A Study of Factors Influencing Availability of Cod in Conception Bay, Newfoundland, in 1985

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A STUDY OF FACTORS INFLUENCING AVAILABILITY OF COD IN CONCEPTION BAY, NEWFOUNDLAND, in 1985

by

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ABSTRACT

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During June 10 to September 18, 1985, data on cod trap catches and effort, oceanographic and meteorological conditions were collected in Conception Bay, Newfoundland. Preliminary analyses of these data suggested several features important to this fishery. Larger cod were caught during the middle of the trap season than at the beginning or end. About 40% of the reduction in cod landings in Conception Bay during 1985 could be attributed to diversion of effort from the cod fishery to the capelin fishery. Early in the season most cod stomachs were empty. After the capelin fishery began, cod were feeding heavily on capelin. An influx of warm, lower salinity water in August coincided with a sharp decline in trap catch. The influence of local oceanographic conditions on trap catches could not be assessed because catch records were unlikely to be sensitive enough and influence was masked by factors such as the influx of large cod taken by traps in July. There is a suggestion that temperatures in the vicinity of cod trap doors may influence the availability of cod to traps.

RÉSUMÉ

Aggett, D., H. S. Gaskill, D. Finlayson, S. May, C. Campbell, and J. Bobbitt. [edited by W. H. Lear and J. C. Rice]. 1987. A study of factors influencing availability of cod in Conception Bay, Newfoundland, in 1985. Can. Tech. Rep. Fish. Aquat. Sci. 1562: iv + 123 p.

Des données sur les prises et l'effort de la pêche de la morue à la trappe et sur les conditions océanographiques et météorologiques dans la baie Conception, à Terre-Neuve, ont été recueillies du 10 juin au 18 septembre 1985. Des analyses préliminaires de ces données portent à croire à l'existence de plusieurs facteurs importants pour cette pêche. Les plus grosses morues étaient capturées au milieu de la saison de pêche à la trappe et non au début ou à la fin. Environ 40 % de la réduction des débarquements de morue de trappe notée pour la baie Conception en 1985 pouvaient être attribués à une réorientation de l'effort de la pêche de la morue à celle du capelan. L'estomac de la plupart des morues était vide au début de la saison mais ces dernières consommaient de grandes quantités de capelans après le début de la pêche du capelan. L'arrivée en août d'eaux chaudes de plus faible salinité a coincidé avec un net déclin des prises à la trappe. L'influence des conditions océanographiques locales sur les prises de cet engin ne pouvait être déterminée car il est peu probable que les données sur les prises soient suffisamment précises et cette influence est masquée par d'autres facteurs, notamment l'arrivée de grosses morues capturées à la trappe en juillet. Certains faits portent à croire que les températures règnant à proximité de l'ouverture des trappes puissent influer sur la capture des morues.

SUMMARY

INTRODUCTION

The inshore Newfoundland cod fishery provides much of the income for the approximately 25,000 inshore fishermen. Many inshore fishermen believe that failure of the inshore fishery is a result of offshore fishing activity, but there are a number of reasons why recent failures may be related to the offshore fishery. A series of hypotheses concerning factors influencing the inshore distribution of cod were summarized by Lear et al. (1983). One of these hypotheses proposed that temperature preference governs much of the migrational/distributional behaviour of cod. The project reported in this document was undertaken in the 1985 fishing season in Conception Bay to obtain evidence to test the hypothesis relating cod distribution to water temperature.

METHODS

Fisheries data were collected by a team of four field observers during the period June 10 to September 18, 1985. Data consisted of cod trap, gillnet and longline catch and effort logs as well as length frequency measurements and volumetric analysis of cod stomachs. A tagging experiment was also conducted at two sites on opposite sides of Conception Bay. Statistical analyses of the cod fishery focused almost exclusively on the cod trap data.

Oceanographic data were collected by current meters and thermographs placed on four semi-permanent moorings, thermographs deployed on fishing gear, and 15 oceanographic stations on two transects. Current speed and direction, temperature at a number of depths, and CTD data were collected.

Meteorological data were collected from five weather stations in eastern Newfoundland. Data collected included sky condition, visibility, weather, mean sea level, atmospheric pressure, air temperature, dew point temperature, wind direction and speed, and cloud type and opacity.

DATA ANALYSIS

Fisheries data were analyzed using a SAS data management and statistics package. Regression analyses on the data collected did not identify predictive relationships between catch and any independent variables tested in this study. However, temperature in the vicinity of the cod trap doors was found to influence the availability of cod to traps, as indicated by catch per effort.

Analysis of the current meter data consisted of time series plots, progressive vector diagrams, bivariate histograms and harmonic analysis. Analysis of the CTD data consisted of producing depth profiles and contour plots of temperature, salinity and density.

Meteorological data analysis consisted of preparation of a general summary of climatic conditions in terms of departures from the long-term normal of the

primary climatic parameters. Satellite imagery provided useful data of the sea surface temperature field over Conception Bay between June 15 and July 5, 1985.

NOTABLE EVENTS

In an attempt to highlight important features of the three primary data collection exercises, definitions of notable fisheries, oceanographic and meteorological events were established. From these definitions, several notable events were identified.

Notable fisheries events were: increase in catch per effort during June; stabilization of daily variability of catch per effort on June 24; several significant drops in catch per effort for individual zones throughout the season; and the start of a general downward trend in catch per effort on August 7.

Notable oceanographic events were identified in several zones, but the most significant was the major inflow of low salinity water into Conception Bay between August 14 and 21.

IDENTIFICATION OF A CONCEPTUAL MODEL

In an effort to systematize the body of existing and project-derived information, a speculative conceptual model of cod/capelin/environment interactions was constructed. The model relates to the cod fishery within Conception Bay, and its explanatory power is limited to factors within the bay.

The model starts in early June, follows the rise in cod catch, introduces capelin in late June, and follows the cod trap fishery until its collapse in early to mid-August. While the bulk of material presented in the model comes from previous research and the present project, some aspects are based more on speculation than on hard data.

RESULTS AND CONCLUSIONS

Some points concerning various aspects of cod/capelin/environment interactions were documented during this project.

From these and the conceptual model, a set of general conclusions based on project-related observations and analyses was assembled. These are:

1) The overall success of the cod trap fishery depends on the presence and availability of intermediate and larger sized fish which migrate into Conception Bay from offshore.

2) A portion of reductions in cod landings in recent years in Conception Bay can be attributed to diversion of effort from the cod fishery to the more

lucrative capelin fishery. In 1985, this reduction was estimated to be approximately 40%. Because the value per kg of the larger cod available during this period is high, the lost dollar value to the fishery exceeds 40%.

3) The weekly variation in availability of cod to cod traps in Conception Bay is influenced by interactions between the cod and capelin populations, as shown by these observations:

   a) Peak availability of cod to traps coincides with the peak in the capelin fishery.

   b) Capelin comprise the vast majority of the food source for cod inshore.

   c) As feeding of cod on capelin increases, the availability of cod to traps decreases.

4) Two groups of cod are found in Conception Bay during the trap season: one possibly resident group consisting of smaller fish and one migrant group of larger fish whose presence appears to be linked directly or indirectly to that of capelin.

5) Although a general trend of decreasing availability of large cod occurred in late July and early August in 1985, an influx of warm, lower salinity water during early and mid-August coincided with the end of availability of these fish to the trap fishery.

6) In 1985, the cod availability peak in Conception Bay closely followed the trend in tidal amplitudes during late June and early July.

7) The intermediate and larger sized cod usually do not enter the shallow water at the head of Conception Bay. They may be blocked by an unacceptable oceanographic regime.

8) Cod are more available to traps set on the east side of Conception Bay than in other parts of the study area. This may be due to the possible presence of a migration route along the east side of the bay.

9) Catch per effort varied syncronously in all parts of the study area in 1985, making it difficult to test the hypothesis that small-scale environmental phenomena influence the general availability of cod to traps.

10) Temperature in the vicinity of the bottom of cod trap doors may influence the availability of cod to traps, as indicated by catch per effort.

11) Daily variability of cod landings at individual trap sites in Conception Bay may be due in part to hunting behaviour by cod.

INTRODUCTION

The inshore Newfoundland cod fishery provides a large measure of the income for the approximately 25,000 inshore fishermen. The gears they employ vary from modern steel 18 m stern draggers down to skiffs and handlines. The majority of cod fishing activities are undertaken by vessels smaller than 11 m in length fishing on day trips within 10-15 nmi from home port.

The cod trap fishery generally involves crews of two to six fishing 8- to 16-m vessels hauling two to six traps per day. Traps are normally set in well-defined traditional locations which can be readily accessed from the home community once or twice per day. The trap fishery requires operation very close to shore and unfamiliarity with berths makes setting of traps difficult or impossible. All of these features conspire to force the majority of inshore fishermen into a position of waiting for cod to come to them. While this makes for a highly energy-efficient fishery, the productivity of the fishery and hence inshore fishing incomes is highly susceptible to changes in availability of fish to the gear.

Inshore fishermen frequently believe that failure of the inshore fishery is a result of offshore fishing activity (Lear et al. 1986). Although this no doubt contributed to the poor fishery in the early 1970's, there are a number of reasons why recent failures do not seem to be explained in this way.

There are several alternate explanations. One is based on fishery scientists inference of the temperature preferences of cod from observations of changes in catch rates through depth ranges which also reflect varying temperatures (Lear et al. 1986).

Templeman and Fleming (1956, 1963) found that longline catch rates were highest at depths corresponding to the junction of cold Labrador Current waters and deeper warmer oceanic waters. Templeman and May (1965) noted that Hamilton Bank cod were to be found in the shallows on the Banks in August but that they were concentrated at depths of 230-320 m in waters of 1.8 to 3.5°C in April and May. NORDCO Ltd. (1981) presented data on fishing locations for the foreign offshore trawler fleet which also suggest that cod concentrate in particular depths which presumably correspond to temperature preferences.

These observations led to a series of hypotheses concerning the inshore distribution of cod and the influences of coastal oceanographic conditions on these distributions. These hypotheses were most recently summarized by Lear et al. (1983) but credit for their formulation resides with Templeman and Fleming (1956, 1963). Analyses by Akenhead et al. (1982) were not able to explain variability of trap catches and total inshore catches in terms of capelin biomass or temperature but they were indicative that these factors may well be important. The crux of these hypotheses is that temperature preference governs much of the migrational/distributional behaviour of cod, even though factors such as capelin availability may also be important. It is assumed that cod will be found in waters that have temperatures falling in a preferred range and that, if these waters make up layers within which cod traps are set, catch rates will be high. If only part of the range is fished by trap or only a small part of the trap depths is exposed to suitable temperatures, the catches will be small.

This project was undertaken in the 1985 fishing season in Conception Bay to obtain additional evidence to test the hypotheses relating cod distribution to water temperature. The project monitored catch and effort in the trap fishery in selected areas and extensive monitoring of oceanographic conditions was undertaken. Meteorological conditions which might be anticipated to modify oceanographic conditions were also monitored.

PHYSICAL SETTING OF CONCEPTION BAY

Conception Bay is a large embayment located on the Avalon Peninsula. The mouth of the bay, which is approximately 32 km wide, opens in a northeastward direction to the North Atlantic Ocean. The distance from Holyrood at the head of the bay to the middle of the mouth is approximately 70 km. From Cape St. Francis on the eastern headland to Topsail Cove, the shore is steep with elevations reaching over 250 m in places. Between Topsail Cove and Holyrood Bay the shoreline is frequently formed of rocky baymouth bars extending across numerous small embayments along the relatively narrow, low coast. Inland the terrain is composed of rugged hills rising from 200 to 300 m above sea level. On the west side of Conception Bay from Holyrood northward to Carbonear, the coast is deeply indented with numerous narrow bays oriented in a northeast-southwest direction. To the west, hills and ridges, similarly oriented, rise to heights of 150 to 250 m. Northward from Carbonear to Split Point at the western headland, the shoreline is rocky with numerous open bays. Hills to the west on the Bay de Verde Peninsula reach elevations of 200 to 250 m.

While details of the physical oceanography of Conception Bay are described elsewhere in this report, a brief outline is appropriate here. In northern Newfoundland waters, the Labrador Current bifurcates into an offshore and inshore branch. The main branch follows along the eastern edge of the Grand Banks moving southward through the Flemish Pass. A weaker secondary branch spreads cold, relatively low salinity waters along the east coast of Newfoundland as it flows southward through the Avalon Channel. Surface water temperatures over Conception Bay range from near the freezing temperature appropriate to the surface salinity (approximately -1.7 to -1.8°C) during the mid-winter period to a mean of approximately 13°C during August, the warmest month. Maximum sea-surface temperatures during August may reach about 17°C occasionally.

In a typical winter season, pack ice reaches its normal maximum extent off the mouth of Conception Bay in mid-March, persisting there for about 2 weeks before commencing to retreat. A northerly flow during this period will force the ice to drift to the head of the bay at times. In severe winter seasons, ice has reached Conception Bay in the third week of January and has persisted until approximately the middle of May. A late retreat of the pack ice acts to delay the heating of the surface waters during the spring and summer months.

METHODS

DATA GATHERING

Fisheries

Data were collected by a team of four field observers during the period June 10 to September 18. Data consist of cod trap, gillnet and longline catch and effort logs as well as length frequency measurements and volumetric analysis of cod stomachs.

Catch and effort: Meetings were held in early June with representative fishermen and the fishermen's committees in Bryant's Cove, Port de Grave, Foxtrap and Portugal Cove. Efforts were made to identify trap crews who would be working on the western and eastern shores of Conception Bay and others who would be trapping around Kelly's Island. In this process, it was determined that the Port de Grave community of fishermen would provide a greater probability of continuity of some cod trap fishing throughout the capelin fishery than would the smaller community at Bryant's Cove. It was also determined that no trapping would take place on Kelly's Island in the 1985 season. For operation purposes, the project activities were coordinated in terms of three operational areas. These were for simplicity considered as Port de Grave, Foxtrap and Portugal Cove.

In cooperation with fishermen, four traps were selected for intensive observation and instrumentation with thermographs in each of the three areas. Initial criteria were that the trap would be fished for most or all of the season and that they would be selected as being berths which typically were good producers and which fishermen felt were berths that were generally equally good.

In practice, a catch and effort data base was built up for 36 trap berths fished by Port de Grave fishermen between Holyrood and Bay Roberts. Five of these berths were instrumented. Seven trap berths were monitored in the area from Holyrood to Kelligrews Point, and four of these were instrumented. Eight traps in the area between Portugal Cove and Ore Head were monitored, and four of these were instrumented. Four traps fished by Port de Grave crews at Cape St. Francis were also monitored. Catches from six crews gillnetting between Colliers and Green Point, two netting at Cape St. Francis and four crews line trawling in the area of Bell Rock and one at the east end of Bell Island were also monitored; some of these latter activities were accompanied by monitoring of temperatures using thermographs (Figure 1).

A total of 19 crews were actively involved in catch and effort monitoring activities. Five crews chose not to contribute information to the programme or had logs which had not been used correctly and which could not be analyzed. Fourteen crews from Port de Grave kept logs and provided information as did four crews from Foxtrap and one from Portugal Cove. Crews were provided with a token honorarium at the end of the season in appreciation of their efforts.

Field workers distributed catch and effort logs (Table 1) to fishermen or compiled them by maintaining regular contact. The logs documented daily catch for individual traps or for identified groupings of catches (Table 2) and, for the most part, also identified when and why no fishing took place and when traps were not hauled because a pass with the depth sounder did not show any fish present. Logs used by gillnetters identified the number of nets hauled and longline logs noted the type of bait and time of day that gear was set and hauled as well as the total catch and the water depths being fished.

Landings slips were not used to estimate the catches because variable amounts of dumping of small fish were occurring. In order to obtain total catch estimates and to be able to identify individual trap catches, even when several traps were hauled in each trip, it was necessary to use an estimate of the quantity of fish based on the volume in the boat and fishermen's experience. Previous observations by NORDCO Ltd. have suggested that this method is generally accurate to within about 10%. This level of inaccuracy was deemed as acceptable and the only possible solution since weighing of batches of fish at sea was not possible.

Length frequency measurements: Field workers attempted to sample randomly and measure 100 fish, at least from one trap, in each of the three study locations on each fishing day. Fork lengths were measured to the nearest centimeter using wooden measuring boards. All fish, from which stomachs were taken for analysis, were also measured.

A total of 134 length frequencies were measured, 13 from Port de Grave, 34 from Foxtrap, 88 from Portugal Cove, and 2 from Cape St. Francis. No measurements were made on gillnet-caught fish and data on longlined fish have not been analyzed because of the different selectivity characteristics of these gears.

Stomach contents analyses: Efforts to obtain daily stomach analyses from 20 fish at each location were more successful at Port de Grave and Portugal Cove than at Foxtrap. The total number of samples was 26; 7 from Port de Grave, 4 from Foxtrap, 14 from Portugal Cove and 1 from Cape St. Francis.

Volumetric analyses were performed on fresh stomachs. Stomachs were carefully cut out and emptied onto paper plates. Prey items were sorted, numbers counted and volumes determined by addition of prey material to graduated cylinders containing a known start volume of sea water. While observers did record contents of species other than capelin, only minor numbers of amphipods, euphausiids and crabs were found occasionally, and quantitative analysis has been restricted to capelin content and total feeding condition.

Tagging: A total of 781 fish were successfully tagged with spaghetti tags. Tagging was undertaken after the capelin fishery when cod trap fishing had been resumed by many of the Conception Bay cod fishermen. The tagging procedure involved brailing fish from a trap, one or two operators applying the tag and releasing the tagged fish over the side of the fishing vessel as rapidly as possible. Attempts to hold tagged fish in a floating cage for 15 minutes were abandoned because the high water temperatures apparently hindered recovery, either killing the fish or enfeebling them to the point that it was clearly advisable to retrieve the tags. When fish were tagged and released, only a few (less than a dozen) failed to swim actively and, with the exception of these which were recaptured, the released fish are assumed to have had a high rate of survival.

Tagging in the Harbour Main/Chapel Cove area was attempted on July 23, 24, and 26. No traps had fish on the 23rd and catches were so small that only 214 could be tagged on the 24th. No fishing took place on the 25th, and on the 26th a further 183 were tagged. These were from one Harbour Main trap and one from Chapel Cove.

Tagging on the eastern side of the bay was undertaken at St. Thomas's on July 31. A total of 384 fish were successfully tagged and released from the trap. This trap location was selected as being a central eastern shore location where fishing was successful. The trap operator summarizes the performance at this trap berth as being at least half as productive as his Portugal Cove trap noting that "whenever the trap was hauled, there was 1000 kg or more" and that over a peak period of about 3 weeks when this berth was fished about 16,000 kg of cod were taken.

Standard spaghetti tags used by the Department of Fisheries and Oceans were employed with returns being handled by Fisheries and Oceans in the traditional manner.

Instrumentation of cod traps with thermographs: Pairs of thermographs were deployed on cod traps as close to 4 m and to 20-30 m depth as possible. Thermographs were started and lashed into purse seine mesh bags which were in turn lashed to the front panel of the cod trap near the door or were attached to a line to the surface from one of the moorings. Depths of attachment have been estimated as accurately as possible but can only be interpreted as approximate since currents may have induced significant lateral and vertical displacements.

Table 3 summarizes the durations and locations of deployment. Five traps were monitored on the west shore and because of the poor and sporadic fishery, coverage of the entire season was only achieved on one trap although generally at least three were instrumented at any one time. Thermograph data from this area were obtained at depths around 8 m and 30 m. On the south shore four traps were instrumented throughout their fishing season. Thermographs were successfully set uniformly at 4 m and 27 m depth. In the Portugal Cove area, four traps were instrumented but one instrument failed and another was lost from one of these. Two traps were instrumented throughout the season and thermographs were placed on the third prior to the resumption of the full cod trap fishery after capelin seining.

Instrumentation of line trawl and other fishing gear: An effort to monitor gillnets off Portugal Cove and off Brigus in September yielded too few data to be useful. A total of 26 line trawl tub sets were monitored with at least one thermograph attached to one end of the groundline. A total of 15 had two thermographs set approximately 1 km apart at either end of the gear.

Catch, set time and soak duration as well as bait type and depths at either end of the line were recorded. Thermograph tapes were read manually for an average temperature during the period that the gear was fishing.

Oceanography

Concurrent with collection of data on the Conception Bay fishery, a broad range of physical oceanographic parameters was examined. Some of these were achieved through the establishment of semi-permanent current meter and thermograph stations, some through instrumentation of cod traps, and finally some through periodic occupation of established oceanographic transects. The following subsections describe the deployment of this equipment and preliminary treatment of data.

Current meter moorings: Current meters were moored in four locations in Conception Bay. The locations are shown in Figure 2. Moorings 1, 2, and 3 contained Endeco current meters at 7 m and Aanderaa current meters at 50 m. Unfortunately, no data were recovered from the Endeco meters because one was pulled from the mooring and not returned, and the remaining two instruments failed to sample correctly.

Speed, direction, and temperature were recorded by the Aanderaa current meters at 50 m on Moorings 1 and 2. The instrument on Mooring 3 gave temperature but no speed or direction data. Mooring 4 contained an Aanderaa current meter at 3 m. This meter showed some problems attributed to rotor pumping but nevertheless contained useful information until July 10. Then the instrument began to record erroneous data apparently due to electronic failure. There were no pressure or conductivity data from the Aanderaa current meters because the sensors had been previously removed.

Aanderaa data: Meter Serial No. 3306 and 3302 from Moorings 1 and 2 provided good data without any errors. Meter Serial No. 3583 on Mooring 3 had no speed recorded. Meter Serial No. 4350 on Mooring 4 contained numerous spikes in speed, direction, and temperature beginning on July 10. These spikes resembled the sort encountered from low battery power. Filters were designed to remove the spikes from the data.

The data were transcribed to 9-track magnetic tape and the calibrations applied by Aanderaa Instruments Ltd. The magnetic variation of 25°W was later applied to the data. The sampling interval was 20 minutes. The positions of the moorings and the times of first and last good record are found in Table 4. The calibration coefficients are given in Table 5.

Endeco data: Endeco Type 174 current meters were placed in Moorings 1, 2, and 3 at approximately 7 m from the surface. They were attached to the moorings by a tether. The Endeco meters measured current speed and direction, temperature, and conductivity. Data were collected only at Moorings 1 and 2 as explained previously. Information on the data record is given in Table 6.

These current meters were rented from Endeco Inc., and deployed by NORDCO Ltd. on June 4, 1985. The sampling times were set for 10-minute intervals to give approximately 80 days of data. The maximum speed measured by the instrument is a direct function of the sampling time. For a 10-minute sampling time, the maximum speed which can be measured is supposed to be 44.8 cm/sec.

It was necessary to send the data to Endeco Inc. for data processing. Most of the processing is carried out by the tape reader such that the binary data are not available. The data from Conception Bay could have been sometimes higher than the maximum velocity, and this would then result in wrap-around data. The maximum velocities measured on these particular meters were 38 cm/sec, and never reached the maximum value of 45 cm/sec. On the meter from Mooring 2, the first 10 hours of data were missing. Endeco explained this as being lost data because the instrument had a recording problem with block size at the beginning of the record. This leaves the time base on this data set to be in doubt.

Efforts were made to correct the data. Nevertheless, care and suspicion need to be exercised in any uses or analysis. Oceans Ltd. attempted to correct the data by the following criteria. Each data point was assumed to have one of two possible values. The current speed which gave the least acceleration when compared with the previous speed was the value which was chosen. Another problem was that too many zeroes occurred in the data sets. These zeroes were assumed to be error flags. The zeroes in the data were replaced by the previous velocity value, before the selection criteria were used. By this method, revised data sets were constructed. The data were subsequently filtered and plotted and harmonic analysis performed. The results of the harmonic analysis together with the time series plots indicated that the data were still in error and that the Endeco current meters had malfunctioned.

Ryan thermographs: For additional temperature data, 47 Ryan thermographs were deployed between June and September 1985. Nine of these thermographs were attached to the current meter moorings. The thermographs were attached on Mooring 1 at 15 m and 180 m; on Mooring 2 at 10 m, 25 m, and 180 m; on Mooring 3 at 15 m and 180 m; and on Mooring 4 at 10 m and 25 m. Two additional thermographs on Moorings 1 and 3 gave no data due to flooding. Thermograph 65937 on Mooring 1 begins on June 28 instead of June 3 because it was added to the mooring to replace one which had flooded during deployment.

The other 38 thermographs were located on fishermen's nets situated near to shore around Conception Bay, between Port de Grave and Portugal Cove. The locations are shown in Figure 3. Information on the approximate depth, location, and record length are given in Table 7.

The data from each thermograph were initially recorded as a trace on a paper chart inside the instrument. The traces were later digitized to hourly values and archived on computer tape by NORDCO Ltd. As with most strip chart recorders, the timing which is associated with rotation has a tendency to vary from calibration values. This problem was noted on a few of the thermographs. The time base for each was subsequently compressed or stretched to match the known time interval, assuming that the discrepancy was a linear function of time. In addition, the temperature was adjusted on a few records to match a calibration check from a more accurate thermometer. The same thermometer was used at all thermograph locations. Care was taken to get as accurate information as the instruments would allow. Nevertheless, there remains a larger margin of error than obtained from the temperature time series on the current meters.

CTD profiles: Temperature and conductivity profiles were carried out in Conception Bay by NORDCO Ltd. between June 19 and September 18, 1985. The measurements were made from a small boat using an Interocean Model 514D CTD connected to a digital display recorder. The system permitted only discrete values of temperature and conductivity at 5-m depths.

Most measurements were carried out along two transects. Transect A was located between Kelligrews Point and Burnt Point. Transect D was located north of Bell Island, extending from nearshore (north of Portugal Cove) to the 90-m contour. Additional profiles were made in Portugal Cove and around Kelly's Island. The locations of the CTD stations are shown in Figure 4, and the sampling times are given in Table 8.

