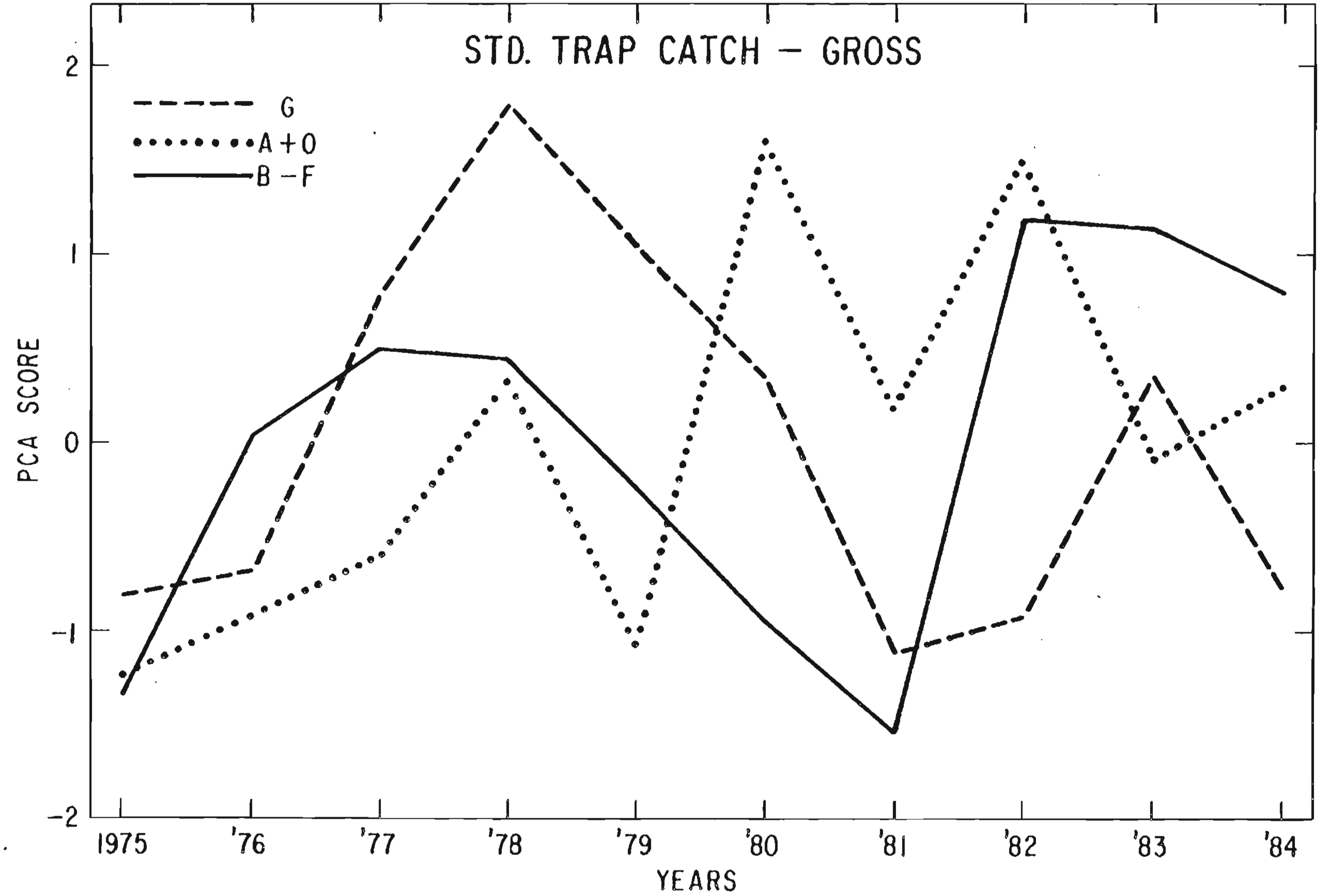

Fig. 16. PCA scores for standardized gross cod trap catches in Areas G, A and O, and B to F during 1975-84.

