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Northwest Atlantic Fisheries Organization

Serial No. N031

NAFO SCR Doc. 80/II/5

SPECIAL MEETING OF SCIENTIFIC COUNCIL - FEBRUARY 1980

An Examination of Criteria for the Short-term Forecasting of Inshore Abundance of Squid (*Illex illecebrosus*) at Newfoundland

by

G. V. Hurley[1]
Department of Fisheries and Oceans
Northwest Atlantic Fisheries Center
P. O. Box 5667, St. John's, Nfld., Canada, A1C 5X1

Abstract

An examination is made of criteria for short-term forecasting of inshore abundance of Illex at Newfoundland. The basis for the annual forecasts is an index of the relative numbers of Illex caught in spring research surveys on the southern Grand Banks and the relative inshore abundance of squid at Newfoundland later in the season since 1946 (updated in this paper for the period 1966-79). The interpretation of forecast information in recent years (since 1966) is complicated by year-to-year differences in the design of offshore research surveys. Also, gear innovation and intense foreign market demand have contributed to increased fishing effort in the inshore fishery making it difficult to assess the relative annual abundance over the entire period.

Migration of squid onto the shelf in the spring appears to be temperature dependent. Better offshore catches of squid were made in warmer waters.

Year-to-year fluctuations in landings inshore do not appear to be cyclic nor are they correlated with yearly anomalies of monthly water temperatures on the Grand Banks.

[1] Present address: Bonavista Cold Storage Company, P. O. Box 1357, St. John's, Nfld., Canada, A1C 5N5

INTRODUCTION

The ommastrephid squid, Illex illecebrosus, is a seasonal migrant to Newfoundland waters. It usually appears offshore on the Grand Banks during May and June where it has been moderately exploited by an international trawl fishery in recent years (about 5,000 MT in 1978) and inshore later in the season (July-November) where it has been fished traditionally with jigging devices (Hurley, 1979). The inshore landings reached record high levels in 1978 (40,000 MT) and will be even higher in 1979.

Illex is believed to be a short-lived species with a life span of between nine and 24 months (Au, MS 1975); Efanov and Puzhakov (MS 1975); Mesnil (1977); Squires (1967)). A special meeting of the Standing Committee on Research and Statistics (STACRES) of the International Commission for the Northwest Atlantic Fisheries (ICNAF) concluded that the management of fisheries for such a species should be based on a definition of pre-season biomass that might be available to the inshore and offshore fisheries later in the season (Anon, 1978).

Pre-season forecasting would allow consideration/implementation of such management options as catch quotas, regulation of fishing effort and the date for onset of fishing. Short-term forecasting has been used successfully as a management tool in the offshore fishery for the Japanese squid, Todarodes pacificus, another member of the family Ommastrephidae (Kasahara, 1975).

Successful efforts have been made to forecast the relative inshore abundance of squid at Newfoundland (Hodder, 1964; Mercer, 1966). This forecasting capability was based on the observation of Squires (1957) that that the incidental captures of squid taken on the southwest edge of the Grand Bank in May or June in haddock surveys appear to indicate the relative abundance of squid to arrive inshore later in the season. Because of the usefulness of this index it was updated to 1965 (Mercer, 1966; Squires, 1959) from the original period (1946-52) considered by Squires (1957).

The purpose of this paper is to provide a further updating of the forecast index for more recent years (1966-79) from the results of various types of research surveys which were carried out in the same general area and time of the year as the earlier haddock surveys.

The importance of physical factors such as water temperature in explaining differences in the year to year availability of Illex in Newfoundland offshore and inshore waters (ICNAF Subarea 3) is examined.

Some significant developments in the inshore fishery are discussed in relation to their possible influence on the interpretation of the forecast index.

Materials and Methods

Information for this paper was drawn mainly from the operations of the Canada Department of Fisheries and Oceans research and chartered fishing vessels based at St. John's, Newfoundland. Earlier groundfish research surveys aboard the INVESTIGATOR II (1946-64) and A.T. CAMERON (1960-65) provided information on incidental captures of Illex reported in Table IX of Mercer (1966) for the period 1959-65 and in Tables I and III of Squires (1957, 1959) respectively for the period 1946-58. Most of these surveys were aimed at capturing haddock and were conducted at established fishing stations on transects located along the southern edge of the Grand Banks (ICNAF divisions 3N,0) until 1968 after which they were terminated (Templeman et al. 1979).