Calibrations were carried out by collecting water samples and measuring the salinities on a Guildline Autosal salinometer. The water samples were collected from different depths and on different days for a representative salinity range. The temperature sensor was calibrated in a temperature bath with a thermometer. The temperature values from both sensors are given in Table 9. The calibration values were derived using the method of least squares fit to find the second degree polynomial. The temperature calibration constants were as follows: A=0.3802E-002, B=9.7827E-001, C=1.3386E-003. With the temperature corrections made, the salinities were calculated using the conductivity data which corresponded with the water samples. The salinity values from the Interocean CTD compared with the correct values from the water samples are given in Table 10. Again the second degree polynomial was derived which gave calibration constants for salinity of A=2.6939E-001, B=4.0328E-001, C=1.5656E-002. Using these two polynomials, the temperature and salinity profiles were calculated and plotted.

Note that the low salinity water samples gave apparently inconsistent results. Most of the water samples came from Conception Bay, but the lower salinity water was mixed using a salt supply instead of using Conception Bay water diluted with distilled water. Because this solution had a different ionic composition, its electrical conductivity differed from Conception Bay (Lewis 1981) giving erroneous salinities for the surface water. Once the problem was diagnosed, the low salinity calibration values were deleted and new calibration coefficients derived. The corrected calibration constraints for salinity are A=5.5994, B=1.4573, C=-8.9286E-003. Using the corrected coefficients, salinities and densities were recalculated and revised plots produced.

Meteorology and Satellite Imagery

Surface weather observations: Throughout the summer field program, hourly weather observations from Torbay (St. John's Airport), Bonavista, Argentia, and Kelligrews were logged at the NORDCO Environmental Forecast Centre. Torbay and Bonavista are Atmospheric Environment Service (AES) weather stations at which observations are taken 24 hours per day. The Argentia weather station was a contract weather station supported by Mobil Oil Canada Ltd. which was operated 24 hours each day. The Kelligrews weather station was run under contract to Mobil Oil Canada Ltd. for a 6-month trial period that ended August 30, 1985. At this station, hourly weather observations were normally taken 13 hours each day from Monday to Friday in support of offshore helicopter operations. Missing data for the Kelligrews station were provided by Mr. L. Blagdon of the Newfoundland Weather Centre at Gander. The location of these stations in relation to Conception Bay is shown in Figure 5.

Each hourly weather observation from these stations includes a report of sky condition, visibility and weather, mean sea level atmospheric pressure, air temperature and dew point temperature, wind direction and speed, and cloud type and opacity. The wind data are 2-minute average values whereas the other parameters are instantaneous observations.

The Bow Drill I drilling rig was anchored in Conception Bay near latitude 47°36.5'N, longitude 53°08.5'W, from Tuesday, June 18, to Sunday, June 30, 1985. During this period, hourly observations were taken 12 hours each day to support helicopter flights. These data are in essentially the same format as the land station reports. Not all the observations taken during the period are available.

In addition to these data, total hourly run of wind and the prevailing direction for a recording anemometer located at the Holyrood generating station (Figure 5) were provided by the Scientific Services Unit, AES, in St. John's for the months of June, July, and August. The anemometer siting is not ideal due to sheltering effects by the generating station for west to northwest winds (pers. comm., M. Miller, Port Meteorological Officer, St. John's).

Time series plots of air temperature, mean sea level (MSL) pressure, and wind velocity for the Torbay Airport (Figure 6), Kelligrews station, and Bow Drill I data have been prepared by the NORDCO Ltd. computer group. The time series plots, along with the Holyrood wind data, may be found in Nordco Ltd. (1987).

The time series plots for Kelligrews are not continuous as a consequence of the station operating schedule. The Bow Drill I record is short and contains a number of gaps. The wind data for Holyrood covers the entire study period but contains three periods of 3 to 5 days duration in which the data are missing as a result of instrumentation failure.

Weather maps: Surface and upper air weather maps as well as hard copy GOES and NOAA satellite imagery have been archived for the summer months by the Environmental Forecast Centre at NORDCO Ltd. These data, in conjunction with the local weather observations, were used to investigate the nature of synoptic weather features that may have influenced the circulation within Conception Bay.

Satellite imagery: To investigate the variation of sea surface temperature (SST) distribution over Conception Bay during June, July and August, data tapes of NOAA polar orbiting satellite infrared imagery for 30 time periods were ordered from the Satellite Services Division, NESDIC/NCOC, NOAA, Washington, D.C. Although the criteria were not explicit, the selected time periods were limited, in general, to 2 or more hours with a sky coverage of three tenths or less of low cloud. NOAA was requested to examine the IR imagery for the selected periods and provide NORDCO Ltd. with all scenes for which Conception Bay appeared to be cloud free. A total of six scenes were provided which apparently meet this criterion. Table 11 gives the date and times of the scenes received.

Useful SST data were derived from the computer tapes for the first 4 times listed above. The scene for July 6 was not suitable for SST analysis. The image for August 26 (a night-time pass) shows a uniform temperature field over Conception Bay which suggested that the bay was obscured in fog or had a low cloud cover; this assessment is supported by local weather observations. In an afternoon image from August 26, Conception Bay was located at the extreme edge of the image. The analysis algorithms are unable to function at such large zenith angles, so useful satellite derived SST data are not available for August 26.

The analysis of sea-surface temperature was made using the NORDCO Ltd. DEC VAX-11/750 computer interfaced with a Ramtek 9465 colour graphics display processor. In tests carried out using actual surface and near surface temperature measurements from Conception Bay taken during the project, it was found that the best estimate for SST was obtained by using the satellite derived brightness temperature directly. The average difference was found to be 0.3°C or less depending on which data channel was selected.

Color photographs of the display screen image showing the analyzed SST field over Conception Bay are given in Nordco Ltd. (1987) for NOAA scenes 1, 2, 3, 4, and 6 (Table 11). A colour photograph of the temperature scale, applicable to all images, is also provided in Nordco Ltd. (1987).

DATA ANALYSIS

The methods of data collection and the types of data collected have been described elsewhere (see Methods). In this section, we describe the steps taken in preparing the data for statistical analysis and the procedures employed in the data analysis.

Fisheries Data Preparation and Analysis

Data preparation: The overall analysis was performed using the SAS data management and statistics package. Use of this package requires the preparation of documented data sets.

Initially, three types of catch data were assembled. The first of these included all data on catches with gillnets. The second included all data on catch from single cod traps. The third contained all catch records associated with more than one trap. (Such records resulted from several traps being hauled by a single boat without a return to the quay.) These data sets were used as a basis for two SAS data sets. The first combined both the gillnet and single trap data, whereas the second contained all the multi-trap data. Both data sets contain records of date, location, catch, effort, and type of gear. The first data set also contained records of zone and number of gillnets, when they were used.

In parallel with the creation of the catch files, the thermograph data were assembled into a documented SAS data set. Records within this file contained the date, location, time, and zone of the record, the identification number of the recorder, and the temperature.

In assembling this file, the data were checked and a number of thermograph records were discarded. There were two primary reasons for rejecting thermograph records. The first was that in some cases when the thermograph was taken from the water, the tape was exhausted. Hence, there would be no valid way of associating temperatures on the tape with a date. The second reason for discarding records was when the elapsed times, calculated from increments shown on the tape, and from the start and end dates written on the tape, were in substantial disagreement. This disagreement could be rectified by the use of a correction factor, but if this factor was less than .9 or more than 1.4, the thermograph record was discarded.

Application of these standards reduced the number of locations for which there was a continuous thermograph record at both the top and bottom of a trap. Thermograph records for both the top and bottom of a trap were desired because the key temperature variable affecting catch rates was hypothesized to be the temperature difference between the top and bottom of a trap. (Other possible relationships were explored as well, but this was believed to be of importance based on previous work - Templeman 1966.) Locations for which thermograph data from both top and bottom of the net were available were: Location 2, Location 4, Location 6 and Location 9.

In order to conduct an analysis of the possible relationships between catch and temperature, a file containing daily values for catch and temperature for the five locations listed above was created. For temperature, this necessitated averaging, over a day, the 3 hourly values contained in the thermograph files. Thus, a new SAS file was produced, which contained the location and date of each period, as well as temperatures and depths at the upper and lower recorders, the differences between upper and lower temperature and depth, and the ratio of the differences.

This file was merged by date and location with a limited version of the catch file, containing data for the five critical locations only. The result is the primary file on which the analysis is based.

Analysis: The objective of this part of the study was to establish useful and interesting predictive relationships between catch and various predictor variables. Many of the predictor variables studies were temperature-related. Two different sets of data were analyzed. The first set of data was collected for the individual cod traps to which Ryan thermographs were attached. The second set of data was weekly catch data. Weekly catch data were calculated from a pool of the daily catch data from individual traps. Four pools were used, and are labelled Groups A, B, C and D, respectively (see below). The criteria for membership within a given group were oceanographic, specifically four areas deemed to experience a uniform oceanographic regime were defined. All traps within a given area were then assigned to the same group. The oceanographic data that were used with the weekly catch data for a given group were extrapolated from specific data that were collected at current meter moorings and thermograph moorings at locations in the appropriate areas.

The Methods Section of this report (specifically Data Analysis) contains a description of the variables which were created from the data that were collected. It presents the results of the statistical analysis that was conducted on the data, details the results of the mathematical analysis which was performed on the equations generated, and summarizes the findings.

a) The variables - Because the variable definitions were quite different in the two data sets, the variables will be described separately. We shall begin with the individual trap data.

- Individual trap variables. The predictor variables were surface temperature, deep temperature, and the difference between the temperatures, as described in the previous section.

  The dependent variable was daily catch (kg). Catch data were not available every day; there were some days when the fishermen did not go out, and other days when the traps were not hauled. Frequently, the reason for this was poor weather. These situations are distinct from times when traps were not hauled because there were no fish. Situations of the first type were treated as missing values; situations of the second type were assigned catch values of zero and treated as another data point. Missing values were coded according to "Effort" as follows: not out, not hauled (wind), or not hauled (current).

- Weekly catch data. There were numerous predictor variables tested against the pooled weekly catch data:

  1) TEMPBOT: Temperature at trap bottom (30 m) [degrees Celsius];
  2) TEMGR30: Temperature gradient (0 to 30 m) [degrees Celsius/meter];
  3) TEMGRBOT: Temperature gradient (bottom to -1.0 degrees Celsius) [degrees Celsius/meter];
  4) DM1C: Depth of -1 degree Celsius isotherm;
  5) DOC: Depth of 0 degree Celsius isotherm;

6) DP1C: Depth of 1 degree Celsius isotherm;
7) DP2C: Depth of 2 degree Celsius isotherm;
8) DP3C: Depth of 3 degree Celsius isotherm;
9) DP4C: Depth of 4 degree Celsius isotherm;
10) DP5C: Depth of 5 degree Celsius isotherm;
11) DP6C: Depth of 6 degree Celsius isotherm;
12) DP7C: Depth of 7 degree Celsius isotherm;
13) DP8C: Depth of 8 degree Celsius isotherm;
14) SALINITY: Salinity at 30 m;
15) SALGRD30: Salinity gradient from 0 to 30 m;
16) SALGRBOT: Salinity gradient below trap bottom.

These data were generated weekly for the four general locations in the Conception Bay area as follows:

GROUP A: Portugal Cove Area (Traps 1 to 4) (In Zone 3)
GROUP B: Lance Cove Head (Traps 5 to 9) (In Zone 2)
GROUP C: Brigus (Traps 20, 29, 44, 50, 51, 55, 58, 59, 64) (In Zone 1)
GROUP D: Colliers Point to Harbour Main Point (Traps 18, 21, 22, 23, 28, 30, 31, 32, 33, 34, 35, 37, 42, 46, 47, 48, 49, 56) (In Zone 1)

The independent variable was average catch for the week, ACATCH (kg/day). This variable was created from the daily data by performing the following calculation:

ACATCH = (Total catch for the week)/(Number of days the trap was hauled)

This variable was calculated for each trap. The associated values of the predictor variables for that trap were determined by noting the Group to which the trap belonged.

b) Statistical analysis - The basic procedure that was followed was the same for both daily trap data and weekly trap data. An outline of this procedure follows:

1) Scatterdiagrams of the dependent variable versus each of the predictor variables were generated. The scatterdiagrams were intended to give preliminary indications of the possible existence and general form of any associations between the dependent variable and the predictor variables.

2) For any predictor variables which indicated some association, a regression was performed of the form suggested by the scatterdiagram (for example, linear, quadratic, log, etc.). If the overall model was significant, insignificant variables were deleted until a final functional specification was obtained in which each term was significant at a level less than 0.1. Note that both the repeated regressions with the same data, as variables are deleted, and the use of 0.1, rather than 0.05 as a nominal Type I error rate, make the likelihood of rejecting the Null Hypothesis when it is true higher than that conventionally used. If an association was tested and no significance was obtained, this result was also noted.

The results of the statistical analysis are presented separately for the two sets of data.

- Daily trap data. For these analyses, two records were required per trap: one for surface temperature, and one for deep temperature. Complete records were obtained for five traps. The following analysis was performed on these five records.

  The functional specifications which were tested on these data were either quadratic or linear. The general quadratic form is:

$$E(CATCH) = B_0 + B_1 x + B_2 x^2$$

where x is some predictor variable. If the quadratic term, x^2, turns out to be insignificant, a linear form results:

$$E(CATCH) = B_0 + B_1 x$$

In general, a quadratic association was tested first and, depending on the results, a linear form tested subsequently. This was because most of the scatterdiagrams suggested at least a weak quadratic association which warranted testing. When quadratic forms were fit to the data, in all cases one intercept was constrained to pass through the origin. This constraint was introduced because the 95% confidence intervals around the left intercepts of the parabolas generally included 0. The constraint is justified statistically, but is incompatible with the normal structure of water columns (isotherms from -1°C to 8°C cannot all converge at the surface), and with the general knowledge that cod catches can be well above zero when surface waters are in the range of +3°C for example (i.e. the 3° isotherm is at depth 0).

The constraint was necessitated by the line of analyses selected, but further analyses allowing non zero catches at 0 depth of some isotherms are warranted. Note that constraining the parabolas to pass through the origin strongly influences their shape, and hence the parameter estimates (Figures 7 and 8). For that reason, results of these analyses should be viewed with caution.

The results of the statistical analysis are summarized in Tables 12 and 13. The following general comments apply to these results.

1) Fewer than half of the locations showed any relationship with the predictor variables (two of five locations).

2) The most frequently significant predictor of daily catch was TEMPDIFF.

3) SURFTEMP was a significant predictor in one location; DEEPTEMP at none.

The lack of interesting regression results suggested a re-examination of the scatterdiagrams. Some clustering of observations around particular values of the predictor variables was observed. Therefore, histograms of

CATCH versus TEMPDIFF and DEEPTEMP were constructed for each location. These histograms led to the regression analysis presented in the following section.

Scattergrams were plotted and examined for weekly catch and each environmental variable listed earlier (see Methods - Data Analysis). Visual inspection of the scattergrams suggested a variety of possible associations (Table 14).

The results of the statistical analysis performed according to the above table are summarized in Tables 15 and 16. Examination of this table suggests the following generalizations. For the predictor variables related to depths of isotherms, DM1C through DP5C, some consistency is present. In particular, for depths of the 2 and 5°C isotherms, a significant quadratic association is obtained for Groups A, B, and D. For depths of 0 to 5°C isotherms, a significant quadratic relationship is obtained for Groups A and B. Group C shows weak associations with each of these predictor variables. Group D consistently shows linear or quadratic associations with these predictor variables. Depths of the isotherms are, of course, not independent. A deep isotherm at a specific temperature suggests subsequent isotherms will also be deep, so there is a lack of independence among the predictor variables. The statistical analyses did not address this detail.

Having noted the commonalities for various predictor variables, it was decided to focus attention on DOC through DP4C. The estimated regression coefficients for variables DM1C and DP5C are reported in Table 17.

Table 17 suggests two generalizations. The signs of the quadratic terms displayed are the same for each group for which the quadratic term is significant for all the predictor variables DOC through DP4C. Furthermore, wherever linear associations are obtained, the slopes of the estimated regression lines are all positive. These patterns suggest further mathematical analysis, presented in the next section of this report.

c) Mathematical analysis - For each of the variables DOC through DP4C, significant quadratic relationships were obtained for at least two of the four groups, and each quadratic relationship had a maximum value. The depth of the isotherm which predicted a maximum value for catch was of interest and calculated. Wherever a linear association was obtained, the depth, of the x-intercept of the estimated regression line at which zero catch/day was predicted, was also calculated. For comparison, maximum (or minimum) values and x-intercepts were also calculated for the variables DM1C and DP5C. All these values are reported in Table 18.

Any quadratic regression equation cannot have both a maximium and a minimum, but can have two x-intercepts. Linear equations do not have maximums or minimums, and they have only one x-intercept.

Scatterplots of ACATCH versus four isotherm depths (0°C, 1°C, 2°C, 3°C) were plotted for Groups A and B and are presented in Figures 7 and 8. The estimated regression equations which were computed from these data sets were plotted and are also presented in Figures 7 and 8. In each case, the plot of the regression line appears immediately before its data histogram so that comparisons can be made. The hyphenated portions of the parabolas indicate an extrapolation of the estimated regression lines beyond the range of the data. Any interpretation of these portions of the curves is subject to the usual cautions associated with such extrapolations. Note that all parabolas are extrapolated to the left of the estimated maximum value. This means that not only should predictions in the extrapolated ranges be viewed with caution, but the position and height of the maximum is only weakly determined.

d) Summary of results - The data collected did not support the identification of a strong predictive relationship between catch and any of the predictor variables tested in this study. However, the analysis presented earlier, (see Methods - Data Analysis) did support the following general conclusion:

There are weak but fairly consistent relationships between catch per effort and aspects of the temperature gradient in which the trap is located. This is reflected in the significance of TEMPDIFF with the daily catch data, and the depths of isotherms with the weekly catch data.

Oceanography Data Preparation and Analysis

The data analyses of the current meter data consisted of time series plots, progressive vector diagrams, bivariate histograms and harmonic analysis. The time series plots and bivariate histograms are available in Nordco Ltd. (1987). Bivariate histograms give the number of samples that have speed ranges in specified direction intervals.

Progressive vector diagrams show the distance and direction a particle of water would travel if the flow was spatially uniform. The progressive vector diagrams available in a later section summarizing oceanography results were produced from filtered, hourly-averaged data. A Butterworth filter was used to filter frequencies higher than 0.5 cycles per hour.

Harmonic analysis was performed on the data to separate the tidal constituents and thus gain information on the tidal flow. The values for the constituents are presented in a later section (see Summary of Results - Oceanography). The methods used to compute the tidal constituents were those developed by Foreman (1978) at the Institute of Ocean Sciences. Current ellipse parameters and Greenwich phase lags were calculated by means of a least squares fit method, coupled with nodal modulation.

Before the data analyses were performed, the current data were checked for spikes and erroneous results. The instruments at 50 m on Moorings 1 and 2 contained all good data. The instrument at 3 m on Mooring 4 gave numerous spikes beginning on July 10. These spikes were removed by applying a filter to the data. The speed and direction data also showed problems from rotor pumping caused by turbulence in the surface waters. These irregularities were smoothed by applying a Butterworth filter.

The analysis of the CTD data consisted of producing depth profiles and contour plots of temperature, salinity and density. The salinity and density values were calculated from the temperature and conductivity data before the plots were produced.

Two problems were encountered in determining the salinity values. The problems involved spikes in conductivity data and inaccuracies in the salinity calibration data. The conductivity data included some large spikes which were removed and give replacement values by assuming the same rate of change as occurred in temperature. The salinity calibrations were carried out by collecting water samples and measuring the salinities on a Guildline Autosal salinometer and then deriving calibration coefficients. Problems with the low salinity calibration values were discussed earlier.

The salinities and densities were calculated by using the Practical Salinity Scale, 1978 and the International Equation of State of Seawater, 1980 (UNESCO 1981).

Meteorology

Summary of meteorological variations: A general summary of climatic conditions in terms of departures from the long-term normal of the primary climatic parameters is provided in Table 19 for stations in eastern Newfoundland during the summer of 1985. The stations at Torbay Airport and Bonavista are AES weather stations, the St. John's West station is an agroclimatic station located about 13 km south-southwest of Torbay Airport and Argentia is a recently-closed contract weather station previously supported by Mobil Oil Canada Ltd.

Cooler than normal temperatures prevailed over eastern Newfoundland throughout the summer months at Argentia; all other stations reported cooler than normal temperatures in every month except July. The months of May, June, and July were wetter than normal over the district; August was near normal and slightly drier in comparison to the long-term average while September was a relatively dry month. Torbay Airport and St. John's West reported near normal amounts of bright sunshine during the period as a whole. These data were not available for Bonavista and Argentia.

Figure 6 is a time series plot of mean daily temperatures at Torbay for the summer of 1985. The figure includes the long-term daily mean temperature with standard deviation bars at 10-day intervals and a smooth curve through the mean daily temperatures for each month. Periods of above and below normal temperatures in 1985 are readily descernible from the diagram.

Summary wind statistics for the months of May, June, July, and August 1985 compared with the long-term values at Torbay Airport are given in Table 20. Torbay Airport is the nearest weather station to Conception Bay to have an observing program that has included wind velocity over an extended period of time. The most frequent wind direction in 1985 was typical whereas the mean wind speed was slightly lower than the climatological mean in May and June, slightly higher in July, and considerably lower than normal in August. A more detailed comparison of the monthly wind statistics is provided in Table 21 which gives the percent frequency of occurrence by wind direction and the mean speed by direction for the summer months.

The most noticeable difference between the June 1985 statistics and climatology was for winds from the south-southeast and south. These occurred much more frequently and with higher average speeds than normal. These conditions prevailed early in the month and corresponded to a period of warmer than normal air temperatures. In July, northerly winds were less frequent and lighter than usual. Winds from the southwest and west-southwest occurred 50 percent more frequently than the climatological norm for the month; speeds from these directions were near normal however. July daily mean temperatures were above normal for 22 days of the month at Torbay Airport. The August statistics show that winds from the east to southeast occurred more frequently than normal with average speeds near the long-term mean values. Winds from the south to west occurred less frequently than usual during August 1985 with mean speeds that were significantly lower than the climatological statistics. As suggested above, daily mean temperatures were below normal more frequently than above during August 1985.

The time series plots of wind velocity for stations in the vicinity of Conception Bay are given in Appendices II through V of Data Report 3 in Nordco Ltd. (1987).

Satellite imagery: The infrared satellite imagery provided useful data of the SST field over Conception Bay between June 15 and July 5, 1985, when surface waters were rapidly warming. Colour photographs of screen images of the SST analysis are provided in Appendix I of Data Report 3 in Nordco Ltd. (1987).

The analyses indicate that the surface temperatures over the Bay ranged from near zero degrees Celsius to approximately 5°C on June 15 and warmed continuously to range from 8 to 11°C on July 5, 1985. Typically, the warmest waters were located in the vicinity of the islands and along the southeastern shoreline from about Portugal Cove to Holyrood Bay. On the earliest available image (June 15), the coldest waters were along the western shoreline of the bay. A similar distribution of SST can be seen over Trinity Bay in the same images. This is suggestive of upwelling of relatively cool water along a windward shore. By June 25, the SST distribution had changed substantially; at this time, the coldest surface waters were found towards the mouth of the bay. The temperature range of these data is approximately 3 Celsius degrees. Two days later, a tongue of relatively cool water was located through the center of the bay. On July 5, the coldest surface temperatures were observed along the western shore toward the northern portion of the Bay de Verde Peninsula whereas the warmest surface waters were located in the vicinity of the islands.

METHODS OF IDENTIFYING KEY EVENTS

Notable Fisheries Events

Significant fisheries events were defined in two ways. The first, suggesting a short-term phenomenon, was defined as an event identified by a notable change in daily catch per effort in any of the various zones. Second, indicative of a general, although not necessarily less subtle phenomenon, were changes in long-term trends of catch per effort in the various zones.

These definitions, of course, are quite obvious, as catch per effort can be measured directly given effective monitoring and can be a reliable measure of the availability of cod. Two analyses were attempted in order to make the identification of notable events more empirical. These analyses were 20-day running cross-correlations of catch per effort between pairs of zones, and a comparison of changes in daily catch per effort among zones. The cross-correlations were not useful for this purpose but did highlight some other interesting interactions discussed in a later section dealing with the summary of results for catch per effort. The comparisons of changes in daily catch per effort served to reinforce our previous selection of significant events.

Graphs of trap effort and total catch per day throughout the season are presented in Figures 9 and 10 respectively. Although the levels of catch per effort were relatively stable from the last week of June to the end of the first week in August, daily variability was high in most zones during the first 3 weeks of the season, and on several occasions in July. The stabilization of catch per effort on or about June 24 was identified as a notable event. Drops in catch per effort in Zone 3 on July 12 and in Zone 1 on July 15, 25, and 27 were identified as notable events. The start of a general downward trend in catch per effort for all zones on August 7 was also identified as a notable event. Identification of these significant events was made without reference to any possible causative environmental factors.

Notable Oceanographic Events

The identification of key events from the oceanography data was based on changes in water temperature. Variations in salinity were used in addition to temperature to identify the major event which occurred sometime between August 14 and 21.

The temperature measurements from the current meters, moored thermographs, and thermographs placed on fishermen's nets gave the most useful information for the identification of key events. All the temperature data were searched for important increases and decreases in temperature. In order for a temperature change to be designated as a key event, it had to occur simultaneously at more than one location within the zone of interest. Some zones had more sampling locations than others, but this was not felt to seriously influence the identification of key events.

Key events were identified for three zones within Conception Bay. Some of the events occurred in only one zone whereas others occurred in all three zones. Using the described criteria, six events were identified in Zone 1, five events in Zone 2, and six events in Zone 3.

Meteorology

The complexity of the ocean-atmospheric interaction over the pertinent temporal and spatial scales make the problem of identifying notable meteorlogical events extremely difficult. The global impact of annual variation of solar heating; the large-scale wind-driven circulation of the North Atlantic Ocean; and smaller-scale variations arising from wind forcing associated with the passage of low pressure disturbances of varying intensity that track generally eastward through the mid-latitude regions of the hemisphere; all affect the availability of cod, but are beyond the scope of this study.