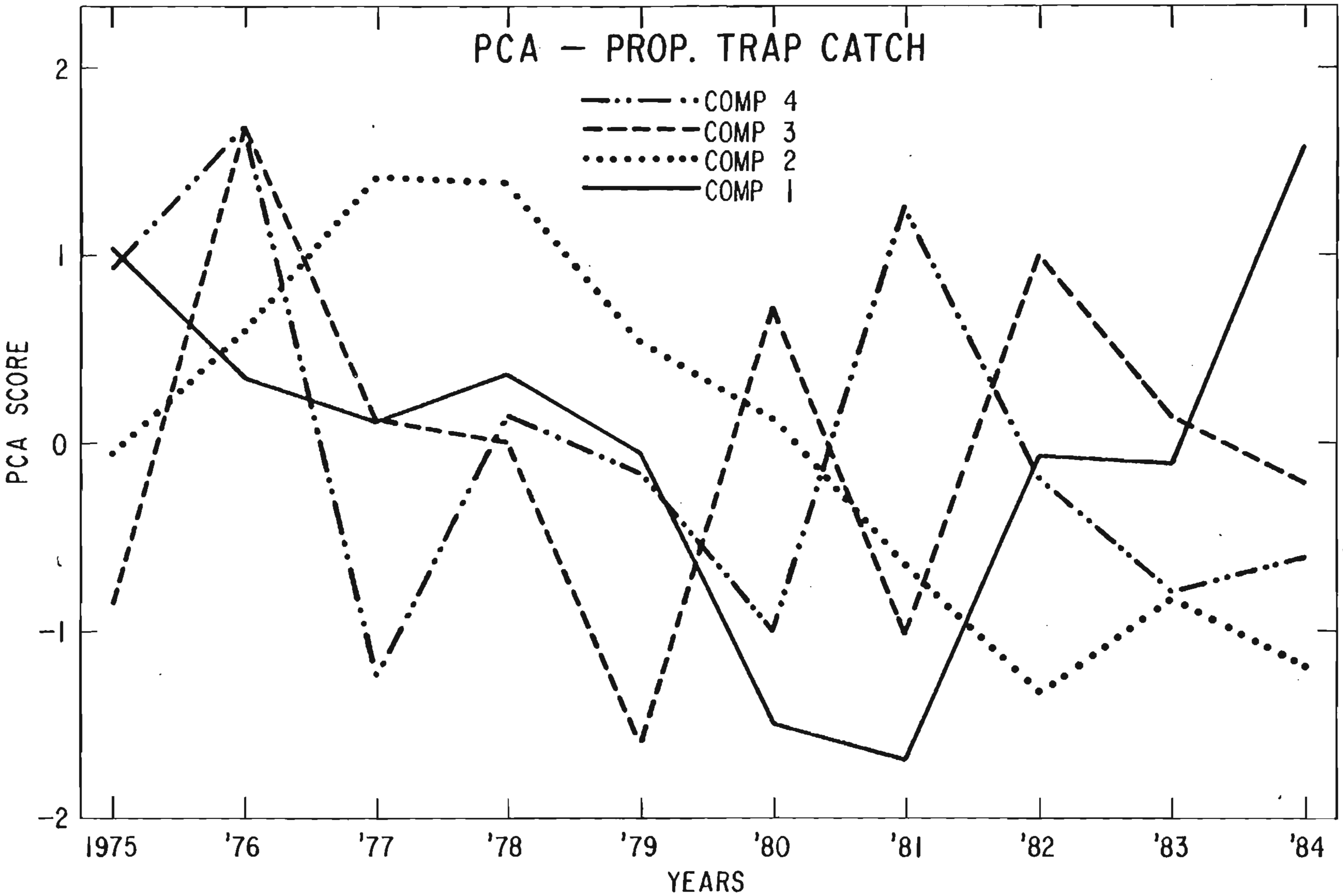

Fig. 17. PCA scores for Components 1, 2, 3 and 4 for the proportional cod trap catches during 1975-84.

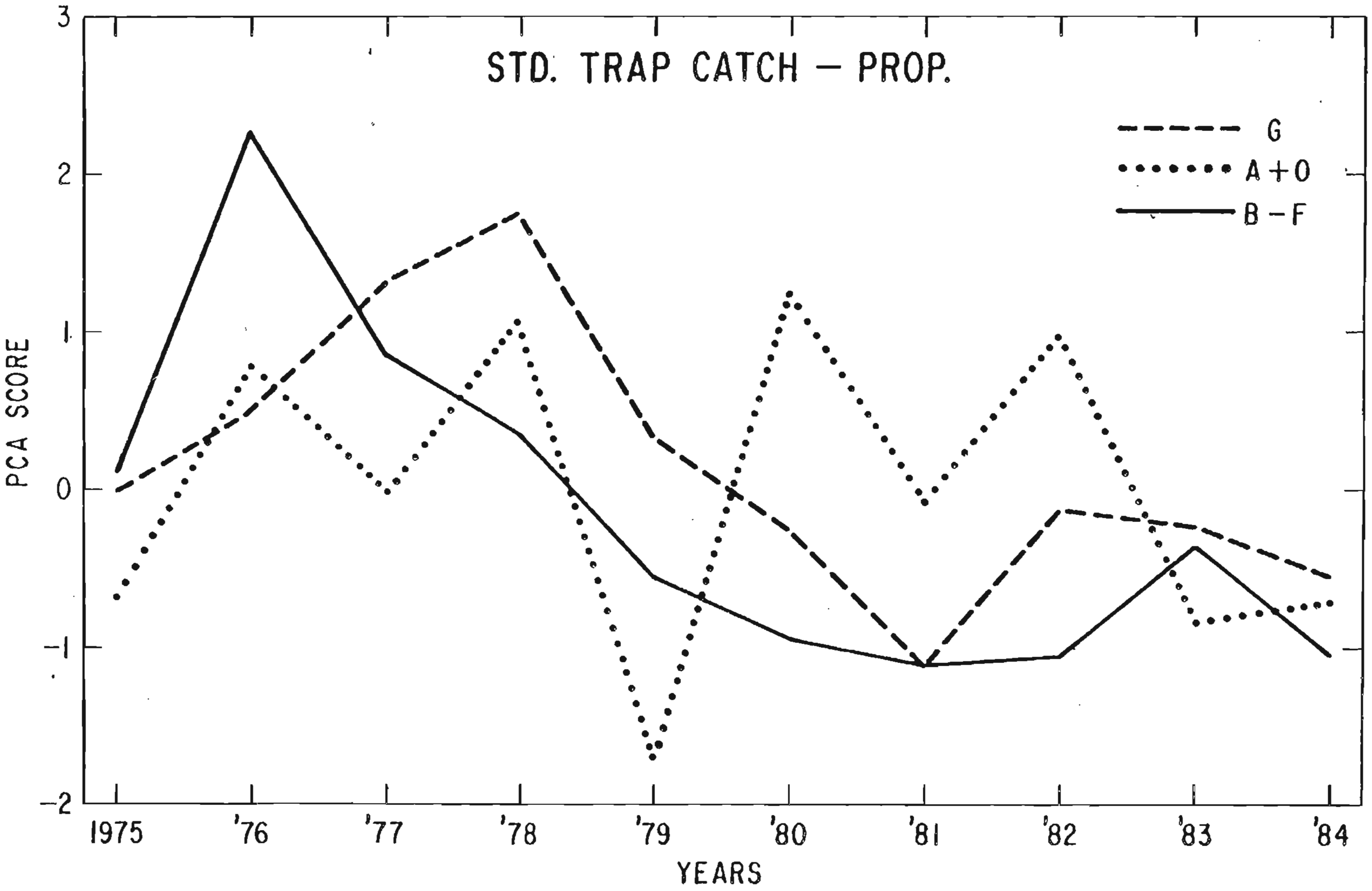

Fig. 18. PCA scores for standardized proportional cod trap catches in Areas G, A and O, and B to F during 1975-84.