More recent offshore catch data (1965-79) presented in this paper (Table 2) were derived from various types of bottom-trawl research surveys also conducted along the southwest edge of the Grand Bank and/or St. Pierre Bank (ICNAF divisions 3N, O, P_s) during the May-June period. The vessels, which were used to carry out these surveys (Table 1) in some years, i.e. A.T. CAMERON (1966-70, 1974, 1975-77), were aimed at catching various groundfish species while those used to carry out surveys in other years, i.e. E.E. PRINCE (1971, 1972); CRYOS (1973); NEWFOUNDLAND HAWK (1978) and ZABREB (1979), were directed specifically for Illex.

For the purpose of year-to-year comparisons of catch per effort between research vessels, it was necessary to estimate the relative differences in fishing power of the vessels used in the surveys (Table 1). It was decided to apply conversion factors according to measurements of mouth openings of different trawl types given by Carrothers (MS, 1974).

Conversion factors of 0.77 for catches made by the Yankee 41.5 (A.T. CAMERON) and 0.68 for catches made by the high-lift Engels type (CRYOS, NEWFOUNDLAND HAWK, and ZAGREB) using a 28 mm liner were applied to adjust those catches downward to the fishing power of the smaller Yankee 36 trawl (INVESTIGATOR II, E.E. PRINCE).

The average bottom temperatures given in Fig. 4 for the surveys listed above (1946-79, excluding 1947) were obtained from set details and summaries of individual surveys.

The distribution of catches (successful 30-minute bottom tows) and bottom temperatures (Fig. 2 and 3) on the southern Grand Banks in the spring of 1978 and 1979 was derived from research surveys conducted by the following vessels: A.T. CAMERON, May 25-June 8, 1978; NEWFOUNDLAND HAWK, June 3-20, 1978; A.T. CAMERON, June 12-25, 1979; ZAGREB, June 16-26, 1979.

The sea surface temperature contours shown in Fig. 2 and 3 were redrawn from weekly charts of sea surface temperature distributed by the Canadian Forces Base, Halifax, Nova Scotia.

The yearly (1953-78) anomalies of sea surface temperatures at Station 27, which is situated two nautical miles off Cape Spear near St. John's at 47°31'50"N, 50°35'10"W were calculated from monthly observations as described by Templeman (1965). He showed that sea surface temperature had the same relative temperature anomalies as other portions of the water column. Data on the yearly (1953-75) number of icebergs south of latitude 48°N were taken from Scobie (1975) for the period 1953-72 and in annual reports of the International Ice Patrol for the remaining years (1973-75).

Annual landings of squid at Newfoundland were used as a basis for estimating relative inshore abundance in recent years by this author (1966-79) and for earlier years (1953-65) by other authors (Mercer, 1966; Squires, 1959). No information was available on year-to-year variations in inshore fishing effort. It should be noted, however, that the introduction of the Japanese drum jigger to the Newfoundland inshore fishery in 1965 undoubtedly increased efficiency and produced relatively higher landings as compared with the earlier hand-line jigger fishery. The intense interest of foreign buyers and the expansion of inshore production capability since 1975 accounts for disproportionately high landings since 1976.

Results

Table 1 is an updating for more recent years (1966-79) of data given by others (Materials and Methods) for earlier years (1946-65). It can be seen in Table 1 that the adjusted values of catch per effort did not appreciably alter the relative magnitude of the actual values.

There were two distinct and contrasting periods of Illex abundance inshore since 1967 as indicated by the landings. From 1968 to 1974 there was a noticeable paucity of Illex inshore. Beginning in 1975 however, there was a significant increase in yearly landings to record high levels during the 1976-79 period. The reliability of the forecast index is examined in Fig. 1 for the entire period (1953-79) for which information is available on inshore landings.

The relationship appeared to be rather good in some years. For example, there were relatively high average catch rates recorded offshore during the spring in certain years (1954, 61, 64, 76, 78, 79) and correspondingly high landings recorded inshore later in the season. On the other hand, relatively high average catch rates during offshore surveys in 1971 and 1972 contrasted noticeably with the poor landings and the observed scarcity of Illex in coastal waters during those two years. The relationship was tenuous and provided poor predictability particularly in years when relatively low average catch rates were observed in offshore surveys. For example, a wide range in the levels of inshore landings from less than 1000 MT (1958-62) to nearly 8,000 MT (1965) for the pre-1966 period, and from less than 1000 MT (1968-70) to nearly 30,000 MT (1977) for more recent years (Fig. 1) corresponded with a relatively narrow range of catch per effort values (less than 2000 animals per 100 h trawling) recorded in offshore surveys.

The lack of precision in the above relationship may be explained partly by physical factors such as water temperature and salinity. These factors may have determined the year-to-year availability of squid to bottom trawls offshore on the Grand Banks and to the jigging devices in the Newfoundland inshore fishery.