Local winds may produce direct wind-driven circulations which influence the temperature-salinity profile over relatively small temporal scales. Because these changes are more likely to be observable than those due to large-sale forcing, only wind measurements obtained nearby were used to identify notable meteorological events which may be important. Variations of other meteorological parameters, such as surface air temperatures and solar insolation (hours of bright sunshine), were considered but their direct influence would be extremely difficult to assess.

Notable meteorological events were selected on the basis of marked change in wind velocity which prevailed for periods of about 12 hours or longer. The wind record for Torbay Airport was used because it was the only continuous one available.

A summary of the noteworthy meteorological events includes the following points:

1) South to southwest winds of moderate strength (10 to 20 knots) prevailed over Conception Bay during the period from June 3 to 12.

2) Near calm conditions occurred on June 13, then moderate to strong southwest winds developed on June 14 and persisted through June 16.

3) Mainly light (less than 10 knots) to moderate winds primarily out of the southwest and northeast quadrants occurred from June 17 to 28. It is expected that wind forcing during the period of brisk southwest in mid-June would result in the development of a wind-driven surface current directed toward the northeast or east with compensatory upwelling occurring along the windward shoreline. The SST analysis of June 15 tends to support this expectation.

4) The passage of a trough of low pressure late on June 29 was preceded by moderate to strong southwest winds for much of the day and followed by a

period of strong northeast winds on June 30. Moderate to strong southwest winds redeveloped on July 1.

5) On July 3, a period of moderate to strong southwest winds in the early hours of the day veered to strong southwest winds for about 12 hours, then gradually weakened toward evening.

6) A southwest flow, typical of summer, prevailed over eastern Newfoundland from July 3 through 17. Light to moderate winds were frequently reported during the evening and early morning hours while winds of moderate to strong strength occurred most frequently during the afternoon hours. Occasionally, light northerly winds occurred during the period primarily due to the development of a local sea breeze.

7) A low pressure disturbance affected the area on July 19. This was preceded by a short period of strong southeast winds and followed by a brief period of strong northwest winds.

8) A southwest flow prevailed during the remainder of the month of July. The strongest wind occurred during the 4-day period from July 25 through 28. Thirty knot winds gusting to 45 knots were reported at land stations on the Avalon Peninsula on July 27.

9) Another low pressure disturbance crossed the district on August 2. This event was preceded by a short period of strong easterlies, then followed by strong northwest winds for a period of 9 hours.

10) Winds of light to moderate strength primarily out of the southwest quadrant prevailed between August 4 and 13.

11) A moderate northwesterly flow developed on August 14, increased to strong during the morning of August 15, diminished to light towards evening, then increased again to moderate to strong intensity once more on August 16.

12) Moderate to strong south to southeast winds developed ahead of a low pressure trough on August 20. These winds persisted for about 12 hours before veering into the southwest and gradually diminishing on August 21.

13) The passage of another trough of low pressure on August 24 brought strong west-northwest to northwest winds for a period of about 12 hours.

14) Light to moderate winds of variable direction occurred during the period August 25 to 28 when a moderate southeast flow developed in advance of an approaching low pressure disturbance.

15) A disturbance passed through the district on August 30. Strong northwest winds developed over eastern Newfoundland in its wake. The northwesterly winds gradually diminished on August 31.

SUMMARY OF RESULTS, KEY EVENTS AND PERTINENT HISTORICAL DATA

FISHERIES

General Description of 1985 Season

The 1985 inshore cod fishery in Conception Bay was generally poor, although landings in Zone 3 were acceptable. A review of historical landing data for Statistical Sections 22 and 23, which entirely encompass the present study area, show 1985 landings at 65.9% and 65.2%, respectively, of the yearly average for the previous 7 years.

A striking feature of the Conception Bay cod trap fishery is the extreme variability in landing levels from year to year. In the 8-year period ending in 1985, landings have been as low as 44% and as high as 250% of the 1985 landings.

1985 season: Total weekly landings for the Conception Bay study area followed a general rising trend from about 1600 kg in the first week of June to a maximum of 66,000 kg in the third week of July. Landings were maintained within the 45-60,000 kg range between the first week in July and the middle of the second week in August, at which time they fell from 62,000 kg to 46 kg in a 2-week period.

The zone exerting most influence over total landings was Zone 3. With the exception of the first 2 weeks of June and the first 3 weeks in August, Zone 3 landings represented more than 62% of total weekly landings. Over the entire study period, Zone 3 contributed 55.5% of the total landings.

In contrast to the predominant influence of Zone 3 on the trends in landings for the bay as a whole, the large number of vessels and traps fishing in Zone 1 influence to an even greater degree the effort figures for the bay. Differences between these two zones make it necessary to examine catch and effort data zone by zone. This examination is presented in detail in the following two subsections.

Effort: For the purposes of this evaluation, effort has been defined as the number of traps hauled per day. Vessel-days and person-days were rejected as measures because of the difficulty in differentiating effort directed at the cod trap fishery from effort directed at other fisheries, such as capelin. Days when effort equalled 0 due to poor weather or Sunday observance were dropped from the averages (see Figure 9).

a) Zone 1 - The trap fishery in Zone 1 started abruptly. During the first week of June, traps were set by several crews. Despite landings of less than 100 kg per trap per day, on the 9th of June effort jumped to 26 trap hauls per day. Between June 9 and 27 effort remained high, fluctuating from a high of 29 trap hauls per day to lows of 10 and 11 hauls per day. There was one day when only one trap was hauled.

On the 29th of June, effort diminished to two hauls per day, and over the next 2 weeks remained between one and seven hauls per day. This relative lull in effort corresponds to a shift of activity by most fishermen in Zone 1 from cod to capelin. By July 15, effort had again begun to increase to an average of approximately 15 trap hauls per day. Effort fluctuated over this period from 27 traps to 6 traps. On August 19, effort dropped to one trap haul per day and fishing ceased on August 28. Zone 1 accounted for 64.3% of effort in the bay throughout the season.

b) Zone 2 - Effort in Zone 2 was limited throughout the season to a maximum daily effort of six trap hauls. Trap fishing was initiated on June 3 and over the ensuing month averaged three hauls per day. A slight reduction of effort to approximately 2.5 hauls per day occurred during the capelin season, but by July 21 effort had again increased, this time to an average of between five and six hauls per day. By August 5, effort had begun to decline until termination of the fishery on August 16. Zone 2 accounted for 14.4% of total effort for the bay.

c) Zone 3 - The first effort recorded for this zone occurred on June 12 when two traps were hauled. This level was maintained for one week, then increased to three trap hauls per day. On July 4 effort increased again, up to four trap hauls per day. Effort over this first month of the fishery showed almost no day-to-day fluctuation. On July 13 there was a further increase in effort, to an average of five trap hauls per day. This level was maintained until August 14 although daily variations in effort were more pronounced than in the earlier period. Effort had ceased by August 22. Zone 3 accounted for 17.2% of total effort for the bay.

d) Zone 4 - The fishery in Zone 4 started on July 9, after the peak of the capelin season was over. It was fished primarily by crews from Port de Grave who, being unsatisfied with catch per effort in their own area, decided to set traps in the Cape St. Francis area where landings were expected to be significantly better.

From the start of fishing to the end of the season on August 12, effort remained constant at two trap hauls per day. Zone 4 accounted for 4.2% of total effort for the bay.

e) General observations on effort - Effort in Zones 2, 3, and 4 remained quite stable throughout the season in Conception Bay, with very little fluctuation from day to day. On several occasions, no traps were hauled in one or more zones, apparently due to adverse weather. It also appears that only one trap was ever hauled on a Sunday anywhere in the bay.

Zone 1 did display marked daily variability in effort, although no obvious reason for this could be found. General poor catch per effort in this zone could reduce the incentive for a fisherman to make more than the minimum effort to haul his traps (see Figure 9).

Catch: In this section, we will deal with landings in Conception Bay in relation to two measures: absolute catch, and catch per unit of effort. Absolute catch is measured in kilograms and describes the actual weight of fish caught in a particular zone. Catch per unit of effort is a measure of the relative abundance and catchability of fish in the various zones. This value can be derived by dividing the absolute catch in a zone on a particular day by the number of traps hauled in that zone on that day.

Although the large number of crews and traps in Zone 1 greatly influenced the average effort figures throughout the summer in Conception Bay, the catch per effort figures for Zone 3 overshadow landings figures for the other zones. In terms of catch per effort, there were only 16 days throughout the season when Zone 3 was exceeded by any other zone (Figure 10).

a) Zone 1 - Landings in Zone 1 during the first week set the tone for the season. Catch per effort during this week ranged from 20 to 80 kg per trap per day. Throughout the season, the highest catch per effort was observed to be in the order of 500 kg on August 6. On several days, catch per effort fell to zero.

Total landings in Zone 1 started at a low of 355 kg and climbed steadily, with the exception of one week, reaching a high of 8,553 kg during the first week of July. During the capelin season, the shift of effort in this zone was reflected in total landings for the zone which fell to between 2,000 and 3,700 kg per week from the 7th to the 27th of July. When effort on cod resumed the following week, landings jumped to 18,530 kg, then 33,468 kg before sliding toward zero by the 24th of August.

Throughout the season, Zone 1 contributed 22.0% of total landings for the bay. Average catch per trap haul for the season was 105.6 kg.

b) Zone 2 - Catch per effort in Zone 2 remained quite stable throughout the study period at values between 50 and 500 kg per trap per day. On only two occasions did catch reach 1,000 kg per trap (July 21 and August 7) or fall below 10 kg per trap (June 19 and August 14-16). Landings in Zone 2 followed a general climbing trend from the first to the eighth week of the season. Although interrupted by minor drops, weekly landings rose from 1,267 kg to 6,017 kg in the sixth week, then peaked to 18,344 kg during the fourth week of July. Landings dropped from this point to zero within 3 weeks. Landings in this zone accounted for 14.6% of the total for the bay. Average catch per trap haul for the season was 326.9 kg.

c) Zone 3 - Catch per effort in Zone 3 was consistently higher than for other parts of the bay. Except for the end of the season, catch per effort fell to zero on only four occasions, June 14, 15, and 20 and July 12. On only 15 other occasions was catch per effort in this zone exceeded by that in another zone. These occurred primarily during the last half of the season and were seldom greater than 300 kg.

The season in Zone 3 started on June 12. By June 15, landings had totalled 3,364 kg. During the first full week of fishing, landings were 19,817 kg. From the 23rd of June until the 27th of July, landings ranged from 22,000 kg to 42,000 kg per week.

From this peak during the eighth week of the season, weekly landings decreased to 10,861 kg, briefly rebounded to 18,420 kg, then dropped to 2,177 kg and finally 46 kg during the last week of the season which ended on

August 22. Landings in this zone accounted for 55.5% of total landings for the bay. Average catch per trap haul for the season was 983.7 kg.

d) Zone 4 - Catch per effort in this zone was second only to that in Zone 3. This has traditionally been the case and explains why a portion of this fishery is prosecuted by fishermen who go to the expense of commuting to the area from Zone 1. Traps were not set in this zone until near the end of the capelin season on the 9th of July. At that time, landings commenced at a level of approximately 800 kg per trap per day.

This level was maintained until July 21 when landings dropped to the order of 100 kg per trap. From this point onward, catch per effort attained 1,000 kg on only one date (July 31). Fishing terminated in this zone on August 12.

The most successful week of the season in Zone 4 occurred between the 9th and 13th of July when 11,560 kg were landed. From this level, landings dropped to 9,308 kg the second week and 2,580 kg the third. Landings levels rebounded slightly to 4,372 kg the following week before sliding to 2,976 kg and finally 168 kg on the final week the zone was fished. Landings in Zone 4 accounted for 7.9% of total landings for the bay. Average catch per trap haul for the season was 573.4 kg.

Comparisons and Contrasts Area to Area

In addition to general descriptions of results of the various investigations conducted throughout Conception Bay in 1985, zonal results were compared and contrasted to identify patterns of variability. The measures evaluated were catch per effort, length frequency measurements of fish, quantitative stomach content analysis, and tag/recapture data.

Catch per effort: Comparative catch per effort among zones was examined primarily through the use of cross-correlation analysis. Descriptive statistics of catch per trap by zone are presented in Table 22 followed by the matrix of cross-correlation coefficients for these catch per trap per day data among the various zones. The cross-correlation function of two variables describes the general dependence of the values of one set of data on the other. With the exception of the weak negative coefficient shown for comparisons between Zones 1 and 4, and between Zones 2 and 4, all other coefficients are weakly positive. The strongest cross-correlations occurred between Zone 1 and Zone 2, and between Zone 1 and Zone 3 (.29 and .31), respectively. This tends to indicate that, from a seasonal perspective, little relationship exists in daily catch per effort among different parts of Conception Bay.

In order to test the possibility that such low cross-correlation coefficients were the result of time lags between zones, cross-correlations were performed on data lagged from 1 to 4 days. These correlations are presented in Table 23. Time lags were not particularly important. Highest cross-correlations occurred on pairings with 0-days lag three times, 1-day lag two times, 2-days lag once, 3-days lag once, and 4-days lag five times. Several of the maxima were negative; few were statistically significant when allowance is made for repeated tests of the hypothesis of no asssociation using the same data sets.

A subjective comparison of daily variability of catch per effort among zones based on visual inspection of graphs of catch per day suggested that for certain intervals during the season, cross-correlation coefficients would be significantly higher. In order to test this, a cross-correlation analysis of 20-day blocks throughout the season was undertaken. Figure 9 illustrates the variability of cross-correlation coefficients between pairs of zones throughout the season.

The dates along the x-axis represent the dates around which the 20-day blocks of days were centered. Some common patterns were present for most zone pairings. Most obvious was the increase in coefficients during the first week of August for Zone pairs 1 and 2, 1 and 3, 1 and 4, and 3 and 4. Minimum coefficients occurred during the first two and one half weeks of July between Zones 1 and 2, and Zones 2 and 3. Prior to these minima, coefficients were high in both of these zone pairs. Pairings with Zone 4 showed no obvious trends of significance. No statistical significance levels can be associated with these patterns of cross-correlations, however, because the method for selection of block size used the same data that were used to calculate the cross-correlations.

Length frequency measurements: Length measurements of random samples of fish were collected at frequent intervals throughout the project. In several cases, due to the small population size, all fish from a single trap were measured.

Length frequency histograms were generated from the data in order to illustrate any differences in mean lengths of fish between zones. These data were presented in accompanying data reports (NORDCO Ltd. 1987). Next, length frequency histograms were generated for each zone for data collected during the middle 2 weeks of each month. This was done to illustrate monthly variability of mean fish lengths. Table 24 and Figure 12 present these data.

Although the mean size of fish caught in Zone 2 remained relatively constant throughout the season, in Zones 1 and 3 the mean sizes of fish taken in July were substantially larger than in June or August. Fish from Zone 4 were only measured during July. Zone 4 fish were of larger average size than fish in any other zone at any time during the project.

One possible explanation for this month-to-month variability in mean fish lengths would be the existence of two separate populations of fish present in Conception Bay during all or part of the fishing season. One population would consist of predominantly small fish (average size of 43-47 cm) which either migrates into the bay early in the year and migrates out quite late, or resides in the bay throughout the year. The second population consists of significantly larger fish which migrate into the bay starting in mid-June.

If this hypothesis of two populations is valid, it could be possible to trace the movement of the second population into the bay using the spatial and temporal variability of mean fish length. Figure 13 illustrates the weekly variability of mean fish length. A comparison of these figures shows a 1-week lag between Zone 3 and Zone 1 in the early season trend to larger mean lengths. The low mean length during Week 2 in Zone 1 was derived from few measurements and is considered unreliable.

This lag suggests that large fish migrating into Conception Bay from farther offshore, enter the fishery first in Zone 3, closest to the mouth of the bay. As more large fish migrate in, the weekly mean length increases. Meanwhile, the same trend is occurring in Zone 1 but as Zone 1 is farther inside the bay, the increase is delayed.

Zone 2, which is located at the head of the bay in generally shallower water, appears not to have these larger fish enter the fishery in noteworthy numbers. Weekly changes in mean fish length during the last 3 or 4 weeks of the season fail to show a clear outward migration, but the general overall trend in Zones 1 and 3 is toward a decreasing mean length.

Stomach content analysis: Stomach contents collected from cod landed in Port de Grave and Portugal Cove were analyzed. As indicated earlier, only small quantities of material other than capelin were found in cod stomachs. For this reason, only comparisons of stomach volumes between areas were considered necessary for purposes of this report.

In order to illustrate trends in stomach fullness and hence feeding rate, the percentage of stomachs found to be empty and mean volume of material in stomachs sampled for Zones 1 and 3 were plotted against sample dates (Figure 14). From these plots it is obvious that some dramatic weekly variability exists in the volume of stomach contents. Volume was low at the beginning of the season, increased to a maximum in mid-July, then decreased toward the end of the season.

Recalling that this trend closely parallels that found in cod lengths during the same period, and assuming that cod of greater length have proportionately larger stomachs, it was felt that some standardization of fish would be necessary in order to have stomach volume represent a more accurate measure of fullness. This standardization was accomplished using the following equation:

$$X_n = 1/(L_c/L_b)^3 \times X_c$$

where
X_n = standardized volume
L_b = base length of fish (mean length in week 1)
L_c = current length (mean length in current week)
X_c = current stomach volume measure (actual stomach volume)

This procedure corrects for variability in stomach volume attributable to variability in the mean lengths of fish. Standardized stomach volumes for Zones 1 and 3 are plotted in Figure 12.

Common characteristics of the two plots for standardized fish are the low volumes which occurred at the beginning of the season, and maxima which occurred in the middle of July. When the data are standardized by size for fish in Zone 1, there is a peak in stomach volume early in the season which did not appear in the original plot, and the mid-July maximum is reduced. The trends identified in the unstandardized plots are not so obvious in Zone 1 when the stomach volumes have been standardized, but remain strong in Zone 3.

Zones 1 and 3 differ markedly in the percent of cod stomachs found to be empty during the first 2 weeks of the season. Whereas in Zone 3 over 80% of the fish caught had empty stomachs at one point, the percent of empty stomachs in Zone 1 barely exceeded 50% and for much of the time remained around 30%. Stomach volumes in Zone 1 never reached 90 ml whereas fish from Zone 3 had stomach volumes ranging from 15 ml to over 150 ml.

The percent of cod stomachs found to be empty in Zone 1 reached zero during the beginning of the second week in July. The percentage did not exceed 10% for the remainder of the season.

In Zone 3, peak feeding occurred on July 16, but immediately after, the percent of cod stomachs found empty jumped to 50%. Mean stomach volume also dropped from 110 ml to 30 ml and continued to decline to zero by the end of the season.

These differences suggest either that some mechanism reduced feeding behaviour in the cod or that, for some reason, capelin became unavailable to cod as a prey species immediately after July 15 in Zone 3. These changes apparently did not occur in fish sampled from Zone 1.

To investigate if temperature changes were associated with the changes in feeding of cod on capelin, relationships between the change in feeding behaviour and a change in the temperature were examined. Figure 15 illustrates the relationship between two measures of the behaviour change and depths of those isotherms previously determined to be important in defining cod habitat (0°C - 5°C isotherms). Although no firm conclusions can be drawn regarding a relationship between depth of the various isotherms and changes in feeding behaviour by cod in Zone 3, marked changes in the depth of the isotherms were associated with changes in the two feeding behaviour indicators.

Tagging: The tagging experiment carried out under this project was described earlier. Although the tagging sites have been assigned to specific zones, it should be noted that both sites were located on borders between zones. The tagging performed in Zone 1 was actually done adjacent to Zone 2. Tagging was conducted July 23, 24 and 26.

The Zone 2 tagging was conducted at the northern edge of Zone 2 in a location more similar to Zone 3 trap sites than typical Zone 2 trap sites. Tagging was conducted on July 31. We would expect the behaviour exhibited by tagged fish to represent some mixture or intermediate form between behaviours of fish from the adjacent zones.

a) Zone 1 - Tag returns from the Zone 1 tagging totalled 45 or 8.8% of fish tagged in this area. Of these returns, 69% were taken in Zone 1. Ninety-four percent of the returns coming from Zone 1 occurred within

1 month of tagging, the majority from the immediate vicinity of the tagging site. A total of 31% of returns were recaptured outside Zone 1. Of this portion taken outside Zone 1, 73% were taken in Zone 2 and 92% of these fish were also recaptured within 1 month of tagging.

The temporal and spatial patterns of returns from the Zone 1 tagging suggest that these fish are not moving to any great extent. No general migratory trends can be inferred from these data, although fish recaptured outside Zone 1 tended to be taken northeast of the tagging site along the east side of the bay.

b) Zone 2 - Tag returns from the Zone 2 tagging totalled 38 or 9%. Of these returns, 8% were taken in Zone 2 and 61% were taken in Zone 3. Seventy-one percent of those fish recaptured in Zone 3 were taken within 1 month of tagging. A total of 6 tags or 16% of all returns from fish tagged in Zone 2 were taken in traps located to the southwest of the tagging site, toward the head of the bay. The remainder were all taken at least 6 km to the north along the northeast side of Conception Bay, stretching around Cape St. Francis.

The temporal and spatial patterns of returns from the Zone 2 tagging suggest that these fish were generally less inclined to remain near the tagging site, and exhibited a trend of movement northeast out of the bay.

Tagging sites and return locations are illustrated in Figure 16.

Tidal cycles: Many biological phenomena have been linked to lunar and tidal cycles. The mechanism of influence of lunar cycles on behaviour is not well understood in many cases. However, tidal amplitude and periodicity can clearly influence organisms for which the intertidal zone is an important habitat for at least part of their life cycle.

In order to examine any relationships between tidal influences and the availability of cod, plots of the weekly variability of catch per effort and predicted tidal amplitude as derived from the Canadian Tide and Current Tables for St. John's corrected for Long Pond, Conception Bay, were prepared (Figure 17). The correlation coefficient between these sets of values for the whole season was not calculated because the data were not available on comparable time scales. Nevertheless, one obvious feature is present.

During the fourth, fifth, and sixth weeks of the project (June 23 to July 13), the trends in catch per effort closely followed the trend in predicted tidal amplitude (the difference in height above chart datum between adjacent high and low tides). It was felt that, although no obvious correlation existed between these two data sets for the majority of the season, the coincidental peaks during the early part of the season were meaningful. During the one and one half weeks prior to the coincident peaks, the rising trends in both parameters are parallel. Immediately following the peak, both parameters rapidly decline over the same time period. These trends suggest some direct or indirect causal relationship. Although it is possible that tidal amplitude could directly influence catch per effort, one additional factor was examined.

Figure 18 shows a plot of tidal amplitude and capelin landings over the 1985 season. Again, as time scales were incompatible, no correlation coefficient was calculated. It is likely that capelin, preparing for intertidal spawning, were being influenced by tidal amplitude (Templeman 1948).

OCEANOGRAPHY

General Description of Conception Bay Ocean Climate

This section provides a general description of the Conception Bay ocean climate with special emphasis on water movement regimes, and the interaction of weather patterns on water movement. The existence of a large-scale mass transport of warm, low salinity water which moved into Conception Bay in early August, coinciding with a reduction in cod trap landings, is discussed.

Circulation in Conception Bay: The currents in Conception Bay were measured at a depth of 50 m at two locations. These two locations are shown in Figure 2 and designated as Moorings 1 and 2. Currents were also measured at the head of the bay at a depth of 7 m in the location shown as Mooring 4.

At a depth of 50 m, the current circulation was weak with mean current speeds of approximately 20 cm/sec at Mooring 1 and 15 cm/sec at Mooring 2. At Mooring 2, the mean velocity was 5.4 cm/sec in a 160° direction. The bathymetric contours are aligned in a northeast/southwest direction such that the current was directed diagonally to the contours, or across the bay. This indicates that the flow into Conception Bay is either located in a narrow stream close to shore or at a water level deeper than the current meters were moored.

In general, the current at Mooring 2 was flowing in a south southeast direction. However, between June 14 and 19, the current flowed in a northeast direction out of the bay. From July 3 to 10, the current flowed southwest into the bay, and between August 24 and 26, the current flowed in an east direction.

At Mooring 1, the current flowed east in June and early July and then changed to northeast, out of the bay, from July 19 to the end of the record. The only anomaly occurred during June 16 to 19 when the current flowed southeast for a 4-day period. The progressive vector diagram in Figure 19 shows that the mean velocity was 7.7 cm/sec in a northeast direction.

Harmonic analysis was performed on the current data collected at 50 m at Moorings 1 and 2 to separate the tidal constituents and thus gain information on the tidal flow in Conception Bay. The semidiurnal and diurnal constituents in Tables 25 and 26 show that the tide was of the mixed, mainly semidiurnal type. M2 was the largest semidiurnal constituent followed by N2, L2, and S2. The diurnal constituents K1 and O1 were both smaller than either of the four semidiurnal constitutents.

Elliptical hodographs for the semidiurnal constituents are given in Figure 20. The tidal current is a combination of the constituents represented by the hodographs. At Mooring 2, the overall effect would be a larger ellipse representing a semidiurnal tidal flow of approximately 5 cm/sec. At Mooring 1, the tidal flow would be more complex because three of the four ellipses are elongated and orientated in different directions.

The harmonic analyses gave mean velocities of 7.7 cm/sec directed out of the bay at Mooring 1, and 5.4 cm/sec across the bay at Mooring 2. These results agree with the values extracted from the progressive vector diagrams in Figure 19.

At Mooring 4, located west of Kelly's Island, the current was measured at a depth of 7 m. At this location, the current usually flowed in a southeast or onshore direction as shown in the progressive vector diagram in Figure 17. The mean southeast velocity was 6.1 cm/sec. There were three occasions when the current flowed east. These events occurred on June 7 and 8, June 23 to 25, and August 20 to 22. There was also one occasion between June 9 and 17 when the current flowed south for a period of 9 days.

Wind effects on current flow: In the planning of this study, it was presumed that wind played a significant role in the circulation within Conception Bay. It was hypothesized that the redistribution of the water properties from wind stress might affect cod movements within the bay. The results of this current meter program give no evidence to support this hypothesis. The wind velocities from St. John's Airport and Holyrood generating station were plotted to the same time scale as the current velocities at 3 m and 50 m. At a depth of 50 m, there was no visual correlation between the currents and wind stress. The wind-driven surface currents would not have extended to 50 m, but if winds had played a significant role at the surface, there should have been some form of reverse currents or current anomalies at the sampled depth (Figure 19).