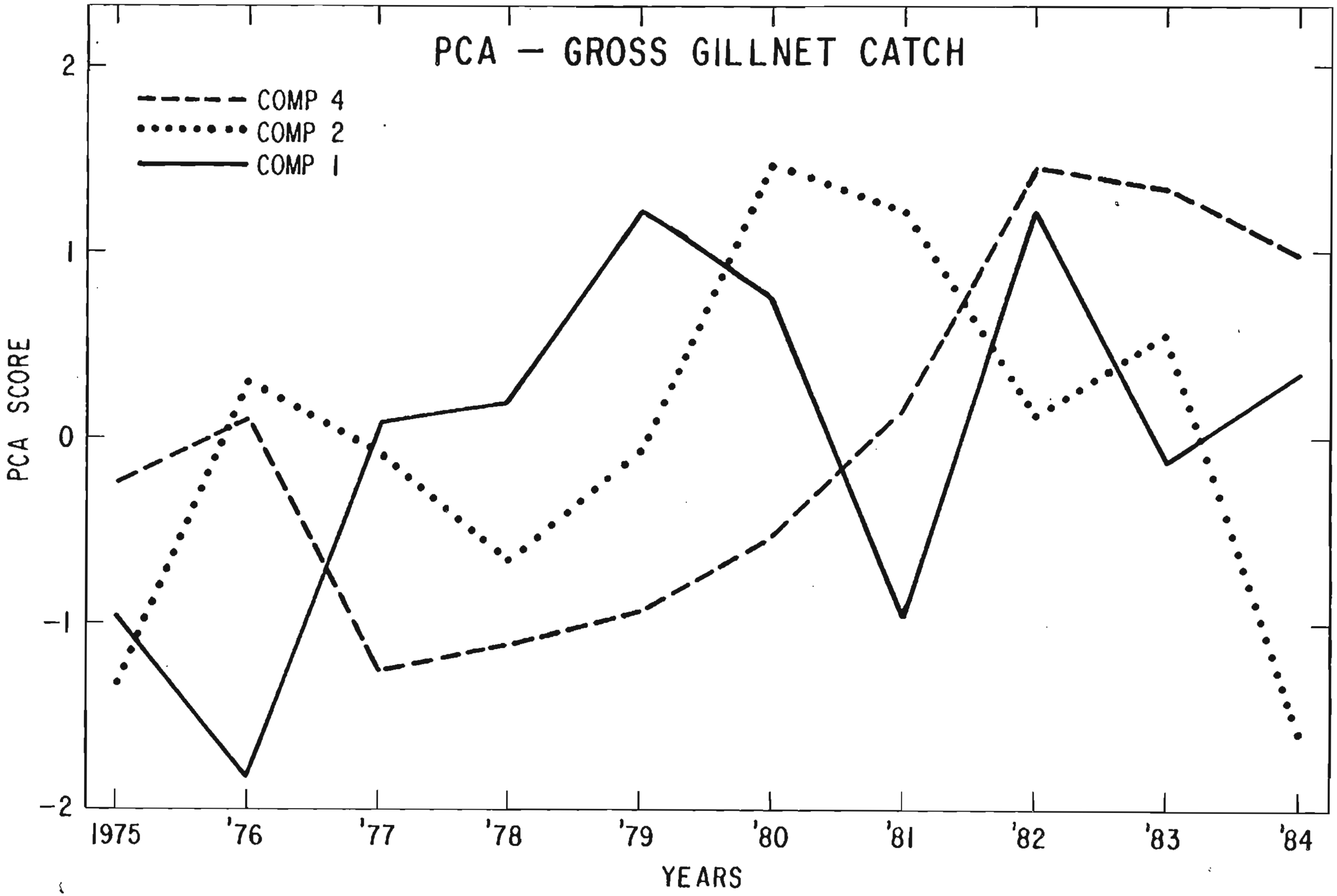

Fig. 19. PCA scores for Components 1, 2 and 4 for the gross gillnet catches during 1975-84.