Offshore Distribution and Abundance of Illex on the Grand Banks in 1978 and 1979.

The relationship between water temperature and the distribution of captures of squid offshore was investigated in surveys made during 1978 and 1979 in order to examine the influence of water temperature on the availability of

Illex to bottom trawls. A summary of the distribution of catches (successful 30-minute bottom tows) made during these surveys is shown in Fig. 2 and 3 respectively

As a general observation, the areas where squid were caught in the highest numbers coincided with the steepest gradients of sea surface isotherms and bottom temperatures greater than $5^{\circ}C$.

Steep isotherm gradients represent the boundary between the cold Labrador Current and the warm outreaches of the Gulf Stream. This mixture of coastal water and Gulf Stream water has been termed the Slope Water Current (Mann, 1967). Reiniger and Clarke (1975) showed that surface features of the currents in this part of the Grand Banks reflected the same flow patterns and temperature fields that exist at greater depths.

In both years the steepest gradients of sea surface isotherms and the $5^{\circ}C$ bottom isotherm were located near the shelf break area. Also, most of the significant captures of squid in both years occurred in this area in depths ranging from 100 to 500 meters and on the oceanic side of the 5° bottom contour, i.e. in water warmer than $5^{\circ}C$. This was also observed in other earlier surveys (Frost and Thompson (1932), Hodder (1964), Mercer (MS 1973), and Mercer and Paulmier (MS 1974)). The average bottom temperatures at fishing stations along the southwest slope in which squid were caught in 1978 and 1979 were 8.0 and $5.9^{\circ}C$ respectively (in research surveys by the chartered fishing vessels NEWFOUNDLAND HAWK and ZAGREB in 1978 and 1979 respectively). The catch per effort in 1979 (140,200 animals per 100 hours trawling) was considerably higher than in 1978 (20,800) in these surveys.

The Long-Term Relationship of Average Bottom Temperature and Catch per Effort During Offshore Surveys.

Water temperature appears to be an important factor in determining the limits of distribution of Illex offshore on the Grand Banks and, therefore, perhaps the year-to-year availability of Illex to bottom trawls used in spring research surveys (Fig. 2 and 3).

To examine this possibility, the long-term (1946-79, excluding 1947) relationship of average bottom temperature and catch per effort during spring research surveys was investigated (Fig. 4). All of the surveys considered in Fig. 4 took place along the southwest edge of the Grand Banks (except surveys in 1950 and 1953 which were carried out on the northern Grand Bank).

The catch per effort is expressed in numbers of animals caught per 100 hours bottom trawling for purposes of comparison with the original calculations of Squires (1957). Only actual values of catch per effort are given in Fig. 4. The values adjusted for gear bias are not included for reasons given above. All catch per effort values greater than 12,000 animals per 100 hours trawling are parenthesized at the appropriate data point. The average bottom temperature for each survey was determined from all successful sets including those sets which had nil captures of *Illex*.

The average values of catch per effort for surveys in 1964, 1971, 1972, 1978 and 1979 are noticeably higher than other values of catch per effort shown in Fig. 4 and are associated with correspondingly higher average bottom water temperatures (4.01-7.1°C). Most nil and relatively low values of catch per effort were recorded when the average bottom water temperature was lower than 3°C.

The Relationship of Iceberg Numbers and Inshore Water Temperatures with Fluctuations in Annual Landings of *Illex* at Newfoundland.

Water temperature may be an important factor in determining the availability of squid to the inshore jigger fishery and/or affect the hypothesized offshore-inshore migration of *Illex*. Since water temperature has been shown to exhibit cyclical year-to-year fluctuations in the Northwest Atlantic (Burmakin, 1972) it may be possible to observe cyclical patterns in the relative annual abundance of squid in Newfoundland coastal waters.

Templeman (1952) tried unsuccessfully to relate qualitative information on relative inshore abundance of squid and fluctuations in water temperature. However, , it may be possible to use records of annual landings at Newfoundland as an indication of relative inshore abundance in order to examine the possible affect of water temperature.

The only long-term series of water temperatures available for the Newfoundland area is from Station 27 (off St. John's). Another possible indicator of temperature conditions on the Grand Banks during the spring may be the number of icebergs south of latitude 48°N of which a long-term record has been maintained (Materials and Methods).

There is no cyclical pattern to the relative inshore abundance of squid as indicated by landings over a 25-year period (1953-78).

Before 1967 there were only two years of extremely poor landings (1958, 1962). This contrasted with the extended period of poor landings from 1968 to 1974 inclusive.