The current at 3 m near the head of Conception Bay also shows little or no influence of wind effects, with the possible exception of the period from July 25 to 27 (Figure 19). During this 3-day period, the current had a predominant northeast flow. This corresponds with prevailing southwest winds between July 25 and 28 which reached 30 knots, gusting to 45 knots on the Avalon Peninsula. Note that wind directions are conventionally quoted as 180° out of phase to current direction, even though both have the same physical direction.

Although there was little evidence of wind effects on current directions in the results of this study, it is not conclusive that the wind has no effect. If current measurements had been recorded near the surface in the central regions of the bay, evidence of wind effects on current flow might have been obtained. Three of the moorings had Endeco current meters placed at 7 m from the surface to measure possible wind effects. All these meters malfunctioned.

Temperature and salinity variations: Temperature and salinity were sampled with an Interocean CTD along two transects in Conception Bay. Transect A extended across the head of the bay between Kelligrews and Burnt

Point near Brigus. Transect D extended offshore, northeast of Bell Island (Figure 4). Transect A was sampled on 11 occasions and Transect D on 8 occasions between June 25 and September 18, 1985.

Between June 25 and August 13, the surface water went through a gradual and continual warming, with surface temperatures increasing from 6°C to 14°C. At a depth of 20 m, the temperatures increased from about 3°C to approximately 6°C during the same period. The thermocline, which had become particularly strong by July 24, began to weaken slowly in early August. During the period under consideration, the 0°C isotherm moved from approximately 35 m to 50 m. The salinity showed only slight variations in the period between June 25 and August 13, although a very slight decrease in surface water salinities was evident in the data collected after July 24. The temperature, salinity, and sigma-t values were derived from the CTD profiles.

During the period between August 13 and 27, both temperature and salinity went through dramatic changes in Conception Bay. The 12°C isotherm moved from 10 m to 35 m along Transect A (Figures 21 and 22) and from 5 m to 25 m along Transect D (Figures 23 and 24). The 0°C isotherm moved below 70 m. The salinity decreased by 1.2 ppt in the upper 30 m along both transects. The data suggest that a significant exchange of water occurred above 70 m during the period.

The strong signal noted in the series of CDT profiles was confirmed by salinity measurements of bottle water samples that were obtained for salinity sensor calibration, and the temperatures measured on both the current meters and the thermographs. For instance, at Mooring 1, the thermograph at 30 m recorded a temperature increase from 4°C to 12°C on August 19. At this location and at Mooring 2, the temperature data on the current meter records (50 m) showed an increase from 2°C to 4°C on August 20 and 21. The thermograph at 25 m on Mooring 2 showed a temperature increase from 8°C to 12°C between August 14 and 17. At Mooring 3, the thermograph record at 15 m showed an increase from 8°C to 12°C on August 16, while the temperature sensor on the current meter at the same mooring measured an increase from 2°C to 5°C on August 19 and 20. At Mooring 4, a thermograph record at 25 m showed a temperature increase from 6°C to 11° between August 18 and 20. A thermograph at 30 m offshore Portugal Cove recorded a temperature increase from 3°C to 11°C between August 15 and 19. Offshore Brigus, a thermograph at 15 m recorded an increase from 8°C to 12°C on August 15 and the thermograph at 30 m recorded an increase from 3°C to 11°C on August 17. The reliability of the timing mechanisms used in the Ryan thermographs is such that it is not possible to state exactly when the major changes in temperature and salinity occurred. Nevertheless, all the measurements show that the event took place between August 14 and 21.

The primary oceanographic problem to explain is the cause of the major change in water properties that occurred over a period of a few days. The current meter data from 50 m depth do not show any obvious anomalies in current speed or direction over the period (Figure 19). The current meter record at the 3-m level Mooring 4 near the head of Conception Bay indicated that a change of current direction from predominately toward the southeast to generally toward the northeast occurred between August 15 and 22. This change alone provides no indication of the cause of the event.

Local meteorological variations in wind velocity, rainfall amounts, and hours of bright sunshine during the period were investigated. Precipitation amounts and insolation received could not have contributed significantly to the major changes in water properties that were observed. Light to moderate winds predominately out of the southwest quadrant had prevailed between August 4 and 13. A moderate northwesterly flow developed on August 14, increased to strong during the morning of August 15, and then diminished to light to moderate in the evening. Northwesterly winds increased to moderate to strong once more in the morning of August 16 and then decreased to light to variable in the afternoon. This period was the only occasion during the summer months when the winds were from the northwest for more than a day.

Wind-driven currents set up during this period may have contributed to the advection of warmer, less saline water into the bay; however, such properties are not characteristic of the water mass normally found in coastal waters outside the bay in August. An annual pulse of low salinity water is seen in the mean statistics for Station 27, located offshore Cape Spear (Huyer and Verney 1975). Data collected from this station in 1985 were examined for change in water properties. It showed that the pulse of low salinity water occurred earlier than usual and, moreover, occurred between August 12 and 21, the time of the change in water mass in Conception Bay. Temperature and salinity data from Station 27 are presented in Table 27. These data demonstrate that the dramatic increase in temperature and decrease in salinity were due to the advection of water into Conception Bay from adjacent coastal waters. It is worthwhile to note that, because the warmer, low salinity pulse occurred earlier than usual, it is an unusual event and may have contributed to the abrupt end of the trap fishery in 1985.

Significant minor events: In the Portugal Cove area (Zone 3), six occasions have been identified as minor events. These have been identified by occasions when the temperature signal showed fluctuations. The events in the Portugal Cove area occurred on June 20 to 22, June 23 to 26, July 1 to 2, July 20 to 22, July 29 to 31.and August 3 to 5. These events all show characteristics of an increase in temperature at the beginning of the event followed by a decrease in temperature at the end of the event.

In Zone 2 off Lance Cove Head and Harbour Main, five events were identified. June 18 and August 10 are characterized by temperature increases. The other three events are characterized by a temperature increase at the beginning of the event and a decrease at the end. The three events were on July 12 to 15, July 19 to 24, and August 4 to 6.

In Zone 1 off Brigus and Bay de Grave six events were identified. June 18, July 28 to 30, and August 11 to 13 are characterized by increases in temperature. The other three events are characterized by an increase in temperature at the beginning of the event and a decrease in temperature at the end of the event. These events occurred on June 30 to July 3, July 19 to 22, and August 3 to 6.

The wind and current data were schematically searched for changes which might explain the reasons for the increases and decreases in temperature. There was nothing significant in the wind or current data which might explain the temperature variations, except for slight anomalies in current direction at the beginning of the season. For instance, the event on June 18 showed temperature increases in Zones 2 and 1 but not in Zone 3. The current meter data showed that at 50 m at both mooring locations, the current flow was opposite to the predominant direction. The current at Mooring 1 was flowing south instead of northeast, and the current at Mooring 2 was flowing north instead of south. This motion appears to indicate that the flow into the bay had either moved farther to the southeast side, or the amount of cold water flowing into the bay had been reduced.

The satellite imagery showed that the surface isotherms were aligned diagonally (north/south) across the bay on June 15 and then moved to a more east/west direction by June 25. The colder water mass which extended along the northwest side of the bay on June 15 had disappeared at the head of the bay on June 25 to be replaced by warmer water. This indicates that the increase in temperature on June 18 was due to a redistribution of the water mass boundary within the bay. The redistribution appears to reflect more on the water movements outside the bay than on local wind conditions from St. John's and Holyrood. This dynamic redistribution of the water mass boundary may explain the temperature increases at Portugal Cove on June 20 and 23 and subsequent decreases on June 22 and 26.

Events occurred in Zones 1 and 3 on June 30 to July 3. The current meter data showed anomalies in current directions on Moorings 1 and 2 on June 30 and July 1, and then a return to the usual flow directions on July 2 and 3. The satellite imagery of July 5 shows that the isotherms are aligned slightly diagonal such that Zones 1 and 3 are in the boundary area, whereas Zone 2, at the head of the bay, is in a warmer region.

There was nothing unusual about the current flow in July and August to explain any of the temperature variations producing events after July 1. More information would be available if there had been current measurements closer to the surface than 50 m. The small amount of information available indicates that the controlling influence comes from outside Conception Bay.

Tides: Data on tides, derived from standard tide tables, were coded for computer use and a correlation between daily catch at various locations versus amplitude of the previous tide was calculated. These results are summarized in Table 28.

A significant correlation was exhibited at Location 3, but at no other site. This suggests that, although tides may exert an effect on catch rates on a daily basis, such an effect is likely local and would be generally insignificant.

METEOROLOGY AND CLIMATOLOGY

The regional variability of the climate of the island of Newfoundland arises as a consequence of location in relation to large-scale atmospheric circulation patterns, position on the eastern side of the North American continent, influence of the Labrador Current waters surrounding the island, and topographic effects.

General Description of Conception Bay Area Atmospheric Climate During the Summer Season

The Newfoundland region is subjected to the migratory low pressure frontal systems and high pressure areas that move eastward, in general, under the control of upper air disturbances travelling in the band of prevailing westerly winds aloft. Relatively large and frequent fluctuation of meteorological parameters associated with these synoptic weather developments are indicative of both the continental and maritime trajectories of air masses that affect the Newfoundland region. The waters of the Labrador Current system surrounding Newfoundland provide a strong modifying influence of the continental air as well as those from remote ocean areas.

The synoptic climatology of the region is controlled to a large extent by hemispheric-scale dynamic and thermodynamic factors. Figure 25 shows the mean upper air circulation pattern and long wave environment on the 50 KPa (500 mb) pressure surface at mid-level of the atmosphere during January and July, respectively. The isopleths are height contours of the pressure surface with the mean winds blowing eastward parallel to the contours. The mean wind speed, which is proportional to the height gradient, is greater during the cold season when the north-south temperature contrast is strongest.

January chart shows a trough extending from a mean minimum height over Baffin Island southward through the Great Lakes region and the Mississippi Valley. The mean upper air flow across the east coast waters is, in general, from the southwest. The band of strongest winds crossing the east coast extends from approximtely northern Newfoundland southward to approximately Chespeake Bay on the U.S. Eastern Seaboard. In July, a mean trough at 50 kPa extends from a low center in northern Baffin Bay southward through the Province of Quebec and across New England. The flow is somewhat more westerly at 50 kPa than during the colder season. At this time of year, the band of strongest winds aloft over the east coast extends from Labrador waters to northern New England. These regions of large height gradient reflect regions of strong temperature gradients that signify marked frontal zones separating colder polar or Arctic air from air masses of tropical or sub-tropical origin (Figure 25).

During a normal July, eight or nine relatively weak low pressure disturbances will pass through the Labrador-northern Newfoundland region to move into the Labrador Sea. Approximately 60 to 70% of these systems will continue roughly east-northeastward to pass south of Greenland while about 35% will curve northward to move into the Davis Strait region (Bursey et al., 1977). As these systems pass by, cold frontal troughs of varying intensity, that trail southward from the low pressure centers will swing eastward across

Newfoundland. Typically, the approach of a cold front during the summer period will result in the gradual development of a period of strong south to southwesterly winds of varying duration. Showery precipitation and veering winds into the west to northwest normally accompany the frontal passage. A weaker pressure gradient associated with the high pressure ridge following the front will typically bring a period of light winds as the ridge slips by, winds will normally back into the southwest quadrant behind the ridge. At times during the summer, particularly in June and August and in years when anomalous upper air circulation patterns develop, low pressure systems will track nearer to or south of the Avalon Peninsula.

The passage of these systems through the district gives rise to cyclonic wind variations typical of low pressure developments. On occasion, gale force winds will occur in association with the passage of frontal trough or low pressure system, but these events are relatively infrequent and of short duration in the summer season.

A marked diurnal variation of the wind speed is frequently observed with a regional southwesterly flow over Conception Bay during the summer months. Heating of the land surface during the day enhances turbulent mixing promoting the downward transfer of eddies containing higher momentum. This typically results in higher mean wind speeds and gusty conditions during the daytime, particularly from late morning until early evening. The northeast-southwest orientation of the topography in the southwestern portion of the bays acts to enhance the effect by funnelling the air. Diurnal radiative cooling in the evening stabilizes the boundary layer, significantly reducing turbulent mixing. Since energy is required to maintain vertical velocity fluctuations in a stable boundary layer, this factor combined with frictional losses at the surface act to lower wind speeds. While the wind speeds during the daytime under these conditions are often sufficient to develop significant surface currents, the relatively short duration of these events is unlikely to produce significant wind-driven effects.

At times of weak pressure gradient over eastern Newfoundland, daytime heating of the land surfaces, particularly on warm days, in combination with the cool water temperatures result in the development of a sea-land breeze circulation system. A sea breeze will frequently develop toward mid-day with winds, having an onshore component, peaking during the afternoon hours and dying off as the land cools in the late afternoon and evening. Wind speeds are generally light, however, and the primary effect in the Conception Bay region is to advect cooler air and, at times, fog over the adjacent land surface, significantly lowering afternoon temperatures along the shore.

Table 21 gives summary wind statistics for St. John's Airport, showing the prevalence of southwest winds over eastern Newfoundland during the summer season. The statistics for 1985 are given as well, allowing a comparison.

The effects of the Labrador Current waters surrounding Newfoundland provide a strong moderating influence on air masses passing across the region particularly near the coast. In the summer period, the waters are relatively cold and act to damp the annual oscillation of temperatures as well as delay the time of year when the daily mean temperatures attain their maximum in comparison to continental locations. The mean daily temperature exceeds 10°C for only 4 months of the year in the Conception Bay area. The smoothed monthly mean daily temperature variations for St. John's Airport are shown in Figure 6. the figure also shows the average daily mean temperature for each day as well as the standard deviation at 10-day intervals throughout the summer. The time series of daily mean temperatures at St. John's Airport during the summer of 1985 when compared with the average mean daily temperature indicates periods when air temperatures were above or below normal.

Surface Wind and Catch Correlations

It has been suggested by Lear et al. (1986) that wind may influence the availability of cod to fixed gears. Several mechanisms have been proposed, mostly related to upwelling as the warm surface layer of water is moved by the wind. For this reason, it was decided to attempt to correlate surface wind against daily trap catches.

The surface wind was defined to be the vector average of the winds over the preceding 12 hours as measured at Torbay Airport. Since this was a vector quantity (u,v), u and v were individually correlated with catch.

Of the five locations tested, only Location 4 showed a significant effect. At this location, a correlation coefficient of -.30 was achieved for v, the N/S component of the wind. Specifically, this indicates that catch rates were enhanced when the winds were out of the north. Location 4 is at Portugal Cove, as are Locations 2 and 3. For comparison, the correlation coefficients between v and catch were -.18 at Location 3 and .13 at Location 2. Thus a wind effect, to the degree that it exists, is inconsistent.

DISCUSSION

AVAILABILITY VERSUS PRESENCE

Availability of a prey species to most gear types or fishing methods is dependent upon two factors: the prey species must be present in the vicinity of the gear being used; and the prey species must be exhibiting a behaviour which enables it to be caught. Although the presence of fish captured in a gear is a direct indication of the presence of fish in the area, an absence of fish in a gear simply is an indication of a lack of availability of fish to that gear. In that case, fish may be either absent from the area or fish may be present but not displaying behaviour conducive to their being caught.

From the point of view of fishermen, the relationship, or lack thereof, between catch and presence is of more than academic interest. If there are plenty of fish present which could be caught, but that the cod trap is an ineffective harvesting method, then this information could assist fishermen in adopting improved harvesting methods.

The Newfoundland cod trap is a passive fishing gear (Mercer and Brothers 1984) whose effectiveness depends upon the longshore movement of cod. Recent research suggests that the availability and catchability of cod inshore in Newfoundland is related to factors influencing the presence of cod in depth zones in which gears are set (Lear et al. 1983, 1986). The design of this study did not permit direct observations of the presence of cod, and results cannot be taken to imply that reductions in catch rate are a result of reductions in the numbers of fish present. Rather, the only data on presence of fish was in the form of catch statistics, so the data analysis and interpretation have been based on and refer to influences upon the availability of cod to cod traps, rather than presence of cod, in Conception Bay. Changes in catch rate are a reflection of fluctuating availability caused by changed presence or altered behaviour resulting in a different rate of catchability.

Behavioural changes could be a result of some combination of factors such as: absolute temperature, temperature gradients, turbidity, salinity, light intensity, etc. These factors may also influence the absolute presence of fish in an area.

Notwithstanding these problems, attempts have been made to extract information on presence from the availability data. Additional comments on absolute measures of presence will be made in the subsection on future work.

MAJOR PHENOMENA

Following analysis of all data collected during the course of the study, a number of events or phenomena became evident as having substantial importance to the fishery. These were:

1) The apparent influx of significantly larger fish into the bay in July (see section dealing with comparisons of length frequency measurements).

2) The rise of catch per unit effort which occurred during June in all zones for which there was effort recorded (see section describing 1985 season and Figure 10).

3) The periods of high cross-correlation coefficients between zones on the east and west sides of the bay (Figure 11).

4) The drop in fishing effort in Zone 1 in early July.

5) The drop of catch per unit effort (CPUE) in all zones in August (see section describing 1985 season and Figure 10).

6) The almost total dependence upon capelin by cod as a source of food during the cod's presence in the inshore region (see section dealing with comparisons of stomach contents).

7) The large pulse of warm, fresh water into the bay coinciding with the collapse of the fishery in August (see section dealing with comparisons of tagging).

In addition to these notable items, several other phenomena were observed for which insufficient data exist for meaningful analysis. These will be discussed in a cursory way and some speculations will be made as to their causes. These phenomena are:

1) The high daily variability of CPUE in several of the zones fished (see summary of results dealing with catch and Figure 8).

2) The high differential catch rates between Zone 3 and Zones 1 and 2 (see summary of results dealing with catch).

3) The high contrast between Zones 1 and 3 regarding stomach volumes and percent of fish with empty stomachs (see section dealing with comparisons of stomach contents).

4) The contrast between Zones 1 and 3 regarding the proximity of tag release and recapture sites (see section dealing with comparisons of tagging).

MIGRATING POPULATION OF LARGER FISH

Data on length frequencies of fish throughout Conception Bay from May to August 1985 were presented earlier. Analyses of these data suggested the existence of two populations of cod: one of small fish, some or all of which are likely resident or overwintering in the bay, and one of larger transient fish. Support for the idea of an itinerant population of intermediate sized and larger fish comes from tagging studies conducted by the Department of Fisheries and Oceans both in inshore and offshore areas (pers. comm., W. H. Lear, Department of Fisheries and Oceans, St. John's). We will take it as an assumption that the population of larger fish migrates into the bay in June and is available to cod traps during certain periods dictated by other factors.

What are the ramifications of this phenomenon? To examine the effects of this mean length frequency trend, we plotted weekly mean length of fish against catch per effort (Figure 26). As expected, catch per effort is strongly influenced by mean length. The correlation coefficient for the two varibles is .84. Moreover, this plot shows that catch per effort peaks simultaneously with mean fish length, that catch per effort is high only for a brief period, and that as mean length decreases, catch per effort declines dramatically. Thus, for the short period when mean fish length peaks, biomass of fish available to the gear is also at its maximum. When the mean size of fish declines to pre-summer levels, the cod trap fishery ceases altogether. Historical data indicate that cod are in the bay but in water deeper than depths in which cod traps are set (pers. comm., W. H. Lear, Department of Fisheries and Oceans, St. John's). In summary, the rise and fall of catch per effort in the cod trap fishery which occurred at the beginning and end of the season seem to be directly linked to the availability of the population of intermediate and larger sized fish which migrated into and out of the areas fished by traps in Newfoundland in 1985.

The relationship between mean fish length and catch per effort indicates that the overall success of the inshore cod trap fishery is strongly related to a population of intermediate sized and larger cod which is available for only a short period in the summer. This relationship is particularly important because larger fish have a higher value per kilogram and so are worth more than equivalent weights of fish caught at other times.

TO FISH OR NOT TO FISH - WHAT WAS THE QUESTION?

The success of fishermen in catching fish, for a given amount of effort, appears to be related to an increase in availability of intermediate sized and larger fish in the fishing zone. If the aim of the fishermen in Conception Bay is to maximize total value of cod landings for effort expended, we would expect to see a direct relationship between the presence of larger, high-value cod and effort.

If we examine the way in which effort varies with mean fish size for some zones in the bay, we see that just the opposite type of relationship occurred. When the presence of larger, high-value fish, illustrated by mean fish length, is at its peak, effort actually reaches its lowest level (outside the start and finish of the season) in Zone 1. On a zone by zone basis, we see that Zone 1 shows this inverse relationship, Zone 2 shows no relationship, and Zone 3 shows a strong positive relationship (Figure 27).

Apparently some other factor is influencing fishing behaviour in some zones, diverting effort from the cod fishery during the period of maximum availability of large fish. In 1985, the capelin fishery, which is a high-intensity, very lucrative fishery, occurred during the one and a half weeks on either side of the lowest point in cod trap effort.

In Figure 28, we have plotted cod trap fishing effort and capelin landings (source of data: Department of Fisheries and Oceans) over the summer. Weekly capelin landings peak exactly when effort in the cod fishery reaches its nadir. If maximum capelin catches are partly due to a maximum fishing effort directed at this fishery, and much of this effort is redirected cod fishermen, then the result is a major economic interaction between the two fisheries.

The phenomenon of effort diversion was particulary marked in Zone 1, where seasonal cod catch per effort was generally lower than elsewhere. Thus, fishermen from Zone 1 might be more likely to abandon a poor fishery to pursue capelin when capelin were available. Unfortunately, this corresponds to that period when their return for effort expended on the cod fishery would have been at its maximum.

In order to evaluate the landings lost during this diversion of effort, an interpolation of landings was done. This was accomplished by projecting effort to follow a linear trend from Week 3 to Week 8. This period covered the capelin fishery. We then multiplied this interpolated effort value by the actual catch per effort observed for those weeks. This assumed that catch per unit effort was independent of effort.

Figure 29 shows the projected landings that might have occurred if effort had not been diverted to the capelin fishery from cod. Total landings and Zone 1 landings would both have been approximately 40% greater. From this we can see that not just cod/capelin interactions but indeed cod fishery/capelin fishery interactions may be an important influence on the progress and total success of the Conception Bay cod fishery.

BIG FISH - MUCH CAPELIN - THEN WHAT?

One of the most interesting biological relationships observed in this study was the relationship between cod availability, the capelin fishery, and predation on capelin by cod. It has been documented by this and other studies (section comparing stomach content analyses; and pers. comm., J. Piatt, Memorial University, St. John's) that capelin is of primary importance as a food species to cod during their residence in inshore Newfoundland waters.

The strategy employed by cod in foraging for capelin is not generally well understood. Just how do cod go about catching and consuming capelin? A simple model might suggest that the mass of inshore-migrating cod follows schools of capelin moving inshore on their spawning migration, preying on individuals at appropriate times. Feeding would be expected to continue throughout the period in which capelin were aggregated inshore.

If this model were valid, we would expect that the presence of cod, the presence of capelin inshore, and the presence of capelin in the stomachs of cod should be highly correlated. In order to test this model with the data we have available, it is necessary to make two main assumptions. It is necessary to assume that catch per effort of cod is an indicator of cod presence, and that landings of capelin are an indicator of capelin abundance. Capelin landings were provided by Department of Fisheries and Oceans, Statistics Branch, from sales slips.

Figure 30 illustrates the weekly patterns of mean stomach volume and cod catch per trap (cod presence). There is a coincident rise in stomach volumes of trap-caught cod and the fall in catch per effort. This appears to indicate an association between a falling availability of cod to the trap fishery and success at feeding. Because the stomach analysis data establish that the cod were feeding almost entirely on capelin, this suggests looking further at possible cod/capelin interactions.

Figure 31 presents graphs of the percent of non-empty stomachs on a weekly basis and weekly capelin landings for Zones 1 and 3, respectively. Both of the graphs show a lag of about a week between the rise in percent of trap-caught fish with non-empty stomachs and the rise in capelin presence as shown by landing data. As well, the percent of trapped cod with non-empty stomachs remains high in both zones well after the capelin fishery has closed.

Detailed information on the foraging behaviour of cod for capelin in Newfoundland waters was lacking. So neither were there detailed biological information on capelin, peak spawning dates, percent spawning per date or catch per effort in 1985. However, from the data collected in this study, it would seem that a complex relationship between cod and capelin exists, and has an important impact on the cod trap fishery. In the next section of this discussion, we present a scenario which could provide explanations for some of the phenomena discussed above.

A CONCEPTUAL MODEL OF COD/CAPELIN/ENVIRONMENT INTERACTIONS IN CONCEPTION BAY ON A SEASONAL BASIS

Some clues concerning various aspects of cod/capelin/environment interactions were uncovered during this project. In some cases, the phenomena were first suggested by anecdotal information. In other cases, phenomena were observed which were unexpected. There are three important limitations on the data underlying this conceptual model. First, there are no direct data on cod or capelin abundance; so, as previously discussed, catch per effort must be used as a surrogate for abundance. Second, the data were collected in a single season, and conclusions may not be generalizable. Third, in many cases component hypotheses of the model were suggested by *ad hoc* examinations of the data, and if the hypotheses were tested at all, they *were* tested with the same data which suggested the hypotheses to begin with.

Despite these limitations, it was felt that the creation of a speculative dynamic conceptual model of the cod/capelin/environment interaction would be useful. This model relates to the cod fishery within Conception Bay, and its explanatory power is limited to factors within the bay. It assumes that a component of the cod population migrates into the bay from the offshore. It also assumes that capelin migrate into the bay from the offshore. However, factors and mechanisms related to the behaviour of cod and capelin outside the bay are beyond the scope of the model. As such, the model sets no limits on how cod enter the bay or why they may not enter the bay, even though these factors clearly affect the success of the cod trap fishery.

One purpose of the model-building exercise is that it can provide a focus and guide for further research, and we take this purpose as the justification for the exercise. The model presented starts in early June, follows the rise in cod catch, introduces capelin in late June, and follows the cod trap fishery until its collapse in early- to mid-August. Documentation of individual supporting information is provided by inclusion of Section and Figure numbers and by reference to other scientific literature.