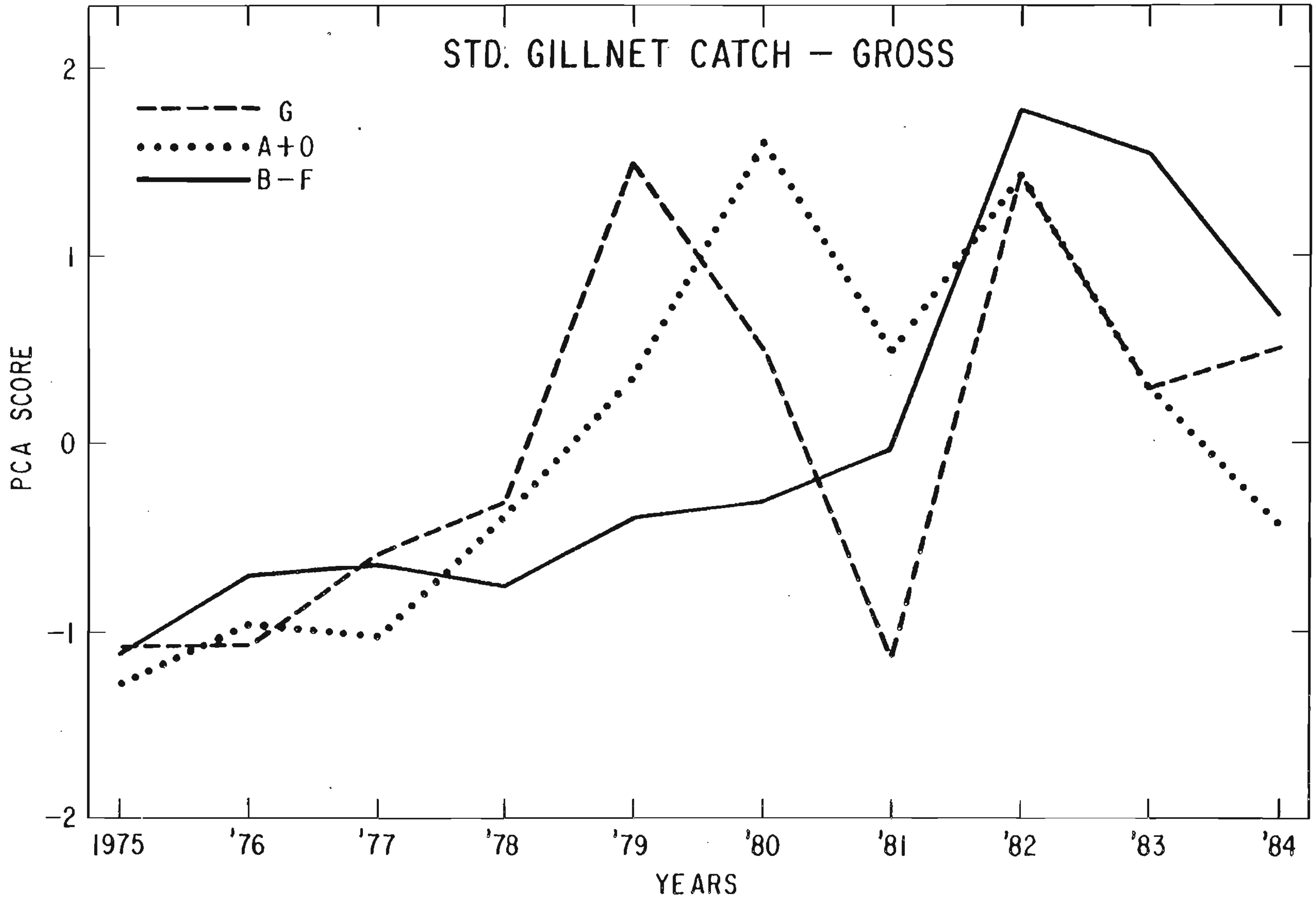

Fig. 20. PCA scores for standardized gross gillnet catches in Areas G, A and O, and B to F during 1975-84.

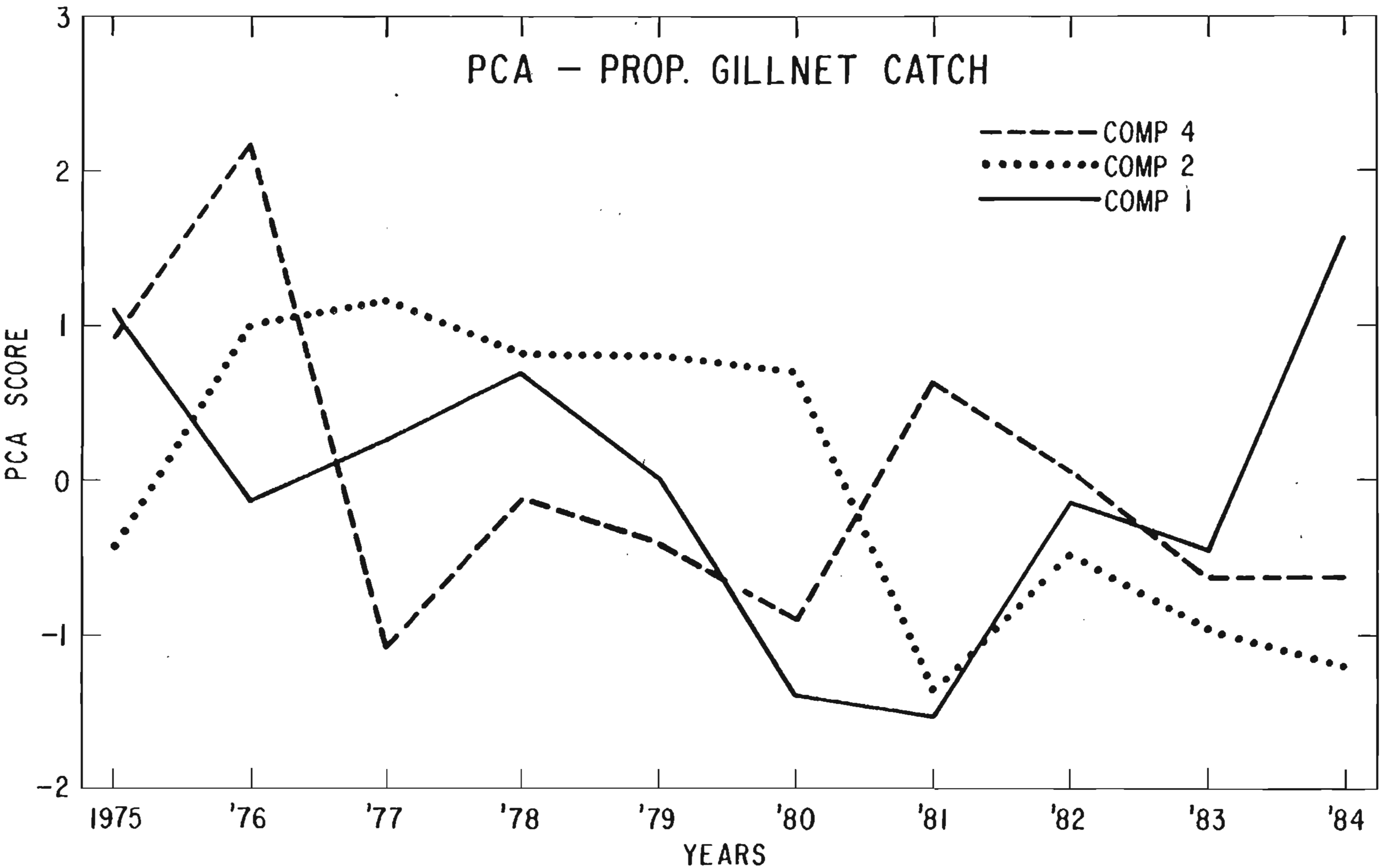

Fig. 21. PCA scores for Components 1, 2 and 4 for the proportional gillnet catches during 1975-84.