The yearly relationshis of anomalies of monthly (January-December and July-November) sea surface temperatures at Station 27 (1953-78), and the annual number of icebergs south of latitude 48^{o}N (1953-75) with annual landings of Illex inshore (1953-78) are given in Fig. 5.

The fluctuations in the inshore landings of squid showed no consistent correlation with the yearly anomalies of monthly (January-December and July-November) sea surface temperatures at Station 27 ($r = 0.02$ and 0.05 respectively) nor with iceberg numbers ($r = 0.32$).

The fluctuations in numbers of icebergs showed a better correlation with yearly sea surface temperature anomalies for the months January to December than for the months July to November. ($r = 0.54$ and 0.26 respectively).

Among recent years (1960-78), 1972 was a particularly cold year as indicated by sea surface temperature anomalies (-0.60 January-December and -0.74 July-November) and iceberg numbers (1584). Landings of Illex inshore (16 MT) were relatively poor in 1972.

Discussion

Reliability of the Forecast Index

Mercer (1966) and Squires (1959) reaffirmed the original observation of Squires (1957) of the usefulness of the forecast index but conceded to its fallibility.

In most years when relatively high average values of catch per effort were recorded offshore during the spring (1954, 61, 64, 78, 79) there were correspondingly high landings recorded inshore later in the season. Hodder (1964) used this information to forecast successfully a high abundance of squid in Newfoundland inshore areas in 1964. In other years, notably 1971 and 1972, there were significant numbers of Illex caught in offshore surveys yet the relative abundance inshore was very low as indicated by landings and observations of fishermen.

The reliability of the index as a forecasting tool was not good in some years of relatively low average catch rates offshore (1965, 67, and 77) and correspondingly high abundance inshore. These anomalies may be explained by physical factors such as water temperature, differences in the year-to-year design of offshore surveys and changes in gear type and effort in the inshore jigger fishery.

The Influence of Water Temperature on the Offshore Distribution and Abundance of Illex

The fishing success for Illex offshore may have been dependent on such physical factors as salinity and water temperature according to Frost and Thompson (1932, 1934). They gave a range of preferred temperatures (2-9°C) for Illex offshore. Squires (1957) reported catches of Illex on the Grand Bank in bottom temperatures between 0.5 and 8.0°C. Hodder (1964) found that the best catches of Illex on the southern Grand Bank were between 6 and 8°C. Mercer (MS, 1973) and Mercer and Paulmier (MS, 1974) observed that Illex concentrated at the edge of the continental shelf in waters generally warmer than 5°C. The movement of Illex onto the banks seemed to be restricted by the presence of cold water overlying these areas. Similarly, in 1978 and 1979 (Fig. 2 and 3) concentrations of Illex were confined largely to areas of the banks penetrated by warm water of Gulf stream origin near the frontal zone (as indicated by bottom temperatures and sea surface isotherms) of the cold Labrador and warm Slope Water currents.

The distribution of squid off the Grand Banks was first observed during a plankton survey in late April-early May, 1979 (unpublished information). Young squid (6.0-12.0 cm mantle length) were caught also in greatest numbers near the boundary between the cold Labrador Current and warm North Atlantic Current (an extension of the Gulf Stream (Mann, 1967)), in water generally warmer than 8°C.

Kasahara (1975) attributed the dense concentrations of the squid, Todarodes pacificus, at the fringe of the cold water areas not only to temperature preference but also food availability. Mercer and Paulmier (MS, 1974) noted a wide diversity of prey species found in the stomach contents of Illex caught on the edge of the Grand Banks.

These observations suggest that oceanographic conditions may have controlled tye year-to-year availability of Illex to bottom trawls offshore. Fig. 4 shows that the highest values of average catch per effort during spring research surveys for the period 1946-79 were associated with relatively high average bottom temperatures (4.01-7.0^{o}C). Very low values of average catch per effort were recorded in colder water (average bottom temperatures less than 3^{o}C).

Frost and Thompson (1932, 1934) postulated that Illex would more likely be found on the shelf when warm, high salinity 'slope water' was plentiful. The observations above concur with those of Scott (1978) and Dufour (MS, 1979) who noted an apparent relationship between year-to-year variations in bottom temperature and biomass levels of Illex on the Scotian Shelf since 1970. They found that prevalence of warm water favoured higher catches of squid.

Possible Relationships of Sea Surface Temperature Anomalies and Iceberg Numbers with Inshore Landings of Illex.

As can be seen in Fig. 5, fluctuations in inshore landings did not show a consistent correlation with either yearly sea surface temperature anomalies at Station 27 (1953-78) or iceberg numbers (1953-75).