Although much of the material included in the model is from previous research or results from the present project, some statements are based more on speculation than on data. These are identified by being enclosed in square brackets [-]. The previously itemized limitations on the model must also be kept in mind.

First Week in June

Some traps are already in the water, but most effort is directed at getting the traps ready and setting moorings on the chosen and assigned berths.

The surface of the bay is still only 4°C and at the bottom of the doors to the traps the temperature remains well below zero.

The only available cod in the bay, [having possibly overwintered from the previous year], are small; average length is about 45 cm. They have very little food in their stomachs and the [largest numbers are found in the warmer water relatively near the surface].

Second Week in June

The majority of trap berths now have traps set in them. The fishery is still slow and only small fish are being caught. The water temperature is still very low, but fishermen in Portugal Cove are beginning to catch a few intermediate sized and larger fish. [These larger fish have likely migrated into the inshore region from offshore regions including the Northern Grand Banks, Funk Island Bank, Belle Isle Bank and Hamilton Bank.] Like the small overwintering or resident fish, these larger fish too have empty stomachs.

Third Week in June

Although no apparent change has occurred in the water temperature, a migration of larger offshore cod is occurring. First seen in Portugal Cove, the larger fish are now found all the way down in the bay to Port de Grave, Chapel Cove and Harbour Main. With the arrival of these larger fish, each haul yields more fish. This is most obviously seen in Portugal Cove. Catches on the east side of the bay have been and will remain better than anywhere else in the bay. Unlike other gear types, traps depend upon the longshore movement of fish in order to function. [It is possible that the larger fish entering the bay travel along established migratory routes on the east side of the bay and are particularly vulnerable to traps set along these routes.]

Capelin are beginning to be found in cod stomachs but at very low levels. The capelin which have entered the bay are rapidly reaching their spawning time. Templeman (1948) observed the earliest spawning at Holyrood to occur on June 15 and the latest on July 10.

Fourth Week in June

The water temperature is slowly rising. Large numbers of maturing capelin are the target of an intense fishery which has drawn fishermen away from the previously slow cod trap fishery. Those trap fishermen which remain fishing cod experience substantially improved catches. The fish are relatively plentiful and large (53.1 cm). Despite the large volumes of capelin in the bay, the cod being caught do not appear to be eating them, and their stomachs are still nearly empty. This suggests that the feeding behaviour of the cod on capelin may make them less accessible to traps, or that the traps selectively take new migrants which have not yet begun to feed on capelin.

First Week in July

The capelin fishery peaks during this week. Capelin are plentiful throughout the bay. Surface water temperature reaches 8-10°C and the temperature at the bottom of the cod traps is 0°C; [which may be close to the larger cod's preferred temperature]. The trend toward greater differences between high and low tides which started the previous week continues and peaks with tidal amplitudes of 2.0 m (Figure 15). [These amplitudes are presumably closer to the optimum for beach spawning by capelin] although the surface water temperature is not too high (Templeman 1948). Coincident with the high tides, the greatest catches of capelin are taken during this week. The intermediate sized and larger cod [which have been migrating into the bay for the past several weeks] are caught in maximum numbers. The mean size of fish taken in the fishery finally increases to the highest value for the season and cod catch per effort peaks (Figure 24).

Although catches show that capelin are abundant there, the larger cod are not being caught in the warmer shallow water at the extreme head of the bay. The cod being caught in that area are no different in size from those that were present at the beginning of the season. The principal contrast between Zone 2 and the other zones at this time appears to be the presence of an abrupt temperature gradient at those stations closest to Foxtrap. [This suggests that although capelin are abundant, the migratory cod may be blocked from moving in close to shore. A possible explanation for this is that the warm surface temperatures are too high for the migratory cod. Alternatively, the migratory cod may be feeding on capelin spawning in the bottom of the bay.]

In the remainder of the bay, intermediate and large cod are being harvested in traps. Despite the very large quantities of capelin available, as evidenced by the fishery landings, capelin are still not being found in the stomachs of trap-caught fish.

Second Week in July

The water temperature at the surface reaches 12°C. The effort expended on the capelin fishery decreases rapidly as the market is only interested in pre-spawn females. As the spawning proceeds, increasing numbers of dead and dying capelin are found in inshore waters. [If cod feed on the post-spawning dead and dying capelin, there would be an abundant food source for the cod. Active pursuit of this food source on the bottom of the bay would tend to make the cod less available to the trap fishery.] Capelin is now being exploited as a food source (Figure 29). Week 6 shows an increase in stomach volume of cod. This feeding activity peaks a week later, then decreases to [mid-June levels] within a week. That the trap fishery falls off coincident with the rise in capelin in cod stomachs is shown by the decrease in catch per effort. The temperature of trap bottoms remains at [an acceptable] 1°C.

Third Week in July

Cod are beginning to retreat into the cooler waters of the bay. The fewer cod being caught are of smaller size in Zone 1 and are full of capelin. Despite lower catch rates, fishermen are returning to the cod trap fishery.

Deep water in the bay remains cold, but the surface water above the distinct thermocline climbs to 12-14°C.

Fourth Week in July

Continuing low catch rates do not deter cod fishermen. A greater effort is expended on the low numbers of increasingly smaller cod than at any other time during the season. [The migratory cod have moved into deep, cool water of the bay and are increasingly unavailable to traps.]

First and Second Weeks in August

Surface temperature on the bay remains warm, around 12-14°C. Water at the bottom of the traps warms slowly to 2-4°C. Many fishermen are reducing their effort and hauling traps less frequently. Catch per effort continues low. The average size of the few fish being caught has decreased to that found near the beginning of the season. The larger fish which made up the bulk of the fishery at its peak have moved out into the deeper water of the bay where, based on anecdotal line trawl data, some will remain until October. Cod stomachs are again nearly empty.

Third Week in August

A dramatic change occurs in the oceanography of the bay. A large mass of 12-14°C water has moved into the inshore region. [Reaching well below the depths at which traps are found, the change in temperature corresponds to a movement of larger cod out of reach of the ever-decreasing fishing effort.] The average size of those fish caught has returned to pre-season levels. [Those cod still available to the trap fishery are likely young fish and may remain inshore all winter.]

Fourth Week in August

A few larger fish [possibly following the eastern shore of the bay on their outward migration] are caught near Portugal Cove but most traps have been removed from the water. Both the resident and migrant fish have little in their stomachs. The trap fishery ceases for the year. Some of the cod which have descended into pockets of suitable water are available to the longline fishery from now until October.

THE RELATIONSHIP OF THE MAJOR PHENOMENA TO THE CONCEPTUAL MODEL

Certain conjectures arise from the information presented in the previous section on major phenomena. These form a unifying thread through the conceptual model. In this section, we will discuss the origins of, the relationships between, and the significance of these phenomena to the present experiment and the fishery. It is recognized that these data reflect observations made over a single season in 1985. Perhaps their greatest value lies in suggesting areas for future research.

INFLUX OF LARGER FISH INTO THE BAY

Length frequency measurement comparisons (see earlier section) presented evidence of a major influx of large fish into the Conception Bay fishery in July. The previous section on major phenomena discussed the possibility that an influx of larger cod was the driving force behind the dramatic increase in catch per effort during the second half of June.

The data collected as part of this experiment have little direct bearing on this migration. The close relationship between the availability of capelin and availability of cod in Conception Bay suggests one of the following:

1) These two species share the same environmental cues which stimulate migration (possibly some temperature/depth function);

2) Capelin as a prey species play a large, possibly overriding, role in the definition of a cod's preferred environment.

According to the model, the inshore migration of fish occurs over a 4-week period beginning in the second week of June. This is consistent with the data which show that within 3 weeks of the initial increase in mean length, the value of mean length peaked and began to decline. Although mean length did not decline to levels as low as those found early in the season, the decline was quite abrupt. This suggests that the fish arrived over a 3- to 4-week period, and stayed long enough to gorge themselves on the high nutritional value capelin. They were then either caught in the fishery, emigrated when the capelin became less available or less nutritionally valuable, or adopted a behaviour which rendered them unavailable to the trap fishery. Figures 24, 28, and 30 illustrate the relationships between weekly mean catch per effort, mean fish length, and stomach volume (feeding intensity).

RISE IN CATCH PER UNIT EFFORT IN JUNE

Following earlier discussion on this topic (note particularly Figure 24), it is a simple matter to see the relationship between the apparent influx of larger fish (as indicated by mean fish length) and catch per unit effort (indicated by catch per trap haul). Furthermore, when the overall catch per effort in the bay decreases, it appears to result directly from a decrease in mean fish length. Thus, a complete explanation for the rise in CPUE is the inbound migration of larger fish.

HIGH CROSS-CORRELATIONS OF CATCH PER UNIT EFFORT

Catch per effort comparisons (see earlier section) presented data and analysis which identified several periods throughout the 1985 fishing season during which a relatively high positive cross-correlation existed between catch per effort values for different parts of the bay. One original premise of the project was that relatively small-scale environmental phenomena could affect one zone in the bay differently from another zone, resulting in a contrasting response of availability of cod in the two zones. By comparing the dissimilarity of the environmental parameters, some general inferences could be made regarding the influence of these parameters on the overall availability of cod in Conception Bay.

Historically, catch rates of fish on the east side of the bay have been significantly higher than on the west side. This phenomenon was felt to support the previous inference, because the prevailing wind regime would generate dissimilar thermal and salinity regimes on the opposite sides of the bay. We might expect a lifting of the thermocline or possible upwelling of deep cold water on the west side, and a pile-up of warm water to greater depths on the east. If this were true, catch per effort on opposite sides of the bay would exhibit a strong negative cross-correlation. This was not found to be the case.

Between Zones 1 and 3, those zones for which the highest negative cross-correlation of catch per unit effort would be expected, the highest positive cross-correlation was exhibited. In addition, when specific period sub-sets were examined independently, certain of these periods showed very high positive cross-correlations. Cross-correlation coefficients of CPUE's between Zones 1 and 3 exceeded .4 from July 3 to 15 and again from August 5 to the end of the season on August 18.

The high cross-correlation between these two zones at the end of the season is easily explained. Throughout the entire bay, CPUE was dropping dramatically day-by-day. As we have already discussed, this was likely due to the decreasing availability of the larger fish and these fish formed the bulk of the Conception Bay fishery.

The correlation between the CPUE for Zones 1 and 3 in early July can also be explained. This effect may be due to the influx of intermediate and larger sized fish from the offshore. On the other hand, these larger fish do not show up in Zone 2 (possibly being blocked out by temperature effects). This accounts for the lack of enhanced correlations between Zone 2 and either of the other zones at mid-season.

The presence of this pulse of larger fish first into and later out of the area fished by cod traps produces a major signal in the data. The signal dominates the short-term, local effects of wind and weather on catches on the east and west sides of the bay. Therefore, the absence of negative cross-correlations between catch per effort in Zones 1 and 3 cannot be interpreted as indicating the weather influences do not occur. Rather, more analyses of these or other data are required, with the season-long signal filtered out, before the original hypothesis can be tested.

MID-SEASON DROP IN COD TRAP EFFORT

Landings in any particular year, of a specific fishery, are dependent upon two factors: catch per effort and effort. Any change in either of these factors is reflected in a change in landings.

Catch per effort is influenced by many factors, only some of which were targetted in this study. In addition to the obvious environmental factors, we expect catch per effort to be influenced by the presence and abundance of prey species, foraging strategy, and the efficacy and selectivity of the fishing equipment and its deployment. Of these, only fishing technology can be manipulated, and then, only in some ways.

In contrast, the effort expended in a fishery is primarily influenced by human factors and only indirectly by the environment and catch per effort.

The Newfoundland inshore fishery is characterized by a series of discrete, limited-entry fisheries, prosecuted during distinct seasons using specific gear types. Ideally, fishermen, as with all other "predators", should function in a manner which should maximize benefit to the "predator" while reducing "costs". In animals, "benefits" are energy and nutrients necessary to support growth and reproduction, and the cost is mostly energy expended in foraging, capturing and consuming prey.

The "benefits" to fishermen are payments for landings; the "costs" are cash operating costs and the value of labour measured as "lost opportunity".

For a fisherman, it is rational to pursue a fishery which yields the highest value for the lowest effort and expense. Where two fisheries overlap in time, we expect a shift in effort from the lesser to the more lucrative.

This shift in effort occurred in 1985 in some locations of Conception Bay between the cod trap fishery and the capelin fishery. In those areas where catch per effort of cod was low and fishermen possessed the equipment and expertise to fish capelin, a shift of effort from cod traps to the various capelin gears occurred. The cod trap fishery was resumed once the capelin fishery became less profitable.

As we have seen previously, the catch per effort of cod by traps in Conception Bay is not constant, but in fact has a short peak, which coincides more or less with the availability of capelin. In the absence of a capelin fishery, the cod trap fishery could have continued uninterrupted and taken the abundantly available cod. Instead, it is estimated the diversion of effort from cod to capelin reduced total cod landings by 40% in the bay and reduced the value of cod landings by something greater than 40%.

DEPENDENCE OF COD UPON CAPELIN

Stomach content analyses (see earlier section) suggest that, during the time that cod are present inshore in Conception Bay, the only significant component of the cod's diet is capelin. A Principal Component Analysis of factors suspected to influence the inshore catch of cod conducted by Lear et al. (1986) suggested that 35% of the variation in proportional catch in that region of the Newfoundland coast encompassing Conception Bay in any particular year could be accounted for by a high absolute and especially a high relative abundance of 3-year-old (mature) capelin (relative to 2-year-old capelin). This model assumes that a large proportion of 3-year-old capelin mature sexually that year.

In order to examine the relationship between the presence of the large cod in Conception Bay and their feeding upon capelin, total weekly mean length and catch per trap of cod were correlated with mean weekly stomach volume. If cod migrate into Conception Bay to feed on capelin, we would expect high correlations between these data sets. Correlation coefficients for these plots were .5 and .13, respectively (Figures 30 and 32).

The most striking features of these plots is that all three data sets have distinct, short duration peaks. Even more interesting is that stomach volume peaks 2 weeks after mean cod length or cod catch per effort peaks.

No data on capelin availability were collected by this project. The only data available on capelin abundance in Conception Bay in 1985 are those collected by the Department of Fisheries and Oceans on catch per week as reported on sales slips. There are no data available on date of spawning, percent spawning per date, or catch per effort, except those collected by Statistics Branch, Department of Fisheries and Oceans, during the short, directed capelin fishery. These data are plotted in Figure 29. Although no correlations were calculated, it appears that a relatively strong relationship exists between cod catch per trap, mean cod length, and gross catch of capelin.

That capelin catch and cod catch per effort appear to correspond temporally suggests that there is some relationship between the availability of these species. The 2-week lag between peak catches and the peak of capelin in cod stomachs suggests that there may be some unknown factor delaying the feeding of cod on capelin. Similar phenomena have been observed in relation to capelin presence and feeding behaviour of seabirds and minke whales (John Piatt, unpublished). Cod catches in gillnets correlated directly with capelin presence in the same study.

Insufficient data on basic biological interactions between cod and capelin, and on foraging behaviour of cod prevented a more detailed evaluation of this phenomenon.

DROP IN CATCH PER UNIT EFFORT IN AUGUST AND FRESHWATER PULSE

As observed (see section describing 1985 season), CPUE drops in all zones during the period from the first to the third week of August. During this period, the hydrographic regime of the bay from surface to 30 m changed. Temperatures at trap bottom rose to 2 to 4° and then to 12 to 14°. During the third week in August, a freshwater pulse which lowered surface salinities occurred. The source of this pulse is likely meltwater from the Canadian Arctic (pers. comm., S. Akenhead, Department of Fisheries and Oceans). It is plausible that the change in oceanographic regime made the surface layer of the bay an unsuitable environment for the larger, offshore, migratory cod.

OTHER PHENOMENA

In addition to the above major phenomena, a number of minor phenomena were noted.

Neither the conceptual model nor the extensive data analysis that was conducted could explain the high daily variability in catch rates for all zones. It appears that an explanation for this type of variability would require direct measures of fish presence.

The differential catch rate between Zone 3 and Zone 2 is explained by the lack of large fish in Zone 2. Possibly, an oceanographic block prevents the migratory fish from reaching the head of the bay. With respect to Zones 1 and 3, the data indicate that the migratory fish reach Zone 3 prior to Zone 1. However, even at their peak, catch rates in Zone 1 do not rival those in Zone 3. The model assumes that traps in Zone 3 may lie on established migration routes. Although this has some explanatory power, it is entirely speculative. The difference is also consistent with the original (Templeman) hypothesis of colder, upwelling water in Zone 2 being less favourable to cod than the warmer water of Zone 1.

The model also provides an explantion, again speculative, for the different nature of stomach volume data for Zones 1 and 3. In Zone 1, all catches contain a high proportion of smaller resident fish. These fish have a different feeding behaviour than the migratory fish. In particular, they are consistently foraging for and feeding on capelin. On the other hand, the migratory fish enter the bay with empty stomachs. Their suggested primary feeding behaviour is to forage for post-spawning capelin. This speculative picture is consistent with the data collected.

Lastly, the tag release/recapture data can easily be explained by the presence of two populations. Fish captured in Zone 1 are postulated to be resident fish; those captured in Zone 3, to be migratory fish. The recapture results are then exactly as one would expect. The Zone 1 fish are recaptured close to point of original tagging. The migratory fish can be recaptured at great distances from the tag site. We note, however, that to the extent that the distribution of instrumented gear (Figures 1 and 3) reflects the distribution of all gear in Conception Bay in 1985, the tagging site in Zone 3 was much farther from any concentration of gear than the tagging sites in Zone 1 were. Hence, even if cod in all zones behaved similarly, greater distances to recovery would be expected in Zone 3 than Zone 1.

CRITIQUE OF EXPERIMENTAL METHODS

Prior to discussing future research, we offer a brief critique of the experimental design employed in the present work. This is included because in the conduct of this experiment some important points concerning ways future experiments could be improved have been established.

In retrospect, the most significant lack of data was an independent measure of the presence of fish. It is recognized that this is a perennial problem in the design of an experiment which attempts to measure fish biomass. Nevertheless, the conclusions generated from these data sets would be considerably strengthened had the data contained information on actual fish numbers present.

A second feature of the design which was lacking was a methodology for investigating the cod/capelin interaction. Again, the conclusions would be considerably strengthened had a series of measurements been taken aimed at investigating this aspect of the cod's environment.

A third critique relates to the oceanographic aspects of the experiment. As can be seen from the data reports, a great deal of the oceanographic data was lost. For example, no usable thermograph data was obtained from the west side of the bay. This obviously limited the comparisons which could be made. Given that the thermograph data were the key to the overall design of this experiment, an alternative design might have been generated which would have prevented this situation. Similar remarks apply to other lost oceanographic data.

Fourth, the experimental design called for the use of winds reported from the Torbay Airport instead of installing measurement devices at the various sites. The analysis did not establish any clear relationship between wind and oceanographic or catch parameters. Because we have no data which would permit us to conclude even that there is a strong relationship between the winds at Torbay and the winds on site, the conclusion of the analysis must be limited to the statement that there is no relationship between the winds as measured at Torbay and the given oceanographic or catch parameter. Since other work has indicated a strong relationship between atmospheric and oceanographic variables (Rose (1987) reported an r^2 of .95), it is a pity that it was not possible to test for similar relationships in Conception Bay.

FUTURE RESEARCH

One purpose in creating the conceptual model was to use it as a guide for future research. In this section, we explore this use of the model. We note that many of the suggestions for further work are not new and have been suggested by DFO scientists long ago. However, this report could not be considered complete without a discussion of these questions.

INSHORE MIGRATION OF COD

Although the model was confined to Conception Bay, a prime feature was its use of an influx of intermediate and larger sized cod as the principal source of biomass contributing to the overall success of the cod trap fishery in Conception Bay. Even though the evidence to support this feature of the model is circumstantial, the feature is consistent with what is known of the life-history of cod. In generalizing the model beyond Conception Bay, the first item of importance would be to quantify the degree of dependence of the inshore fishery on inshore migration of offshore cod biomass.

There are several related questions:

1) What level of inshore migration of cod biomass is required for a successful inshore fishery?

2) What fraction of the total offshore biomass visits the inshore?

3) Is migration to the inshore a feature of every cod's lifestyle? If not, are there distinct populations?

The previous questions are directed at quantifying the degree of inshore migration and its impact on the cod trap fishery. Another focus of research on the question of inshore migration is directed at the nature of the stimulus of inshore migration. If we accept that "migration in fishes has its evolution origins in the 'migration' of required or preferred environment" (Neill et al. 1982), then capelin may be a component of the cod's required environment. Under those assumptions, the presence of capelin can act as an important stimulus for cod migration.

Cod, as with other motile organisms, can be assumed to have a preference for habitats with environmental parameters within a specific range. This range is likely dictated by the cod's physiology. As the values of these attributes deviate beyond the preferred range, an animal's viability is reduced and eventually a lethal limit is reached. For each attribute, there may be a final, single-value preferendum for any particular age, reproductive stage, sex, etc. Even if there are single preferenda for each attribute, it is unlikely that any particular location will possess all the ideal environmental preferenda at one time.

In this simplistic view of the problem, cod maximize survival by choosing the best combination of conditions available. It is logical to assume that the presence of a prey species, at sufficient densities to permit efficient foraging, is a pre-requisite for survival and so would be a strongly influential parameter. Hence, we might expect cod to make whatever environmental physiological "concessions" it is able, to take advantage of aggregated capelin. The simplest view is probably oversimplified, however, and more complicated scenarios are plausible. For the environmental attributes, there may be ranges of values which are equally suitable, rather than single-valued preferenda. For example, there may be a density of capelin where handling time, or even stomach volume, rather than search time, limits feeding rate. Any capelin density above this level could be considered equally preferred. At the same time, other environmental factors must play independent or interactives roles in migration. Thus the key question, what factors or conditions have a positive effect on inshore migration of cod, what factors have a negative effect?

BEHAVIOUR OF MIGRATORY COD WHILE INSHORE

The conceptual model made use of a number of possible cod behaviours to explain various aspects of the data. Although the precise behaviour which results in various aspects of the data remains speculative, it is clear that the behaviour of the cod is a determinant of the success of the trap fishery. For this reason, it is an important area for further research.

The first item in the model of this type was the suggestion that the cod follow definite migration routes into the bay. Based on the differential catch rates from the east to the west sides of the bay, and the time lag in the rise in mean fish lengths, it is suggested that the incoming cod migrate along the east side of the bay. The natural question which arises is:

1) Do the inshore migrating cod follow established routes into and out of the major bays in Newfoundland?

   A positive answer to this question, together with a delineation of the routes would be a substantial benefit to those involved in the harvest of inshore cod. It would then be possible to tailor one's harvesting strategy to take advantage of such routes.

   A second behavioral feature of the model was its use of cod/capelin interactions. These interactions were clearly indicated, even in the limited data available. Specific to the data were the fact that CPUE for cod peaked at the same week as capelin catches, and that CPUE for cod fell off simultaneously with an increase in capelin in the stomachs of cod. The model explained these features by suggesting that the feeding behaviour of cod had a detrimental effect on their availability to cod traps. The likelihood this feature is true is enhanced because most trap-caught cod had empty stomachs. This leads to a series of questions:

2) What is the feeding behaviour of cod on capelin within the bay?

3) Do cod on entering the bay immediately begin feeding on capelin, or is there another factor which stimulates feeding behaviour?

   The model suggested that such a factor might be a preference for post-spawn capelin. Such a strategy might be more efficient from a total available energy point of view, depending on the availability of pre- and post-spawn capelin to predators.

RESIDENT POPULATION OF SMALLER FISH

An important feature of the model was the identification of a resident, or overwintering, population of smaller cod fish. These fish were found primarily in the shallow waters at the head of the bay, although it must be remembered that no data on absolute presence was collected during this experiment. In the global scheme of the model, it is believed that this population of smaller fish is itself transient. It is postulated that these cod eventually migrate out of the bay to join the offshore stock. If this suggestion is accurate, then a number of important questions related to the long run health of the fishery immediately follow. Thus, the aim is to completely delineate the nature of this smaller resident population:

1) Is this a nursery population of the offshore stock?

2) What are the determinants for membership in this population?

3) At what age, size, etc., will these fish venture offshore?

4) After becoming part of the offshore population, do these fish always return to the same bay?

5) What is the prime food source for this population?

6) What is the rate of harvest of this population in the fishery?

7) What effect does present harvest of this population have on the total biomass of the offshore stock over the long term?

8) To what extent do the offshore and inshore populations of cod intermingle during the period when both are in the bay?

HYDRODYNAMIC AND OTHER ENVIRONMENTAL EFFECTS

It has been postulated by several authors that hydrodynamic effects may be an important determinant of daily variability in trap cod catches. Although hydrodynamic effects were employed in the model, their use was not in relation to daily variability. They were used in two other ways. First, it was suggested that the higher temperatures in the surface layer at the head of the bay might serve to block the larger offshore fish from entry into that portion of the bay. Second, it was suggested that the complete change in the bay in August might account for the collapse of the fishery at that time. There are a number of questions.

1) Are there any temperature regimes which are simply unsuitable for mature cod? An upper limit? A lower limit?

2) To what extent do hydrodynamic effects affect migration to the inshore?

3) Is the pulse of freshwater observed during this experiment in August an annual event. If so, does it force the migratory cod from the surface layers of the bays?

4) To what extent is temperature a determinant of the daily variability of cod trap catches?

With respect to the last question, it has been suggested that the hydrodynamic regime exhibits a periodicity with a frequency in the range of 3 to 5 days (Rose, DFO Workshop). A check for periodicity of this type was undertaken on the data associated with instrumented traps. With respect to catch, no data analysis could be made due to the fact that traps were never hauled on Sundays, thus spoiling the time series. With respect to temperature, all the time series showed a high degree of energy at low frequencies which could only be associated with the seasonal component of the series. Although small amounts of energy were present in the power spectra at periodicities of between 3 and 5 days, these peaks were attributed to side-lobes of the seasonal peak. Thus, much longer time series than those collected during this experiment may be required to fully investigate these questions.

GENERAL CONCLUSIONS

This section presents an ordered list of observations and conclusions made during the execution and analysis phases of this project. The order in which they are presented is intended to reflect their potential impact on our general understanding of cod inshore migration and cod/capelin interactions.