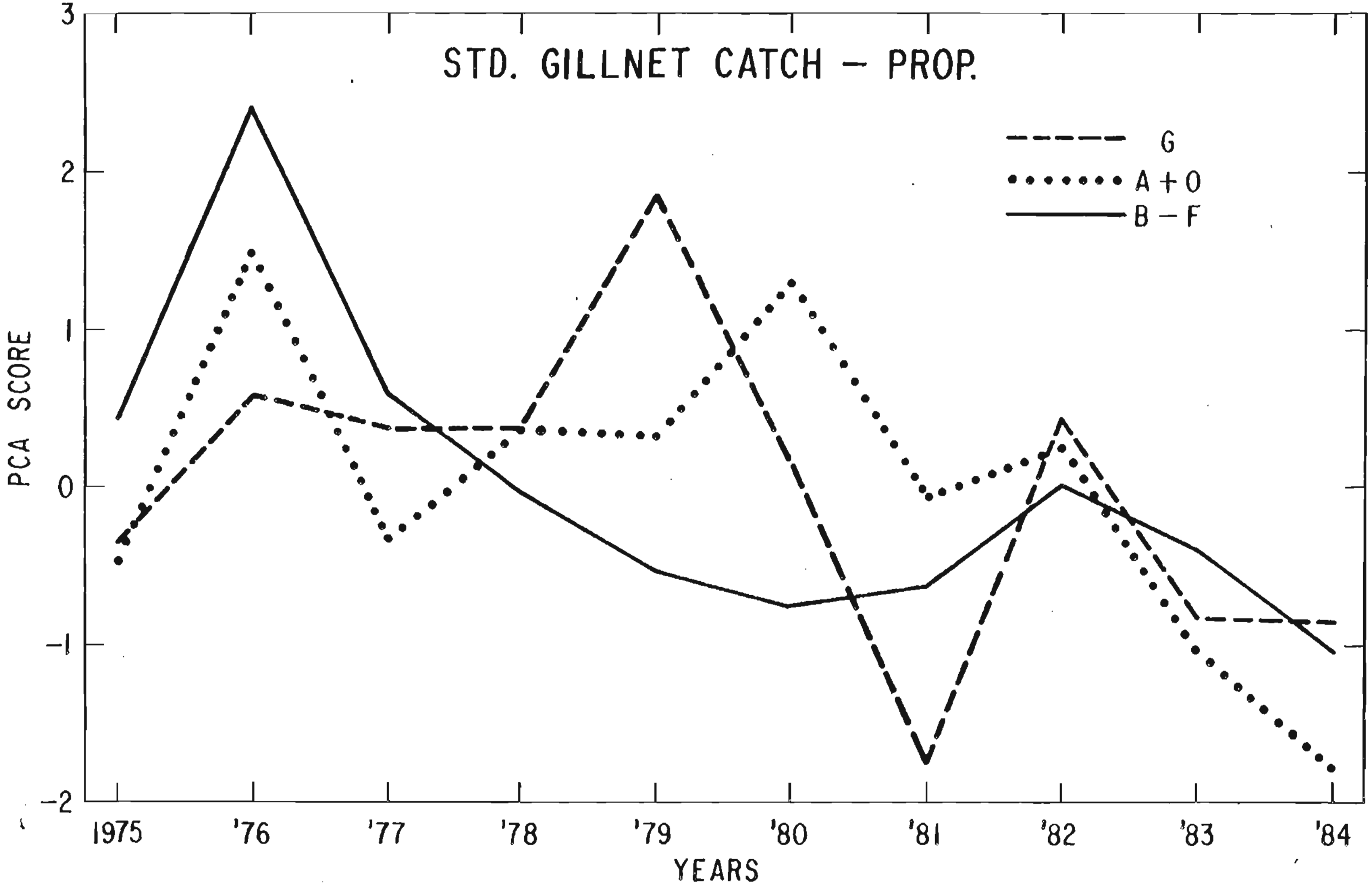

Fig. 22. PCA scores for standardized proportional gillnet catches in Areas G, A and O, and B to F during 1975-84.