The yearly anomalies of monthly sea surface temperatures at Station 27 were derived (Fig. 5) as indicators of relative annual temperature conditions over the Grand Banks since Burmakin (1972) correlated long-term temperature trends at Station 27 with fluctuations in water temperatures over the entire Northwest Atlantic. Templeman (1965) observed that Station 27 was affected by the full intensity of the Labrador Current and that fluctuations in sea surface temperatures correlated well with fluctuations in water temperatures at greater depths. Temperature anomalies at Station 27 have been shown to vary according to a 3-4 year cycle superimposed over a longer 10-11 year cycle. (Burmakin, 1972.)

From qualitative information on the relative inshore abundance of Illex, Templeman (1952) could not detect any cycles of abundance nor could he draw any long-term inferences regarding the possible effects of water temperature on inshore abundance of Illex at Newfoundland.

As was expected, iceberg numbers showed a relatively good correlation with yearly anomalies of monthly (January-December) inshore sea surface temperatures in this study. For some years good agreement has been recorded between Labrador Current flow, iceberg numbers and Grand Bank temperatures (Scobie, 1975; Soule and Morse, 1958; Templeman et al. 1979). This is to be expected since a greater number of icebergs would drift south of latitude 48^{O}N in years when the Labrador Current was relatively cold and flowing strongly under the influence of northerly winds.

Since Illex have been sighted in offshore surface waters in large numbers (Squires, 1959) any unusual Labrador Current conditions which accompany low or high numbers of icebergs south of latitude 48^{O}N would be expected to affect environmental conditions including surface water temperature on the southern Grand Banks and therefore perhaps the offshore-inshore migration of Illex. Squires (1959) postulated that the most important factors which contribute to keeping squid offshore in any year were availability of food and the tendency of Illex to remain oceanic. He did not rule out the possibility that water temperature played an important role in squid migrations.

Only speculative explanations based on environmental factors can be given for the unexpected low abundance of squid inshore during 1972 as forecasted from an offshore spring survey. The inshore migration of Illex from offshore areas may have been impeded by particularly cold waters observed on the Grand Banks that year (Bailey (1975); Burmakin (1972, 1975)). Scobie (1975) reported a record number of icebergs (1584) south of latitude 48^{O}N in 1972. Frost and Thompson (1934) speculated that a strong influx of Arctic water over the Grand Banks in 1933 accounted for the scarcity of squid inshore Newfoundland that year.

Perhaps there are other reasons such as the year-to-year differences in the design of offshore surveys and inshore fishing effort which may explain the apparent anomalies to the forecast index.

Possible Effects of Other Factors on the Interpretation of the Forecast Index.

There may have been many reasons other than hydrological or biological ones why the forecasting capability in some years was very poor.

Offshore survey results could not be compared precisely between years because of differences in the design of surveys, i.e. number of fishing stations, areal coverage, species directed for, etc., particularly in recent years. Even during the earlier haddock surveys certain transects and fishing stations were excluded in some years (Templeman et al., 1979). Surveys in which Illex was directed for (1971, 72, 73, 78, 79) undoubtedly produced biased overestimates of the average catch per effort, since fishing took place presumably in areas where concentrations of squid likely would be found.

The landings in 1965 and 1967, which were predicted to be relatively low from offshore survey results, were disproportionately high. Mercer (1966) concluded that the excess was due to the introduction of the more efficient Japanese jigger in 1965.

Acknowledgements

My appreciation is extended to the many staff members of the Department of Fisheries and Oceans who participated in the surveys used in this study, especially Mr. P. Beck who helped to organize and participated in the 1978 and 1979 surveys. Thanks to Mr. H. Mullett, Draftsman; Mr. G. King, Photographer; Mr. G. Kelland, who provided Station 27 temperature data; Mr. W. B. Bailey, Canadian Armed Forces Base, Halifax, who provided sea surface temperature charts.

Mr. K. S. Naidu kindly reviewed and criticized the manuscript.

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Table 1. Summary of the captures of squid in offshore research surveys on the Grand Banks (1966-79) and the landings of squid at Newfoundland

Year	Dates fished	Total trawling time (hr)	Percentage trawling-time in which squid were taken	No. of squid per 100 hr. trawling	Inshore Landings (M.T.)
1966	May 2-17	29	0	0	5,017
1967	April 22-May 4	39	0	0	6,917
1968	May 7-22	31	0	0	13
1969	June 19-July 2	19	16	42[1] (32)	21
1970	May 21-June 3	14.5	14	2,924[1] (2,251)	111
1971[3]	July 11-22	15	63	8,914	1,607
1972[3]	June 21-July 3	14.5	72	12,660	26
1973[3]	May 8-June 4	21.5	51	1,558[2] (1,059)	600
1974	June 13-27	47.5	16	254[1] (196)	17
1975	May 9-25 June 2-13	88	7	90[1] (69)	3,751
1976	May 28-June 6	26	44	5,540[1] (4,266)	11,257
1977	May 25-June 7	10	0	0	29,678
1978[3]	June 3-20	54	52	20,800[2] (14,144)	40,000
1979[3]	June 16-26	36	72	140,200[2] (95,336)	>50,000

[1] Values given in parentheses represent Yankee 41.5 trawl catches adjusted to the efficiency of Yankee 36 trawl. (See Materials and Methods for details).