1) The overall success of the cod trap fishery depends on the presence and availability of intermediate and larger sized fish which migrate into Conception Bay from offshore.

2) A portion of reductions in cod landings in recent years in Conception Bay can be attributed to diversion of effort from the cod fishery to the more lucrative capelin fishery. In 1985, this reduction was estimated to be approximately 40%. Because the value per kg of the larger cod available during this period is high, the lost dollar value to the fishery exceeds 40%.

3) The weekly variation in availability of cod to cod traps in Conception Bay is influenced by interactions between the cod and capelin populations, as shown by:

   a) capelin comprise the vast majority of the food source for cod inshore;

   b) as feeding success of cod on capelin increases, the availability of cod to traps decreases;

   c) the availability of cod to traps peaks coincidentally with the peak in the capelin fishery.

4) Two populations of cod are found in Conception Bay during the trap season: one possibly resident group consisting of smaller fish; and one migrant group of larger fish whose presence appears to be linked, directly or indirectly, to that of capelin.

5) Although a general trend of decreasing availability of large cod occurred in late July and early August in 1985, an influx of warm, lower salinity water during early and mid-August appeared to end the availability of these fish to the trap fishery.

6) In 1985, the cod availability peak in Conception Bay closely followed the trend in tidal amplitudes during late June and early July.

7) The intermediate and larger sized cod did not enter the shallow water at the head of Conception Bay, possibly blocked by an unacceptable oceanographic regime.

8) Cod exhibit a behaviour in Conception Bay which makes them more available to traps set on the east side of the bay than in other parts of the study area. This may be due to the possible presence of a migration route along the east side of the bay.

9) Catch per effort tended to vary syncronously in all parts of the study area in 1985 making it more difficult to test the hypothesis that small-scale environmental phenomena have significant influence on the general availability of cod to traps.

10) Temperature in the vicinity of the bottom of cod trap doors marginally influences the availability of cod to traps, as indicated by catch per effort.

11. Daily variability of cod landings at individual trap sites in Conception Bay may in part be due to hunting behaviour by cod.

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Table 1. Log used by fishermen and field workers to record daily catch and effort data for this study.

Daily Cod Catch From Fixed Traps in Conception Bay, Newfoundland, 1985

Fisherman ____________________ Community ____________________

Date	Reason For Not Fishing		Fishing Grounds	Total Cod Catch (lbs)	Traps Checked	Water Depth Where Set	Location of Traps With Fish	Comments (ie. water clarity, water temp., whales in area, sign of capelin, weather, etc.)
Jun 10		Example	Black Rock	0	X			Water clear, slub on twines. Bottom visible at 30 m.
			Colliers Pt.	500	X	28m	X	
			Hr. Main	900	X	34m	X	
			Conception Hr.	400	X	28m	X	
Aug 11								
Aug 12								
Aug 13								

Table 2. Summary of the amount of catch and effort data collected in each of the four zones of this study.

Zone	Total number of days observed: Individual traps	Total number of days observed: Groupings of 2 or more traps
1) West Shore	806	95
2) South Shore	214	19
3) Portugal Cove	269	10
4) Cape St. Francis	2	27
More than one zone	--	7
	1291	158

Table 3. Trap number, depth and duration of thermograph deployments on cod traps for the three zones where gear was instrumented.

Zone	Trap No.	Thermograph depth	Duration of data collection
1) West Shore	18	10 m, 30 m	June 21-July 9
	20	4 m, 24 m	June 10-17
	21	8 m, 30 m	June 10-July 13, July 17-August 19
	25	6 m, 30 m	6 m failed, 30 m July 19-August 9
	29	7 m, 32 m	June 28-July 26, August 15-19
2) South Shore	6	4 m, 18 m	June 13-August 5
	7	4 m, 18 m	June 17-August 13
	9	4 m, 18 m	June 17-August 22
	10	4 m, 15 m	July 13-August 5
3) Portugal Cove	1	4 m, 27 m	One thermograph failed, one lost
	2	4 m, 27 m	July 4-August 21
	3	4 m, 27 m	June 13-August 21
	4	4 m, 27 m	June 18-August 21

Table 4. Positions and recording intervals for the four Aanderaa current meters deployed in Conception Bay.

Mooring No.	Meter No.	Location	Time of first good record (GMT)	Time of last good record (GMT)
1	3306	47°47'02"N 52°52'16"W	June 3, 1985 2111	August 28, 1985 1311
2	3302	47°48'33"N 52°59'52"W	June 3, 1985 2250	August 28, 1985 1430
3	3583	47°41'17"N 53°05'38"W	June 4, 1985 0010	August 28, 1985 1530
4	4350	47°31'17"N 53°03'59"W	June 4, 1985 0150	August 27, 1985 1350

Table 5. Calibration coefficients for the second degree polynomial used for calibrating records from the four Aanderaa current meters.

Parameter	A_0	A_1	A_2	A_3
		Aanderaa Meter 3306		
Temperature	-2.512	0.02277	$-1.344e^{-6}$	$1.937e^{-9}$
Direction	-0.3	0.342		
		Aanderaa Meter 3302		
Temperature	-2.542	0.02277	$-1.344e^{-6}$	$1.937e^{-9}$
Direction	1.0	0.343		
		Aanderaa Meter 3583		
Temperature	-2.441	0.02268	$-1.344e^{-6}$	$1.937e^{-9}$
		Aanderaa Meter 4350		
Temperature	-2.581	0.02284	$-1.334e^{-6}$	$1.937e^{-9}$
Direction	5.2	0.343		

Table 6. Positions and recording intervals for the Endeco current meters deployed in Conception Bay.

Mooring No.	Mooring 1	Mooring 2
Location	47°47'02"N 52°52'16"W	47°48'33"N 52°59'52"W
Serial No.	174A184	174A173
Time of first good record (GMT)	June 3, 1985 2040	June 4, 1985 0830
Time of last good record (GMT)	June 20, 1985 0740	August 3, 1985 0120

Table 7. Deployment site and interval of recording for the Ryan thermographs.

Serial Number	Location	Lat.	Long.	Location Number	Depth	Start	End
65937	Mooring 1	47°47'N,	52°52'W	67	15 m	June 28	August 28
65936	Mooring 1	47°47'N,	52°52'W	67	180 m	June 3	August 28
65810	Mooring 2	47°49'N,	60°00'W	68	10 m	June 3	August 28
65823	Mooring 2	47°49'N,	60°00'W	68	25 m	June 4	August 28
65821	Mooring 2	47°49'N,	60°00'W	68	180 m	June 3	August 28
65477	Mooring 3	47°41'N,	53°06'W	69	15 m	June 4	August 28
65834	Mooring 3	47°41'N,	53°06'W	69	180 m	June 4	August 28
65486	Mooring 4	47°31'N,	53°04'W	70	10 m	June 4	August 27
65941	Mooring 4	47°31'N,	53°04'W	70	25 m	June 4	August 28
65343	Portugal Cove	47°40'N,	52°51'W	2	7 m	June 22	September 13
65591	Portugal Cove	47°40'N,	52°51'W	2	15 m	June 20	September 13
65744	Portugal Cove	47°40'N,	52°51'W	2	4 m	July 4	August 22
65954	Portugal Cove	47°40'N,	52°51'W	2	27 m	July 4	August 21
65698	Portugal Cove	47°40'N,	52°51'W	2	30 m	June 17	September 5
65953	Portugal Cove	47°40'N,	52°51'W	2	50 m	June 17	September 10
65616	Portugal Cove	47°38'N,	52°51'W	3	4 m	June 13	August 21
65882	Portugal Cove	47°38'N,	52°51'W	3	27 m	June 13	August 21
65948	Portugal Cove	47°38'N,	52°52'W	4	4 m	June 18	August 22
65945	Portugal Cove	47°38'N,	52°52'W	4	27 m	June 19	August 21
65780	Lance Cove Head	47°29'N,	53°04'W	6	4 m	June 13	August 5
65951	Lance Cove Head	47°29'N,	53°04'W	6	18 m	June 13	August 5
65695	Lance Cove Head	47°29'N,	53°04'W	7	4 m	June 17	August 13
65170	Lance Cove Head	47°28'N,	53°05'W	9	4 m	June 17	August 22
65613	Lance Cove Head	47°28'N,	53°05'W	9	18 m	June 17	August 22
65849	Lance Cove Head	47°27'N,	53°06'W	10	4 m	July 13	August 5

Table 7 (Cont'd.)

Serial Number	Location	Lat.	Long.	Location Number	Depth	Start	End
65799	Lance Cove Head	47°27'N,	53°06'W	10	15 m	July 13	August 5
65349	Harbour Main	47°27'N,	53°09'W	18	10 m	June 21	July 10
65347	Harbour Main	47°27'N,	53°09'W	18	30 m	June 21	July 10
65347	Brigus	47°34'N,	53°11'W	20	4 m	June 10	June 17
65349	Brigus	47°34'N,	53°11'W	20	24 m	June 10	June 17
65947	Brigus	47°34'N,	53°11'W	20	7 m	June 6	August 24
65321	Brigus	47°34'N,	53°11'W	20	15 m	June 13	September 5
65950	Brigus	47°34'N,	53°11'W	20	30 m	June 13	September 5
65685	Brigus	47°34'N,	53°11'W	20	50 m	June 13	September 5
65708	Colliers Point	47°30'N,	53°10'W	21	8 m	June 10	July 12
65795	Colliers Point	47°30'N,	53°10'W	21	28 m	June 10	July 12
65795	Colliers Point	47°30'N,	53°10'W	21	30 m	July 17	August 19
65347	Chapel Cove	47°26'N,	53°08'W	25	30 m	July 19	August 12
65918	Brigus	47°34'N,	53°11'W	29	7 m	June 11	June 24
65905	Brigus	47°34'N,	53°11'W	29	32 m	June 11	June 24
65905	Brigus	47°34'N,	53°11'W	29	7 m	June 28	July 26
65918	Brigus	47°34'N,	53°11'W	29	32 m	June 28	July 26
65918	Brigus	47°34'N,	53°11'W	29	4 m	August 15	August 18
65905	Brigus	47°34'N,	53°11'W	29	20 m	August 15	August 18
65304	Bay de Grave	47°36'N,	53°11'W	36	6 m	June 11	August 31
65223	Bay de Grave	47°36'N,	53°11'W	36	30 m	June 12	June 18

Table 8. Dates and times of CTD samples collected at the various stations in Conception Bay.

Date	Stations	Time (GMT)
June 19	H1 to H7	1400 to 1800
June 25	A1 to A9, B	1412 to 1733
June 26	D1 to D4	1712 to 1825
June 26	E1 to E5	1518 to 1648
July 05	A1 to A9	1344 to 1637
July 05	D6 to D1	1755 to 1921
July 10	A9 to A1	1614 to 1845
July 10	D1 to D6	1256 to 1434
July 18	A1, A9, A8, A3	1155 to 2030
July 24	A9 to A1	1638 to 1840
July 24	D1 to D6	1400 to 1515
August 01	A1 to A9	1305 to 1550
August 01	D6 to D1	1754 to 1910
August 08	A1 to A5	1226 to 1309
August 13	A9 to A1	1455 to 1645
August 13	D1 to D6	1237 to 1331
August 27	A1 to A6	1230 to 1547
September 04	D1 to D6	1405 to 1525
September 13	A1 to A9	1234 to 1500
September 18	A9 to A1	1610 to 1817
September 18	D1 to D6	1306 to 1433

Table 9. Data used to estimate calibration parameters for temperature readings from CTD records.

Thermometer	Interocean CTD
12.25	12.32
11.75	11.71
10.8	10.77
9.7	9.62
8.75	8.64
7.75	7.74
5.5	5.57
4.4	4.38
3.4	3.39
2.25	2.26
1.5	1.46
1.0	0.93
-0.9	-1.36
-1.8	-1.79
-2.0	-2.05

Table 10. Data used to estimate calibration parameters for salinity readings from CTD records. The last seven values were found to be possibly in error, and a recalibration without these points was used in many analyses.

Water Samples	Interocean CTD
32.116	33.874
32.634	34.356
32.508	34.461
32.038	34.131
32.595	34.380
32.225	33.990
32.547	34.425
31.683	33.398
31.964	33.602
31.344	34.028
30.375	31.977
28.425	33.908
32.022	34.184
1.071	0.001
9.954	16.389
12.667	17.676
17.434	22.438
20.634	26.177
30.884	31.086
33.856	34.512

Table 11. Dates and times of satellite infrared scenes received from NOAA.

No.	Date (1985)	Day of the year	Time (GMT)
1	June 15	166	1743-1755
2	June 25	176	1741-1749
3	June 27	178	1718-1728
4	July 5	186	1734-1743
5	July 6*	187	1722-1733
6	August 26*	238	0655-0708

* Little useful data available.

Table 12. Results of tests of the association between daily catch and three temperature variables, indicating which variables met the criterion for possible association. QUAD = quadratic fit significant; NS = neither linear nor quadratic fit significant (P>0.10); no test = no statistical test done, based on inspection of scatterplots.

Location	SURFTEMP	DEEPTEMP	TEMPDIFF
2	NS	No test	NS
3	NS	No test	NS
4	NS	No test	NS
6	QUAD	No test	QUAD
9	NS	No test	QUAD

Table 13. Estimated regression coefficients for significant associations reported in Table 12. None of the constants were significantly different from zero at P<0.10.

Location	Constant	Linear term	Quadratic term
	Predictor variable: SURFTEMP		
6	-245.8	-	6.07
	Predictor variable: TEMPDIFF		
6	53.9	-	7.27
9	35.2	-	3.69

Table 14. Summary of the associations between weekly catch in each group of locations, and the various environmental relations, as suggested by inspection of scattergrams of catch with each predictor variable for each group. Group refers to locations specified in text.

Variable	Group	Form of the association
TEMPBOT	A	Quadratic
TEMPBOT	B,C,D	None
TEMGR30	A,B,D,	Quadratic
TEMGR30	C	None
TEMGRBOT	A	Quadratic
TEMGRBOT	B,C,D	None
DM1C	All	Quadratic
DOC	All	Quadratic
DP1C	All	Quadratic
DP2C	All	Quadratic
DP3C	All	Quadratic
DP4C	All	Quadratic
DP5C	All	Quadratic
DP6C	A	Quadratic
DP6C	B,C,D	None
DP7C	A	Quadratic
DP7C	B,C,D	None
DP8C	A,C	Quadratic
DP8C	B,D	None
SALINITY	All	None
SALGRD30	A,B,D	Quadratic
SALGRD30	C	None
SALGRBOT	All	None

Table 15. Summary of tests of the statistical associations of weekly catch data with the predictor variables. Abbreviations as in Table 12; LIN = linear fit significant at $P<0.10$. Variable names listed in text.

Group	SALGRD30	TEMGRBOT	TEMGR30	Variable TEMPBOT	DMIC	DOC	DPIC	DP2C	DP3C
A	NS	QUAD	NS	QUAD	QUAD	QUAD	QUAD	QUAD	QUAD
B	NS	No test	NS	No test	LIN	QUAD	QUAD	QUAD	QUAD
C	No test	No test	No test	No test	LIN	NS	NS	NS	LIN
D	LIN	No test	QUAD	No test	QUAD	LIN	LIN	QUAD	LIN

Table 16. A summary of tests of the statistical associations of weekly catch data with the depths of the 4 to 8°C isotherms. Abbreviations as in Table 12.

Group	DP4C	DP5C	Variable DP6C	DP7C	DP8C
A	QUAD	QUAD	NS	NS	NS
B	QUAD	QUAD	No test	No test	No test
C	LIN	LIN	No test	No test	NS
D	LIN	QUAD	No test	No test	No test

Table 17. Estimates of the coefficients in the linear and quadratic regression models for weekly catch as functions of depths of each isotherm from -1°C to 5°C. Only parameters of significant ($P<0.10$) models are reported. Variable abbreviations are listed in the text.

Variable / Group	Intercept	DM1C	DM1CSQ	Intercept	DOC	DOCSQ	Intercept	DP1C	DP1CSQ	Intercept	DP2C	DP2CSQ
A	-	80.7860	-0.9729	-	132.3462	-2.6482	-	153.9175	-3.6163	-	173.8079	-4.7610
B	-	6.1469	-	-	27.0408	-0.4638	-	33.9597	-0.7257	-	39.6648	-0.9828
C	-	2.8579	-	-	-	-	-	-	-	-	-	-
D	-	-	0.0394	-	4.8714	-	-	5.8677	-	-3841.76	333.6447	-6.59522

Table 17 (Cont'd)

Variable / Group	Intercept	DP3C	DP3CSQ	Intercept	DP4C	DP4CSQ	Intercept	DP5C	DP5CSQ
A	-	180.6806	-5.3287	2004.578	-	-1.91323	-	175.8285	-5.8104
B	-	47.3763	-1.3975	-	50.7645	-1.6561	-	57.6490	-2.0882
C	-	7.3906	-	-	9.3034	-	-	11.8291	-
D	-	8.4901	-	-	8.4913	-	-	-	0.7010

Table 18. Location of min or max values and x-intercepts of the estimated regression equations relating weekly catch at each location to depths of the -1°C to 5°C isotherms, using the estimated parameters from Table 17.

	DMIC			DOC			DPIC		
Variable / Group	Min	Max	x-intercepts	Min	Max	x-intercepts	Min	Max	x-intercepts
A	-	x=41.518771 (1677.0673)	x=0 x=83.037543	-	x=24.988143 (1653.5429)	x=0 x=49.976286	-	x=21.2809 (1637.76)	x=0 x=42.561914
B	-	-	x=0	-	x=29.15407 (394.17396)	x=0 x=58.30814	-	x=23.397 (397.28)	x=0 x=46.794558
C	-	-	x=0	-	-	x=41.583006	No	Significant	Regression
D	x=0 (0.0)	-	x=0	-	-	x=0	-	-	x=0

Table 18 (Cont'd.)

Variable / Group	DP2C Min	DP2C Max	DP2C x-intercepts	DP3C Min	DP3C Max	DP3C x-intercepts	DP4C Min	DP4C Max	DP4C x-intercepts
A	-	x=18.253144 (1586.2704)	x=0 x=36.506289	-	x=16.9536 (1531.5903)	x=0 x=33.907133	-	x=0 (2004.6)	x=32.368969 x=-32.368969
B	-	x=20.179236 (400.20218)	x=0 x=40.358472	-	x=16.950979 (401.537)	x=0 x=33.901957	-	x=15.327 (389.031)	x=0 x=30.653781
C	No	Significant	Regression	-	-	x=0	-	-	x=0
D	-	x=25.294433 (377.91671)	x=17.724649 x=32.864217	-	-	x=0	-	-	x=0

Table 18 (Cont'd.)

Variable / Group	DP5C Min	DP5C Max	DP5C x-intercepts	Min	Max	x-intercepts	Min	Max	x-intercepts
A	-	x=15.130499 (1330.1865)	x=0 x=30.260998						
B	-	x=13.803192 (397.87031)	x=0 x=27.606383						
C	-	-	x=0						
D	x=0 (0.0)	-	x=0						

Table 19. Climatic departures from long-term average values for four weather stations in eastern Newfoundland.

	May	June	July	August	Sept.
St. John's West - 1985					
Departure from normal mean daily temp. (°C)	-0.8	-0.4	+2.2	-1.1	-0.8
Percent of normal mean monthly precip. (%)	176	127	134	99	51
Percent of normal bright sunshine hours (%)	105	96	111	N/A	100
Torbay Airport (St. John's) - 1985					
Departure from normal mean daily temp. (°C)	-1.4	-0.9	+1.6	-1.8	-0.6
Percent of normal mean monthly precip. (%)	165	103	144	82	46
Percent of normal bright sunshine hours (%)	107	103	110	95	105
Bonavista - 1985					
Departure from normal mean daily temp. (°C)	-0.9	-0.2	+1.3	-1.5	-0.5
Percent of normal mean monthly precip. (%)	165	140	174	103	42
Percent of normal bright sunshine hours (%)	N/A	N/A	N/A	N/A	N/A
Argentia - 1985					
Departure from normal mean daily temp. (°C)	-1.2	-1.1	-0.6	-1.1	-0.4
Percent of normal mean monthly precip. (%)	230	140	270	90	95
Percent of normal bright sunshine hours (%)	N/A	N/A	N/A	N/A	N/A

Table 20. Most frequent wind direction and mean speed (km/hr) by month for Torbay Airport in 1985 and the normals for 1951-80.

	May		June		July		August	
	1985	1951-80	1985	1951-80	1985	1951-80	1985	1951-80
Most frequent direction	WSW	WSW	WSW	WSW	WSW	WSW	W	WSW
Mean speed	21.0	22.9	20.5	22.2	22.8	21.4	16.1	21.2

Table 21. Percent frequency of wind direction and mean wind speed by direction for Torbay airport in 1985.

WIND DIRECTION	MAY 85 % FREQ.	MAY 85 MEAN SPEED	MAY % FREQ.	MAY MEAN SPEED	JUNE 85 % FREQ.	JUNE 85 MEAN SPEED	JUNE % FREQ.	JUNE MEAN SPEED	JULY 85 % FREQ.	JULY 85 MEAN SPEED	JULY % FREQ.	JULY MEAN SPEED	AUGUST 85++ % FREQ.	AUGUST 85++ MEAN SPEED	AUGUST+ % FREQ.	AUGUST+ MEAN SPEED
N	7	19.8	7	27.0	2	12.2	5	21.2	0	-	2	18.0	2	15.7	4	22.0
NNE	5	17.5	6	22.0	5	14.8	5	19.8	1	9.6	3	16.9	3	10.5	3	19.5
NE	3	13.4	5	18.0	6	16.0	5	17.3	2	11.0	3	14.1	3	12.0	3	17.6
ENE	1	11.0	3	18.4	1	16.5	2	17.4	<.5	7.3	2	14.8	3	12.1	2	17.9
E	2	12.8	4	17.2	2	14.1	2	15.2	2	7.1	2	12.9	10	16.1	2	17.4
ESE	4	16.0	3	17.0	2	10.6	2	16.0	1	9.7	2	15.0	8	16.2	2	16.9
SE	7	15.7	5	17.6	6	17.7	4	16.4	1	14.2	5	15.6	6	11.6	4	17.3
SSE	8	20.7	4	20.5	11	23.5	4	18.0	3	23.3	5	18.9	5	15.2	5	19.7
S	10	23.5	6	22.0	19	26.6	6	21.4	6	21.3	8	20.0	5	14.7	7	20.1
SSW	4	28.5	5	22.8	3	18.5	6	21.5	7	20.4	7	21.6	2	11.9	7	21.1
SW	5	24.2	7	24.7	6	22.5	10	24.3	18	23.1	13	23.6	3	11.7	12	22.5
WSW	17	28.6	17	26.9	21	26.0	23	27.2	42	26.3	26	25.4	12	19.3	24	24.0
W	9	23.7	13	25.5	8	22.2	13	25.0	14	22.1	15	24.1	17	18.0	14	23.0
WNW	3	26.3	4	23.9	1	12.0	4	22.0	1	22.1	2	19.0	7	23.1	3	20.0
NW	5	28.3	4	25.0	<.5	8.0	3	22.4	1	18.1	2	20.0	5	20.9	3	20.8
NNW	3	22.3	4	27.7	<.5	6.5	3	22.9	<0.5	26.0	2	23.7	4	26.9	3	21.7
CALM	7	-	2	-	7	-	2	-	1	-	2	-	5	-	2	-

Source + Canadian Climate Normals 1951-1980, vol. 5
Environment Canada
++ Monthly Meteorological Summary, St. John's Airport

Table 22. Catch per trap per day by zone and cross-correlations. Mean, standard deviation and sample size for catch per trap per day in each zone, and Pearson product-moment correlation coefficients of catch per trap per day for each pair of zones.

		Zone 1	Zone 2	Zone 3	Zone 4
Mean		102.2	284.5	961.3	573.4
STD		136.6	270.3	994.2	585.5
N		68	55	57	27
Corr.	Zone 1	1	0.29	0.31	-0.09
Corr.	Zone 2	-	1	.10	-0.16
Corr.	Zone 3	-	-	1	0.17

Table 23. Cross-correlation coefficients for catch per trap per day between each pair of zones; for lags of 0 to 4 days.

Zones	Lag	N	Cross-Correlation
1 2	0	51	0.29018637
1 2	1	40	0.44236697
1 2	2	41	0.14334625
1 2	3	39	-0.02475267
1 2	4	40	-0.05616479
1 3	0	53	0.30970928
1 3	1	45	0.19071466
1 3	2	46	0.23269693
1 3	3	45	0.17077550
1 3	4	45	0.19317177
1 4	0	26	-0.09251327
1 4	1	21	-0.27977516
1 4	2	22	-0.26391661
1 4	3	21	-0.25184719
1 4	4	21	-0.01841600
2 1	0	51	0.29018637
2 1	1	45	0.17588081
2 1	2	46	0.15964420
2 1	3	43	0.02223815
2 1	4	41	0.00032022
2 3	0	46	0.10063953
2 3	1	40	-0.02007631
2 3	2	39	0.05226342
2 3	3	36	-0.17240630
2 3	4	37	0.18662883
2 4	0	23	-0.15681903
2 4	1	19	-0.12203966
2 4	2	20	-0.21118497
2 4	3	18	-0.20196713
2 4	4	19	-0.23634905
3 1	0	53	0.30970928
3 1	1	47	0.17862748
3 1	2	45	0.11615784
3 1	3	43	0.10697998
3 1	4	41	0.08225194

. . . Cont'd.

Table 23 (Cont'd.)