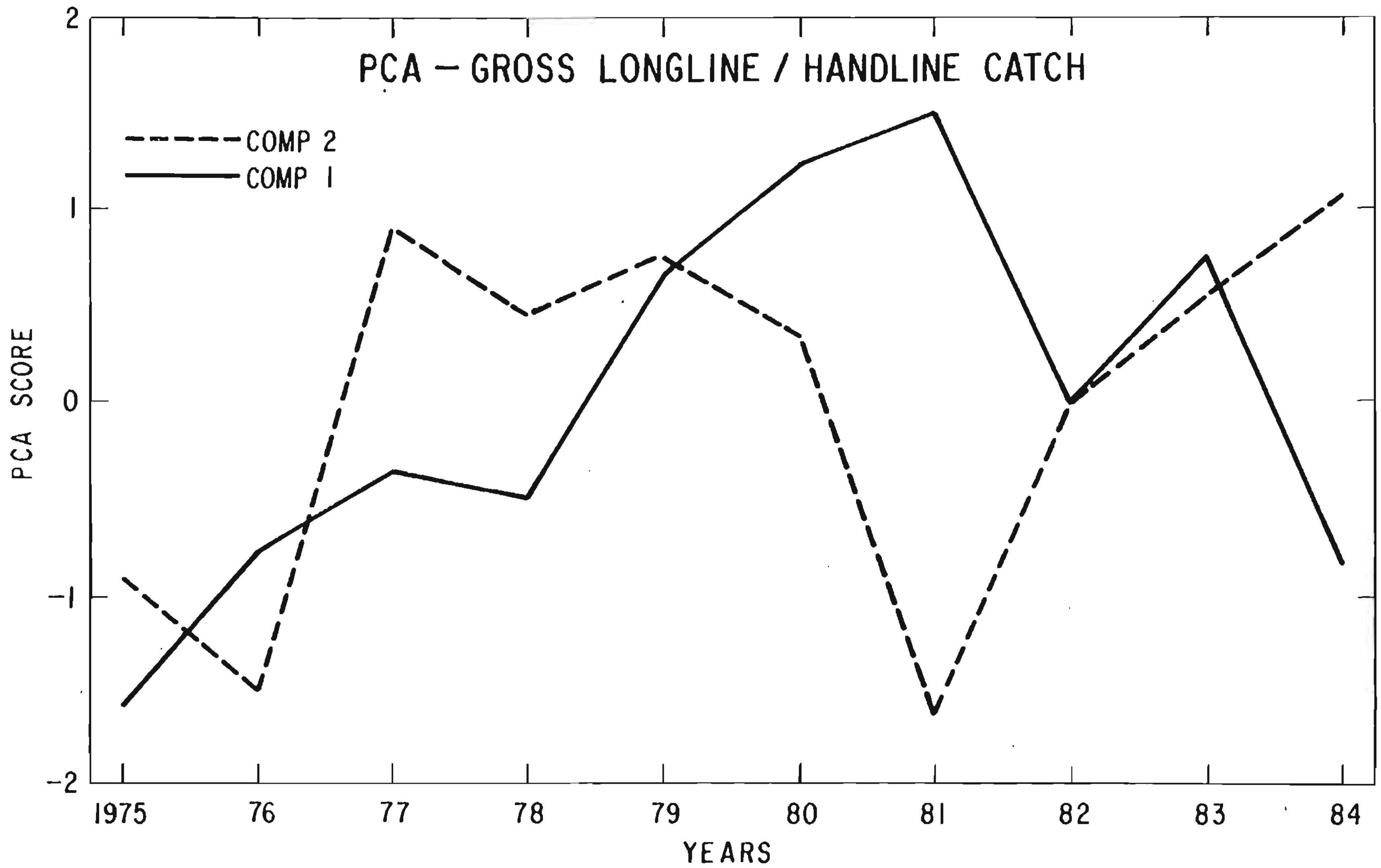

Fig. 23. PCA scores for Components 1 and 2 for the gross longline and handline catches during 1975-84.

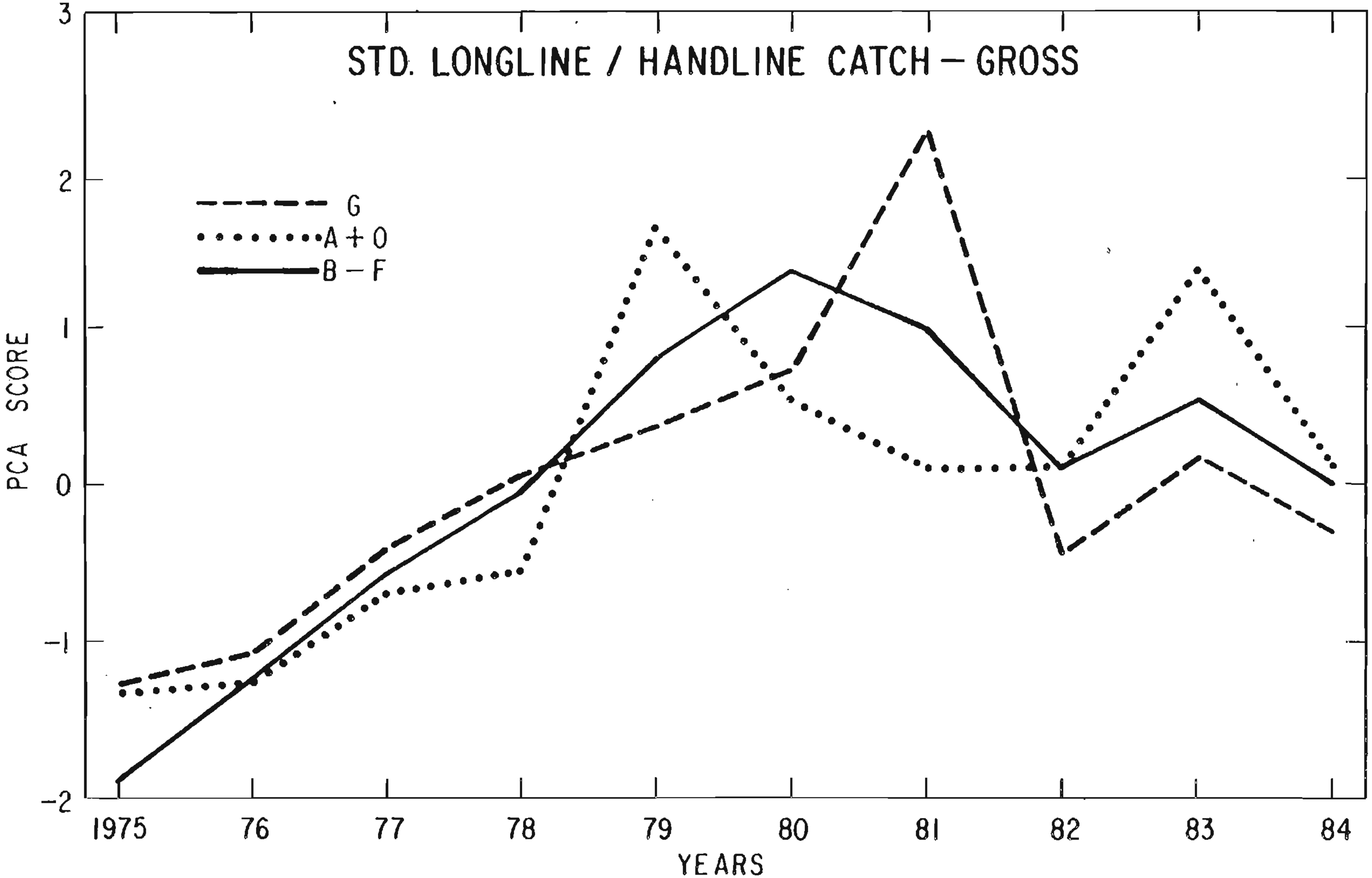

Fig. 24. PCA scores for standardized gross longline and handline catches in Areas G, A and O, and B to F during 1975-84.