[2] Similarly, for high-lift Engels type.

[3] Surveys directed for Illex (see Materials and Methods for details).

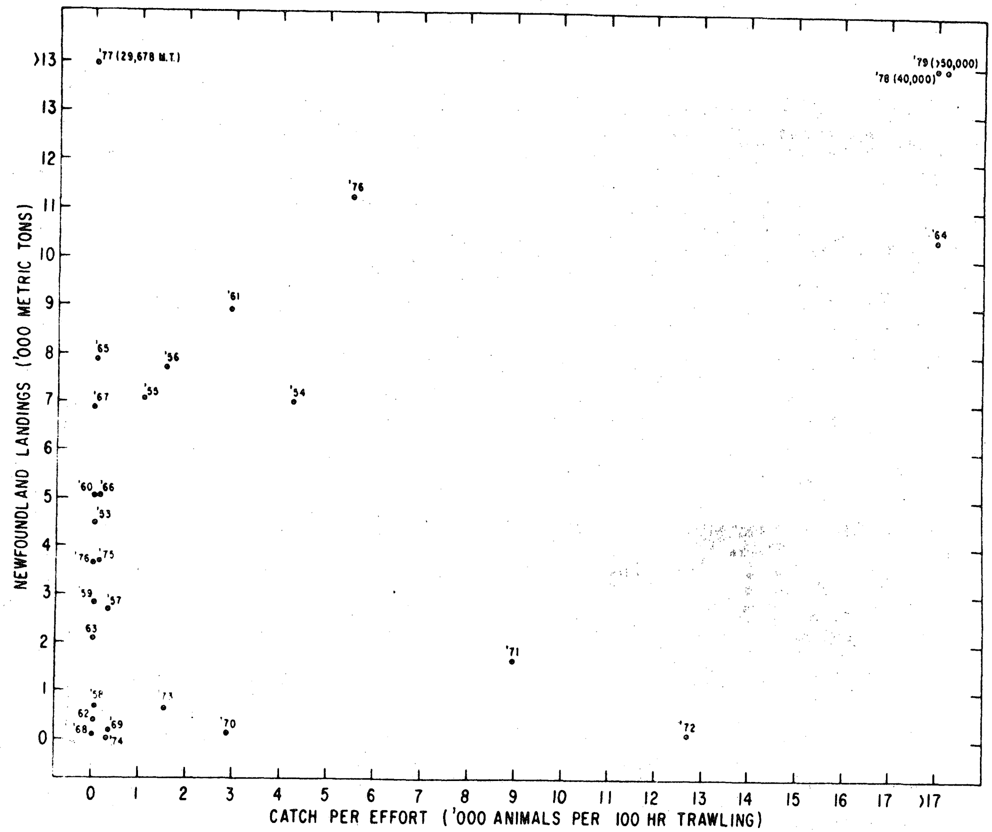

Fig. 1. The catch per effort ('000 animals per 100 hours trawling) from offshore spring research surveys on the southern Grand Banks versus annual Newfoundland landings of squid for the period 1953-79.