Zones	Lag	N	Cross-Correlation
3 2	0	46	0.10063953
3 2	1	36	-0.02818138
3 2	2	33	-0.09318725
3 2	3	31	0.03205261
3 2	4	33	0.20200518
3 4	0	26	0.17108268
3 4	1	21	-0.02067301
3 4	2	21	0.28904613
3 4	3	19	-0.03071309
3 4	4	19	0.37274422
4 1	0	26	-0.09251327
4 1	1	22	0.13268190
4 1	2	23	-0.25430002
4 1	3	21	-0.17915769
4 1	4	22	-0.10460882
4 2	0	23	-0.15681903
4 2	1	19	-0.12381789
4 2	2	19	0.14136515
4 2	3	16	-0.21741447
4 2	4	17	0.04003861
4 3	0	26	0.17108268
4 3	1	22	0.05703969
4 3	2	22	0.24069019
4 3	3	19	-0.05232752
4 3	4	20	0.35520180

JUNE

VARIABLE FISH LENGTH	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ZONE=1						
	229	43.81	4.98	32.50	61.50	0.33
ZONE=2						
	305	46.50	4.31	35.50	59.50	0.25
ZONE=3						
	769	46.34	5.71	34.50	71.50	0.21

Table 24. Descriptive statistics of fish lengths, for samples collected in Zones 1, 2, and 3 during the second and third weeks of June, July, and August and in Zone 4 during July, 1985.

JULY

VARIABLE FISH LENGTH	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ZONE=1						
	243	50.68	6.04	40.50	70.50	0.39
ZONE=2						
	326	46.97	7.08	32.50	73.50	0.39
ZONE=3						
	3365	52.18	8.34	34.50	97.50	0.14
ZONE=4						
	199	53.62	10.79	33.50	99.50	0.77

Table 24 (Cont'd.)

AUGUST

VARIABLE FISH LENGTH	N	MEAN	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE	STD ERROR OF MEAN
ZONE=1						
	111	41.39	5.75	33.50	65.50	0.55
ZONE=2						
	397	44.85	4.64	32.50	67.00	0.23
ZONE=3						
	918	49.84	5.80	37.50	76.50	0.19

Table 24 (Cont'd.)

Table 25. Values of the tidal constituents at 50 m on Mooring 1.

	NAME	SPEED	MAJOR	MINOR	INC.	G	G+	G-
1	ZO	.00000000	7.728	.000	22.8	360.0	337.2	22.8
2	MM	.00151215	2.460	-.273	56.2	326.2	270.0	22.4
3	MSF	.00282193	2.273	-.247	106.8	51.7	304.9	158.5
4	ALP1	.03439657	.290	-.122	108.0	176.0	68.0	284.0
5	2Q1	.03570635	.459	-.329	176.5	329.2	152.7	145.6
6	Q1	.03721850	.365	-.025	148.4	169.3	20.0	318.7
7	O1	.03873065	.521	.038	78.6	92.1	13.4	170.7
8	NO1	.04026860	.277	.055	149.9	62.5	272.6	212.5
9	K1	.04178075	.824	-.173	36.3	156.8	120.4	193.1
10	J1	.04329290	.417	-.030	141.9	217.9	76.0	359.8
11	OO1	.04483084	.165	-.096	158.4	30.1	231.8	188.5
12	UPS1	.04634299	.379	-.212	20.1	214.8	194.7	234.9
13	EPS2	.07617731	.696	.290	151.7	110.1	318.4	261.8
14	MU2	.07768947	.732	-.306	34.1	259.2	225.1	293.4
15	N2	.07899925	1.474	-.158	126.9	248.7	121.8	15.6
16	M2	.08051140	2.190	.118	62.8	203.1	140.3	265.9
17	L2	.08202355	1.455	-1.125	139.2	306.7	167.5	85.9
18	S2	.08333334	.919	.077	2.1	226.1	224.0	228.2
19	ETA2	.08507364	.869	-.038	166.5	13.7	207.1	180.2
20	MO3	.11924210	.374	-.115	129.8	198.3	68.5	328.0
21	M3	.12076710	.560	-.158	109.6	65.6	316.0	175.2

Table 26. Values of the tidal constituents at 50 m on Mooring 2.

	NAME	SPEED	MAJOR	MINOR	INC.	G	G+	G-
1	ZO	.00000000	5.391	.000	110.4	180.0	69.6	290.4
2	MM	.00151215	2.553	-1.313	30.6	302.4	271.7	333.0
3	MSF	.00282193	2.493	1.744	178.1	1.3	183.1	179.4
4	ALP1	.03439657	.667	-.106	144.8	169.6	24.8	314.4
5	2Q1	.03570635	.453	-.155	101.5	145.1	43.6	246.7
6	Q1	.03721850	.340	-.036	39.1	152.8	113.7	191.9
7	O1	.03873065	.421	.172	119.6	183.6	64.0	303.2
8	NO1	.04026860	.219	-.115	150.9	106.1	315.2	257.1
9	K1	.04178075	.680	.179	101.5	226.4	124.8	327.9
10	J1	.04329290	.453	-.116	170.2	275.5	105.3	85.6
11	OO1	.04483084	.148	-.066	96.1	103.0	6.9	199.1
12	UPS1	.04634299	.537	-.017	114.5	57.1	302.6	171.7
13	EPS2	.07617731	1.507	-.997	42.3	.9	318.6	43.1
14	MU2	.07768947	.491	-.284	78.2	276.7	198.5	354.9
15	N2	.07899925	1.259	-.887	159.2	141.7	342.6	300.9
16	M2	.08051140	2.013	.435	32.3	195.8	163.4	228.1
17	L2	.08202355	.970	-.876	63.4	289.0	225.6	352.3
18	S2	.08333334	1.072	-.578	70.1	260.9	190.8	331.0
19	ETA2	.08507364	.656	-.194	20.6	68.7	48.0	89.3
20	MO3	.11924210	.223	.056	38.9	220.0	181.1	258.9
21	M3	.12076710	.197	-.075	7.7	144.9	137.2	152.5

Table 27. Temperatures and salinities at various depths from Station 27 (off Cape Spear), recorded during late July and August 1985.

	Depth (m)	Temperature (°C)	Salinity (%)
July 31	0	11.24	32.05
	10	8.86	32.14
	20	4.04	32.41
August 12	0	10.98	No data
	10	7.27	No data
	20	1.37	32.60
August 21	0	12.11	30.47
	9.7	12.05	30.48
	19.3	9.21	31.30
August 26	0	12.82	30.18
	10	12.77	30.18
	20	11.16	31.14
August 30	0	12.07	30.34
	10	11.83	30.47
	20	10.27	31.02

Table 28. Product-moment correlation of daily catch with amplitude of the previous tide as measured by current meters at five locations around Conception Bay, for summer 1985. For information on locations, see text.

Location	r	P*
2	.19	.35
3	.34	.01
4	.07	.63
6	.01	.95
9	-.07	.72

*P is the probability that an absolute value of r greater than that calculated would occur if there is no correlation.

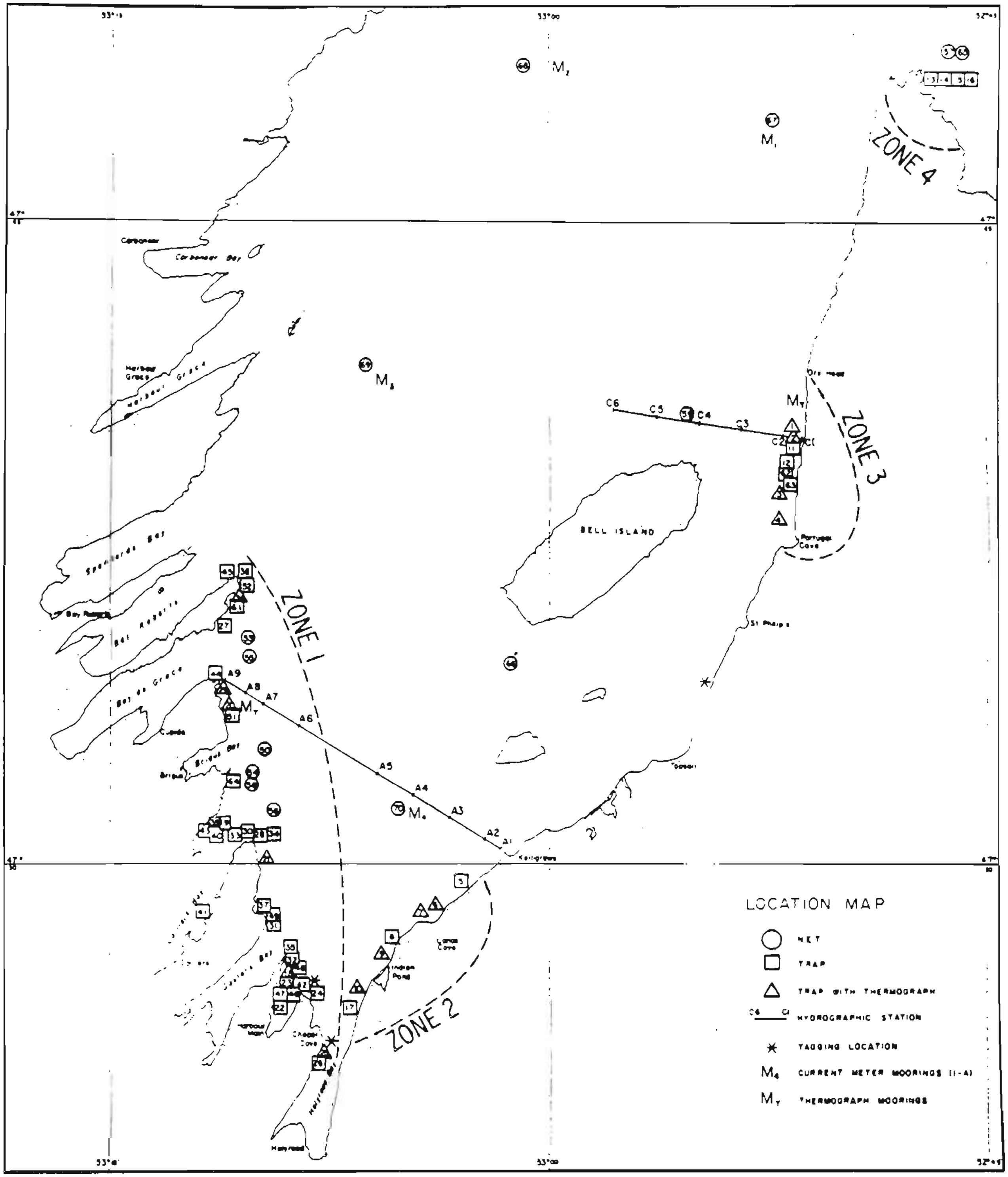

Figure 1. Location of various instrumentation, fishing gear, and hydrographic lines that were sources of data for this study.

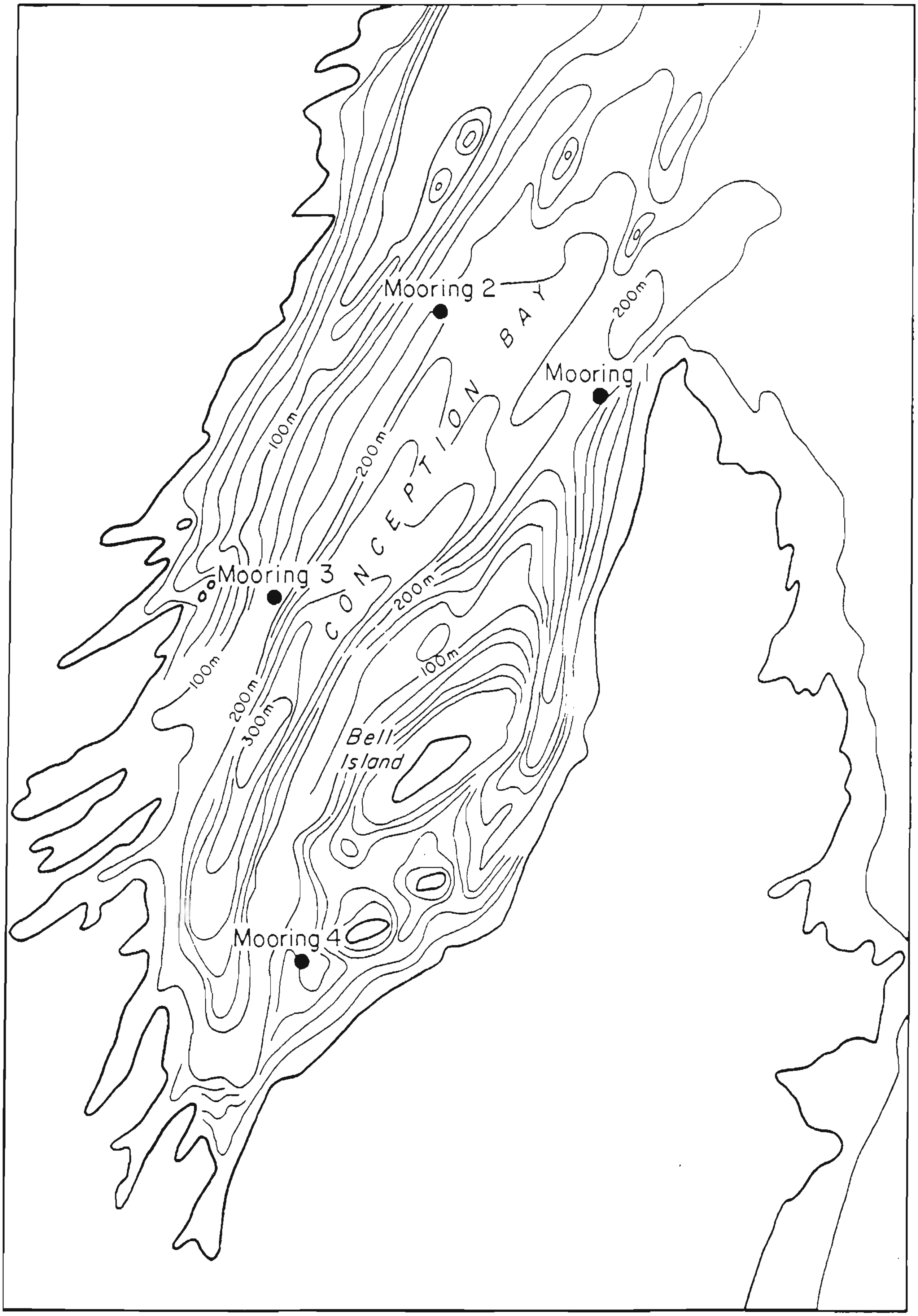

Figure 2. Locations of the four current meter moorings deployed in Conception Bay.

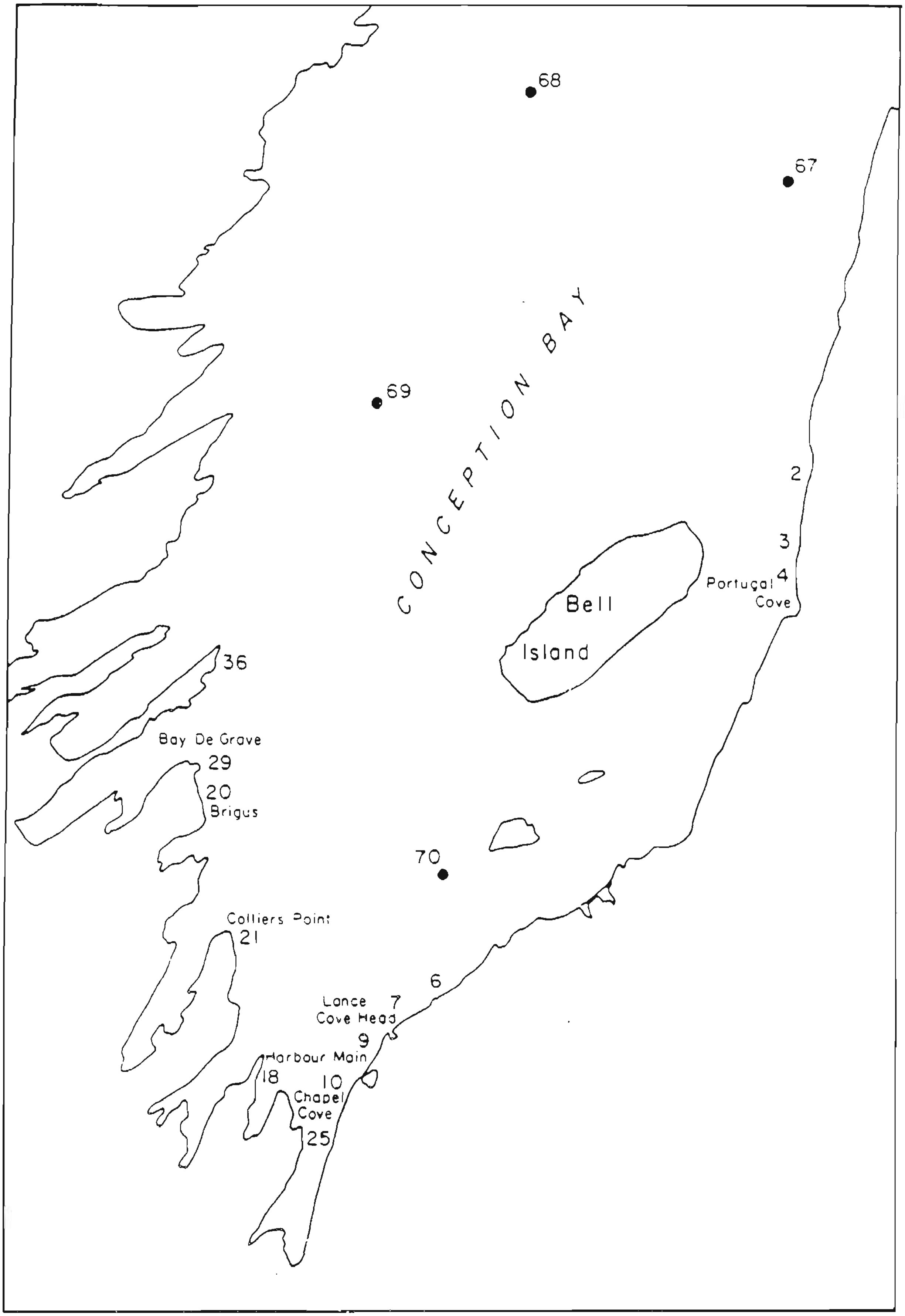

Figure 3. Locations of the 47 Ryan thermographs deployed in Conception Bay.

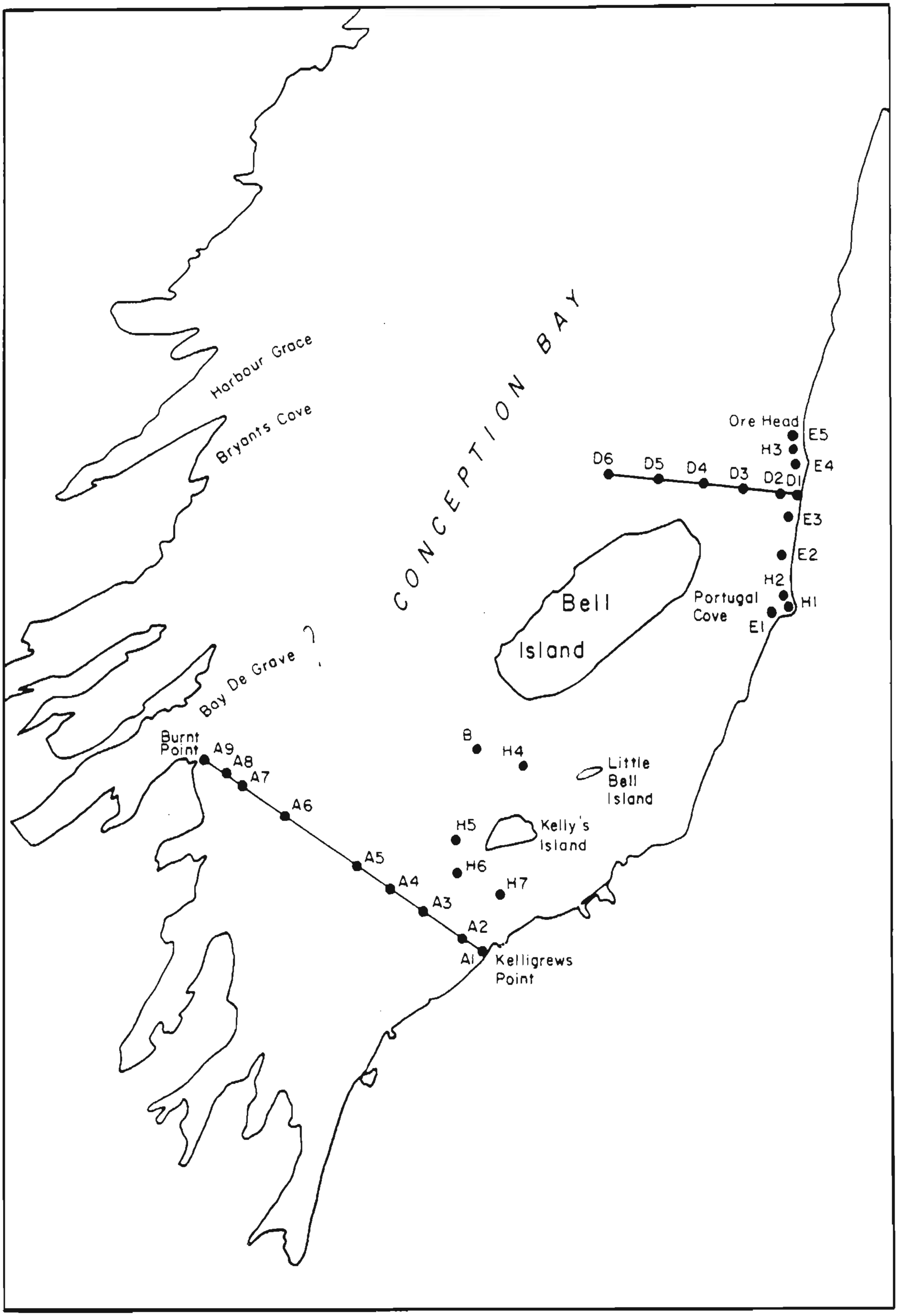

Figure 4. Locations of CTD sampling stations in Conception Bay.

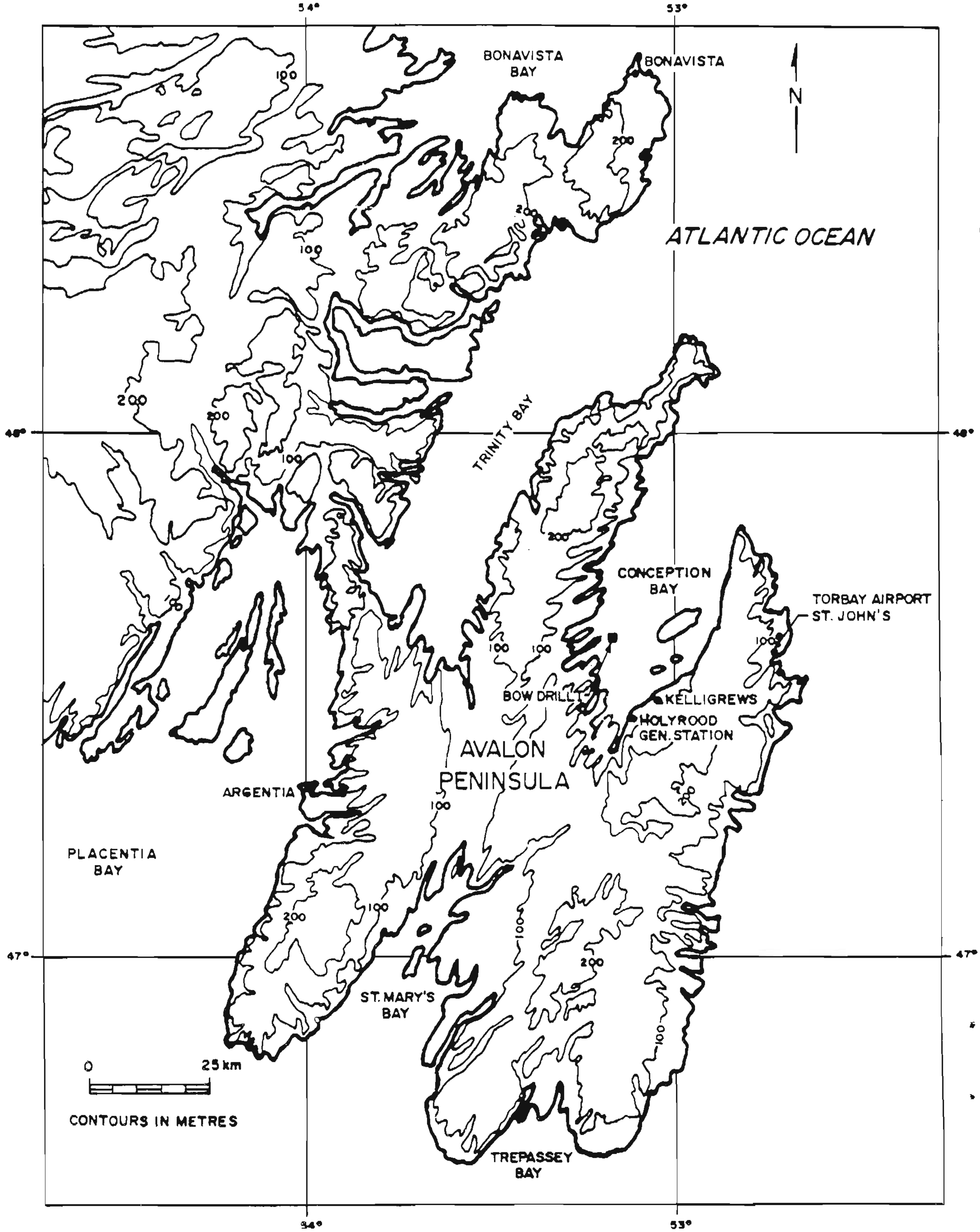

Figure 5. Location of the stations which provided meteorological data for this study.