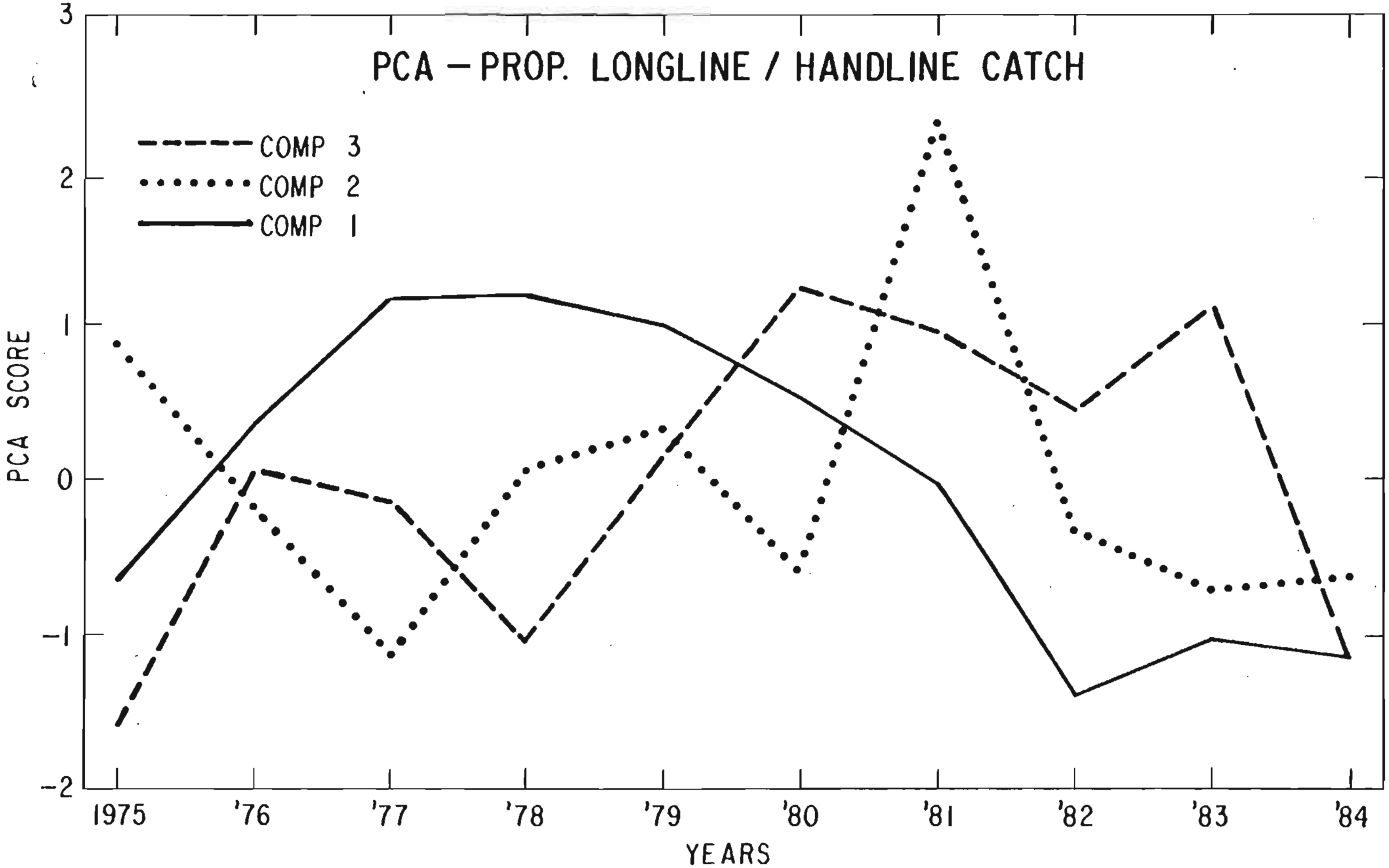

Fig. 25. PCA scores for Components 1, 2 and 3 for the proportional longline and handline catches during 1975-84.