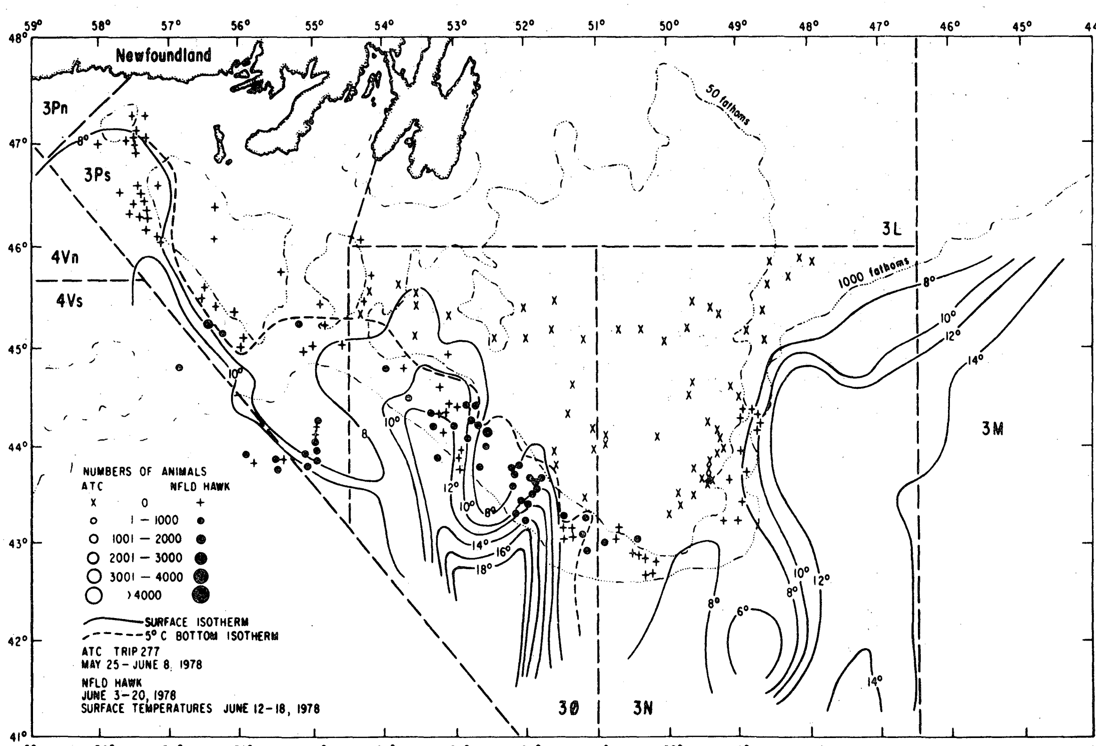

Fig. 2. The distribution of catches of Illex (successful 30-minute bottom tows) during offshore spring research surveys on the southern Grand Banks in 1978. The surface temperature isotherms and the 5°C bottom isotherm are also shown (see legend).

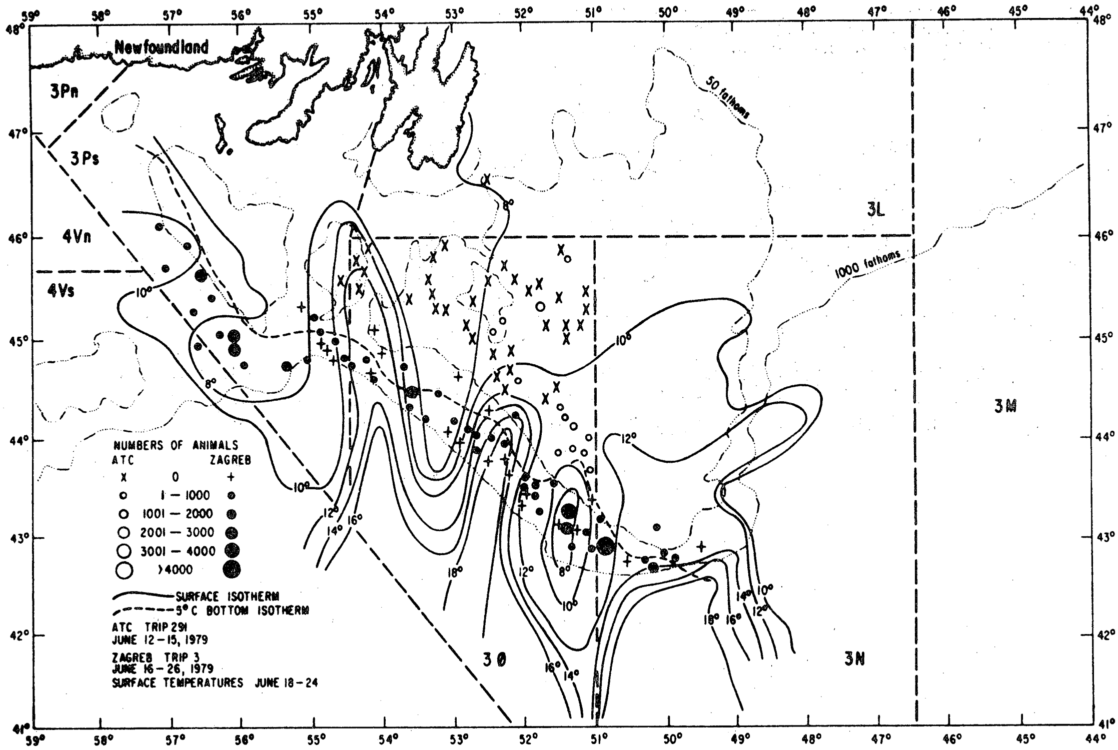

Fig. 3. The distribution of catches of Illex (successful 30-minute bottom tows) during offshore spring research surveys on the southern Grand Banks in 1979. The surface temperature isotherms and the 5°C bottom isotherm are also shown (see legend).

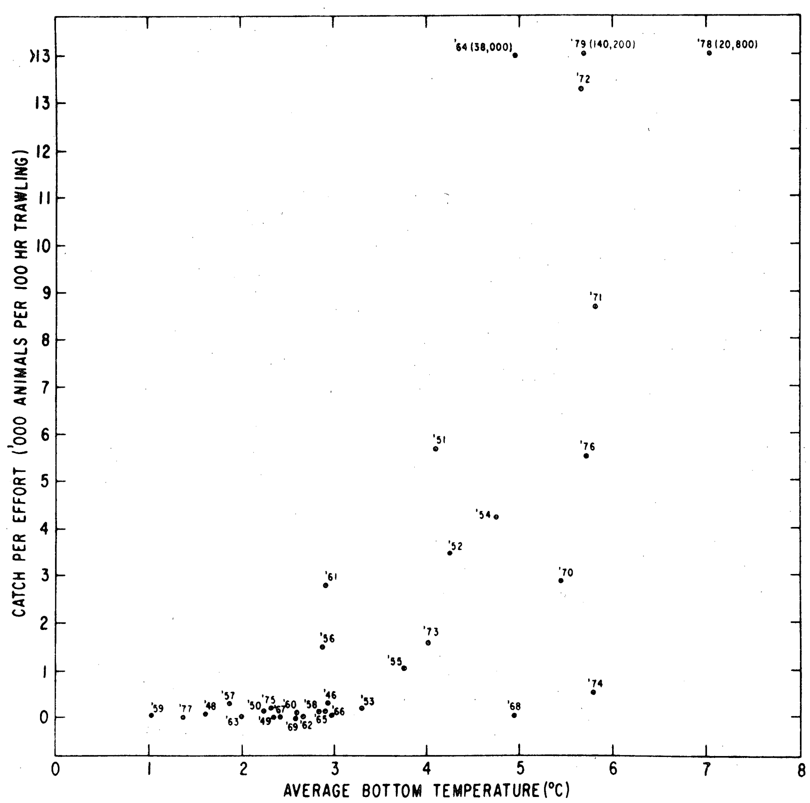

Fig. 4. The relationship of average bottom temperature (°C) and catch per effort ('000 animals per 100 hours bottom trawling) from offshore spring research surveys on the southern Grand Banks for the period 1946-79, excluding 1947. Values in parentheses are values of catch per effort greater than 13,000 animals per 100 hours trawling.

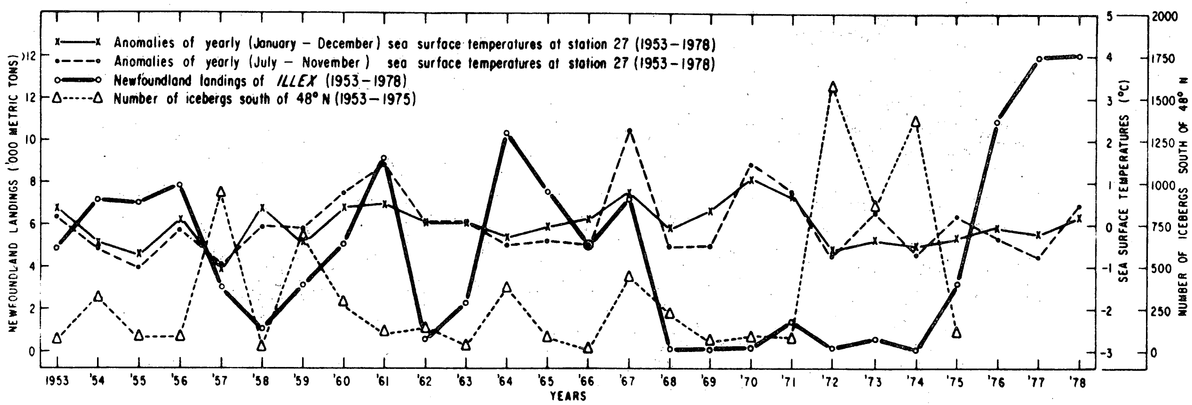

Fig. 5. The relationships of sea surface temperature anomalies (Jan-Dec) and (July-Nov) (1953-78) and number of icebergs south of latitude 48°N (1953-75) with annual Newfoundland inshore landings of Illex (1953-78).