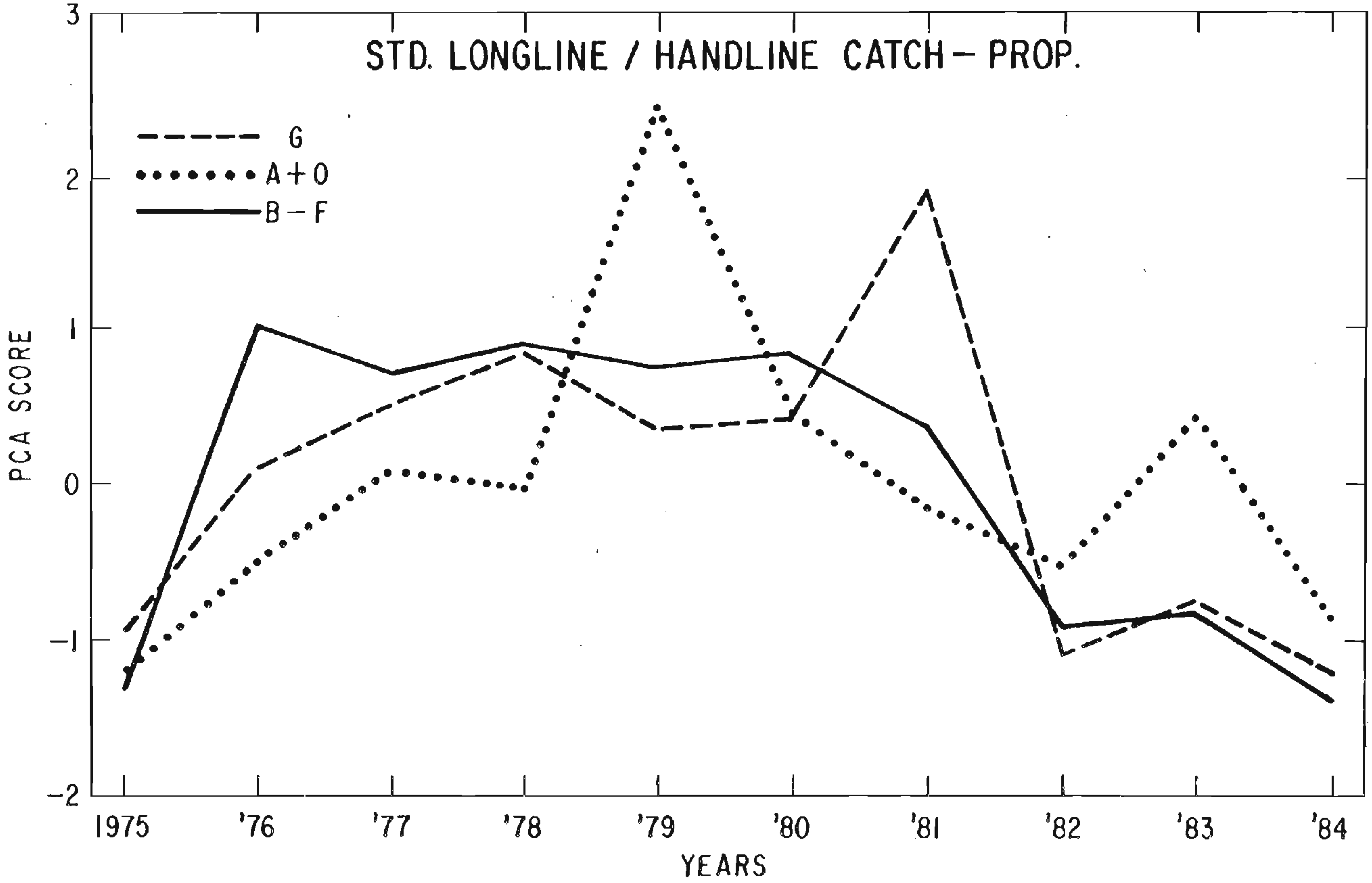

Fig. 26. PCA scores for standardized proportional longline and handline catches in Areas G, A and 0, and B to F during 1975-84.

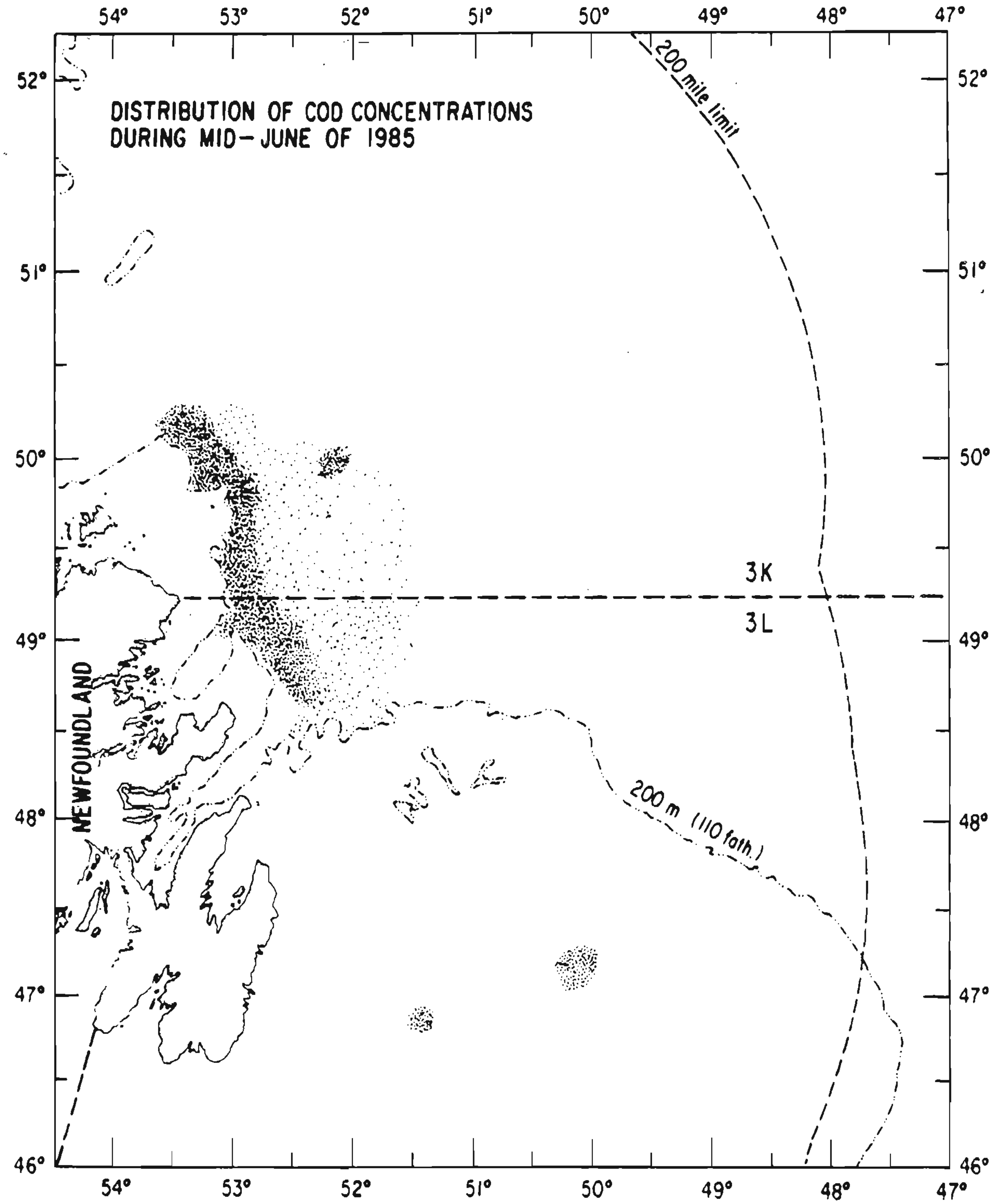

Fig. 27. Distribution of cod concentrations during mid-June 1985 on Wolfall Bank, Central Grand Bank and off the northeast coast of Newfoundland.