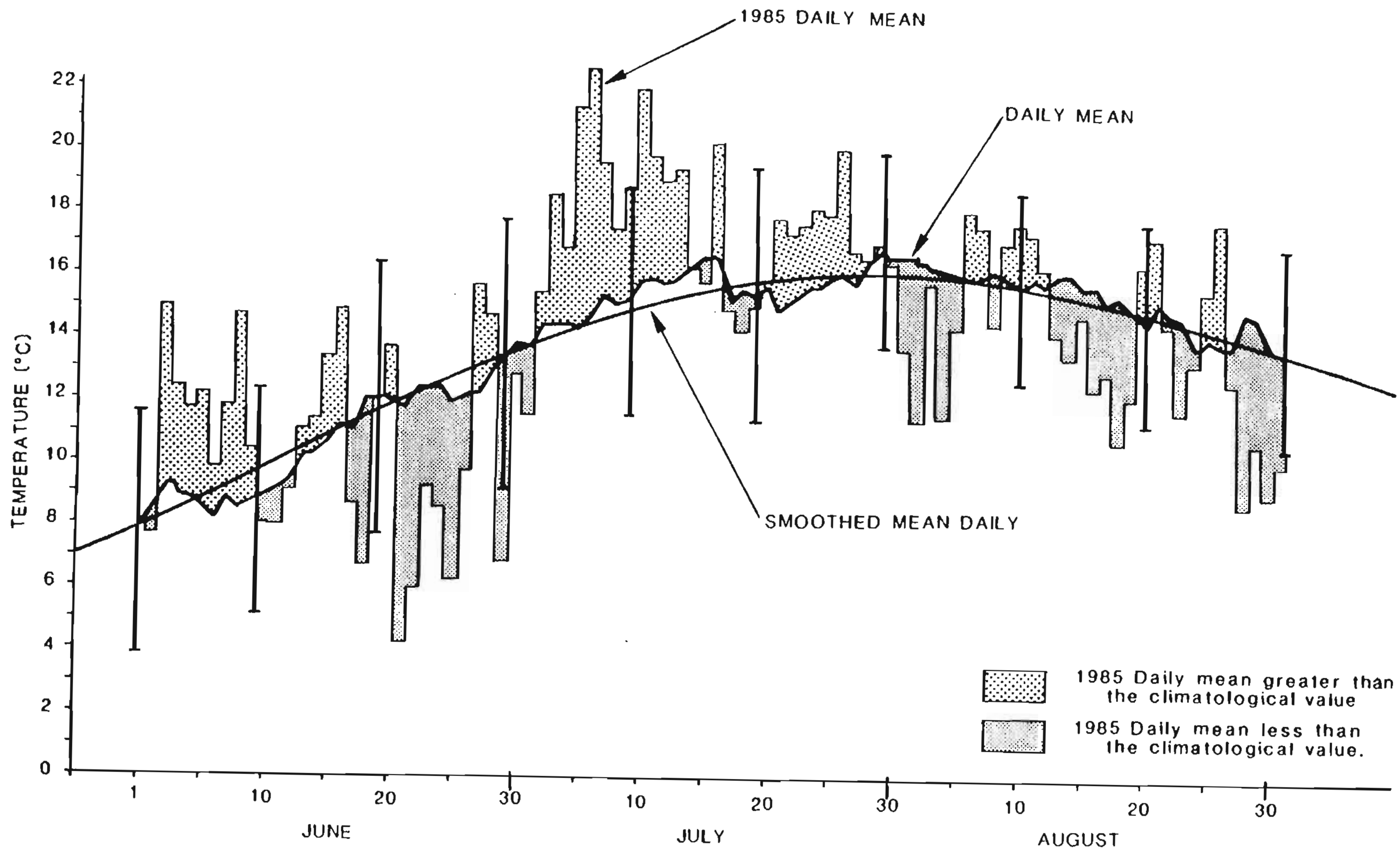

Figure 6. Time series plot of air temperatures showing the 1985 daily mean, the long term daily mean, and standard deviation (10 day intervals) and the smoothed mean, for Torbay Airport. Both positive and negative anomalies for 1985 are highlighted.

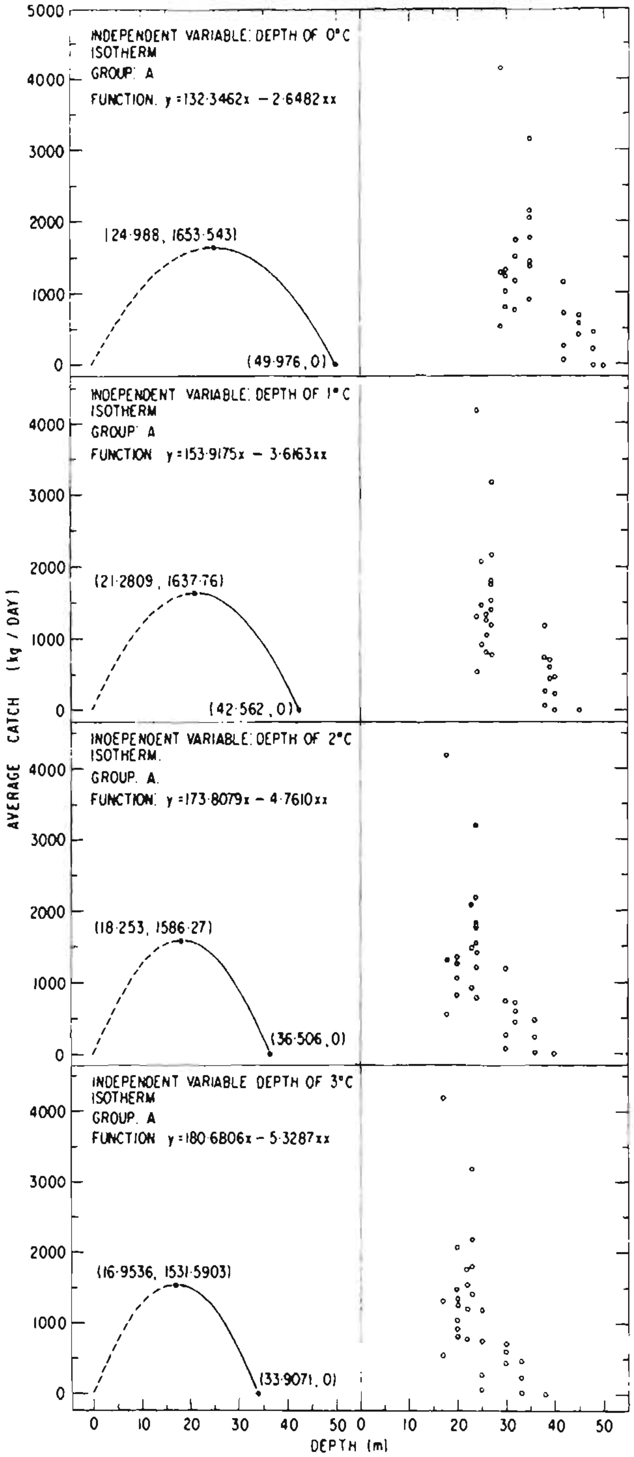

Figure 7. Scatterplots of average catch versus four isotherm depths for Group A and estimated regression equations computed from these data sets.

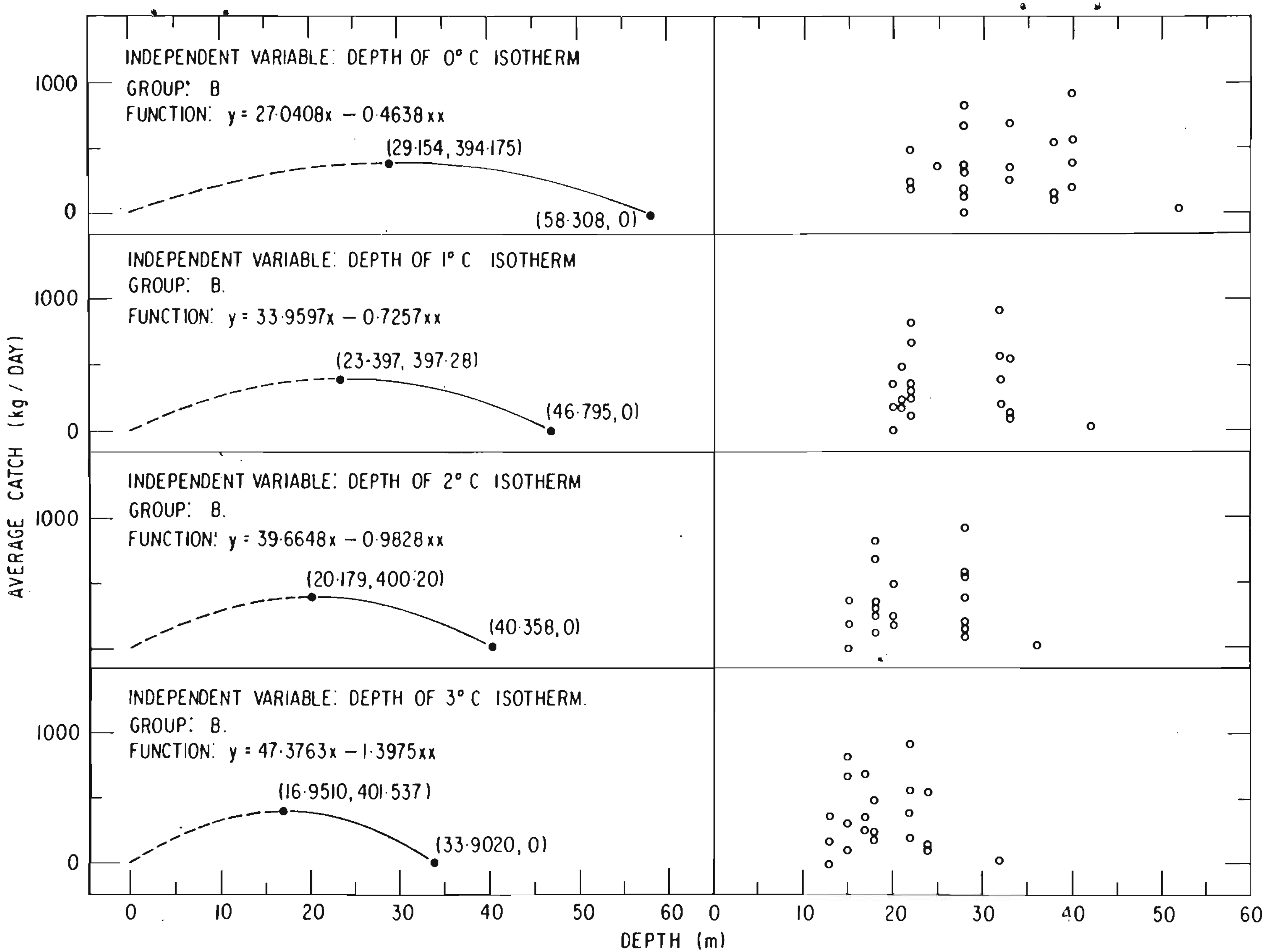

Figure 8. Scatterplots of average catch versus four isotherm depths for Group B and estimated regression equations computed from these data sets.

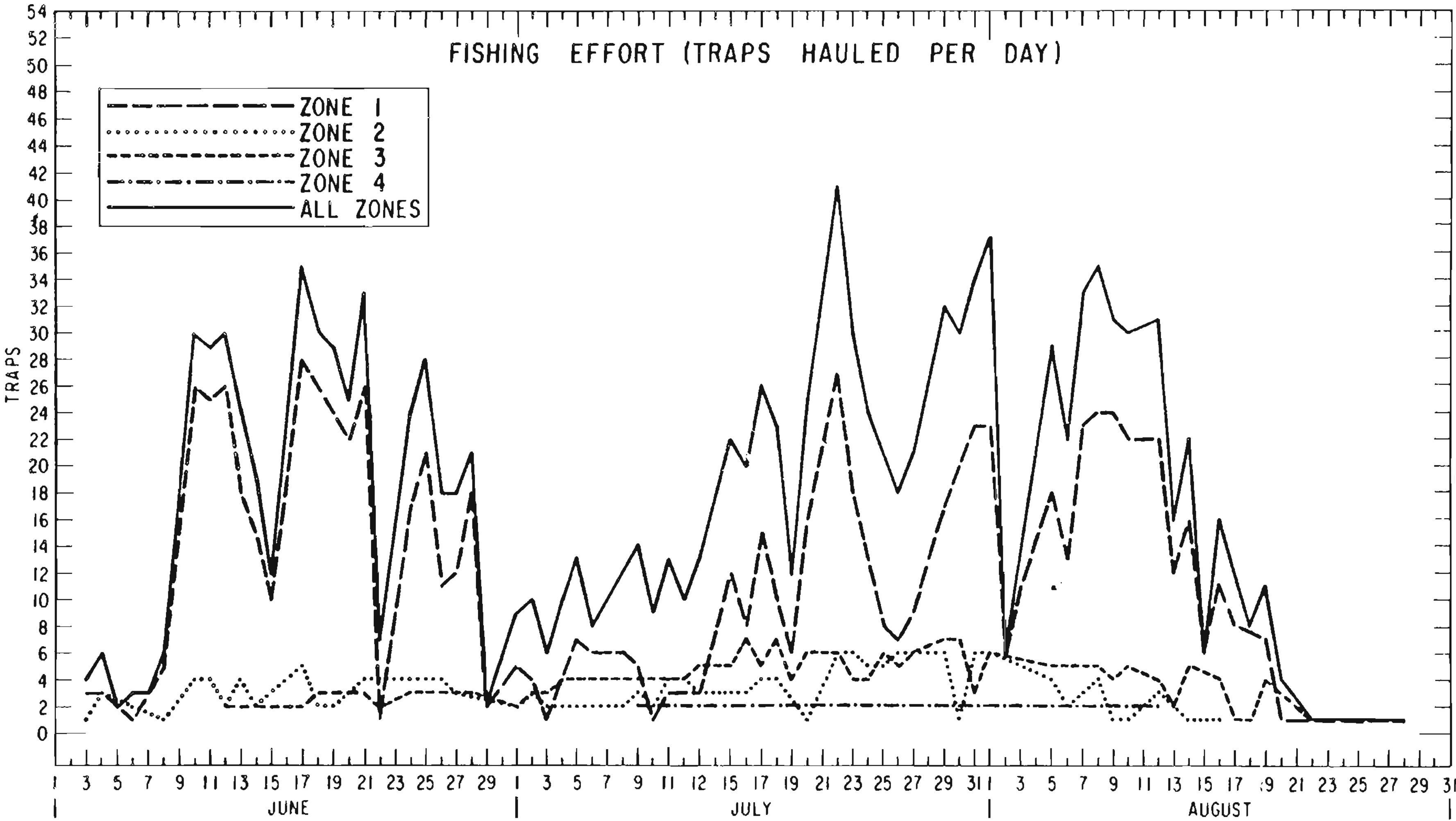

Figure 9. Fishing effort (traps hauled per day) by zone and total during June 3-August 28, 1985 in Conception Bay.

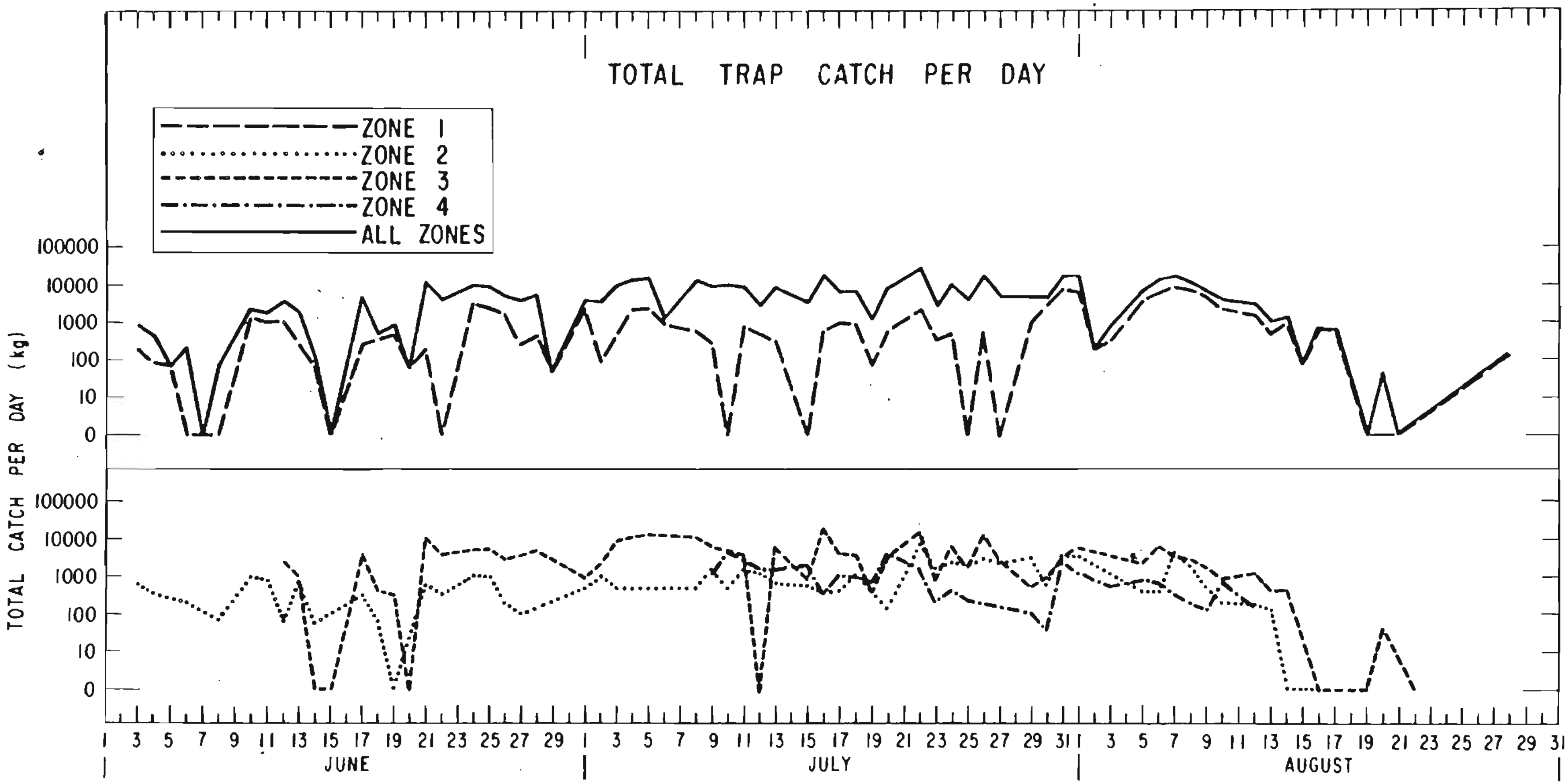

Figure 10. Total trap catch per day by zone and total during June 3-August 28, 1985 in Conception Bay.

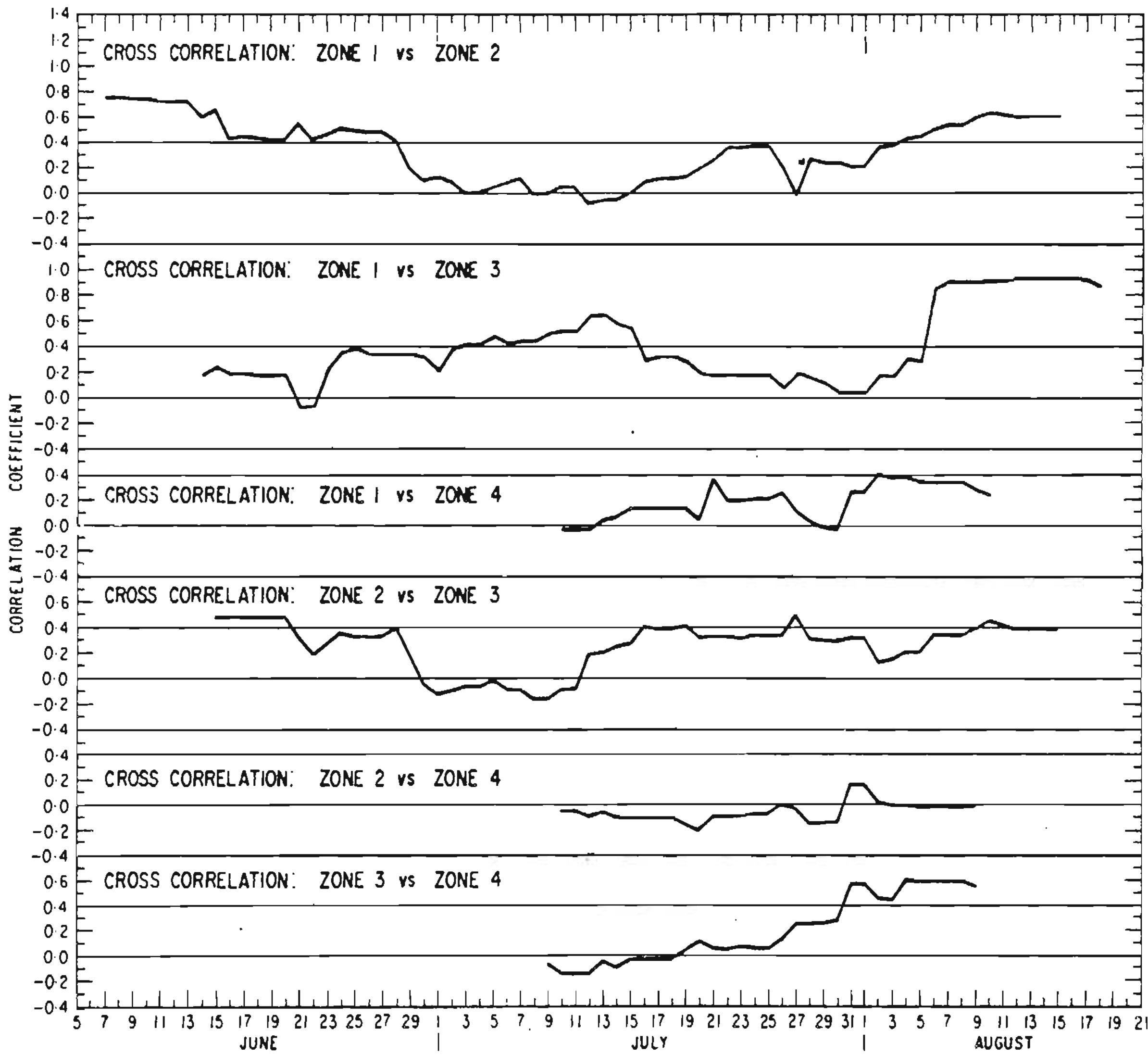

Figure 11. Cross-correlation of catch per trap per 20 day block (blocks centered on dates on x-axis), for Zone 1 vs Zone 2, Zone 1 vs Zone 3, Zone 1 vs Zone 4, Zone 2 vs Zone 3, Zone 2 vs Zone 4, and Zone 3 vs Zone 4.

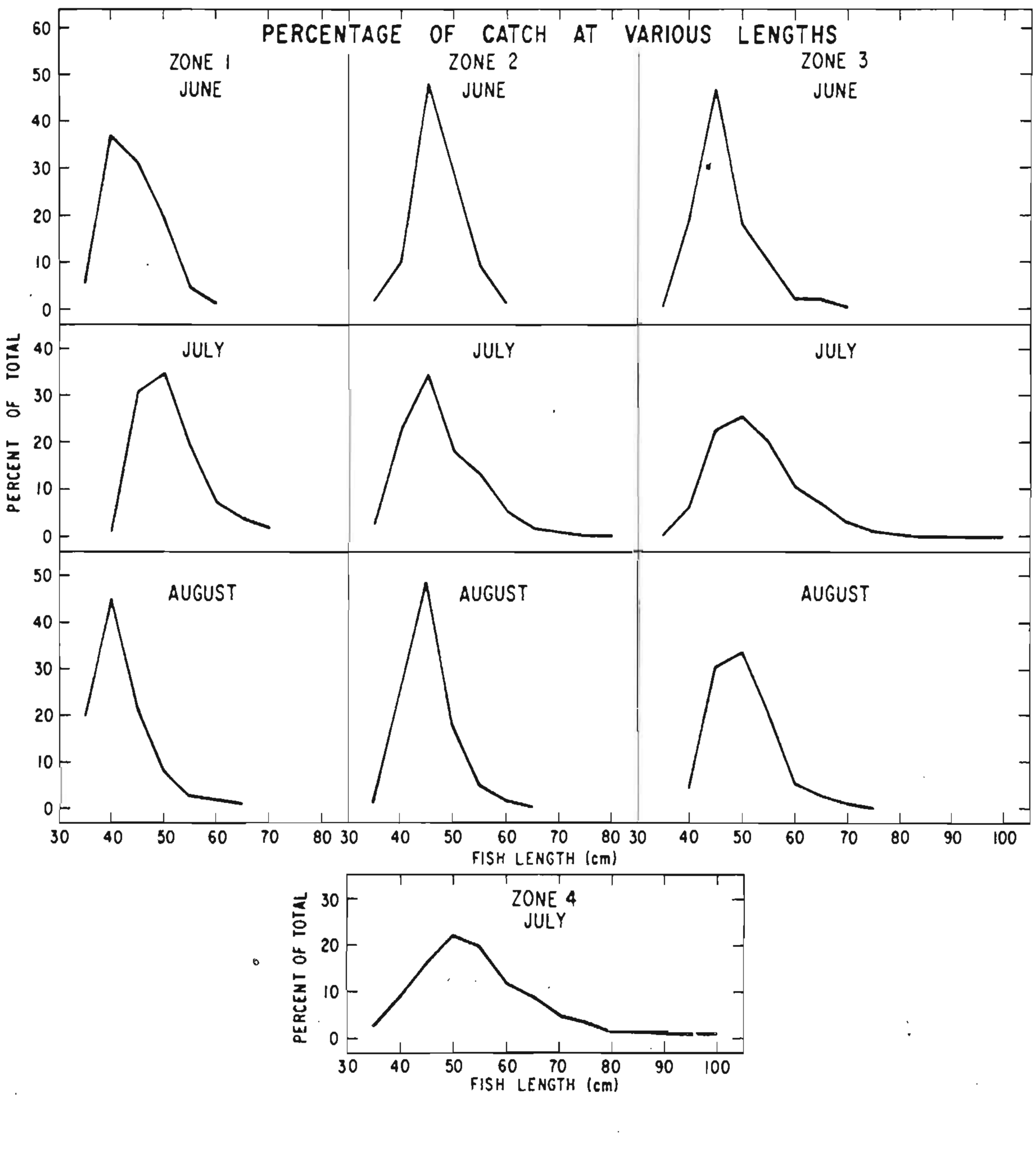

Figure 12. Percentage of catch by 5 cm length interval for samples of cod taken in each zone and month.

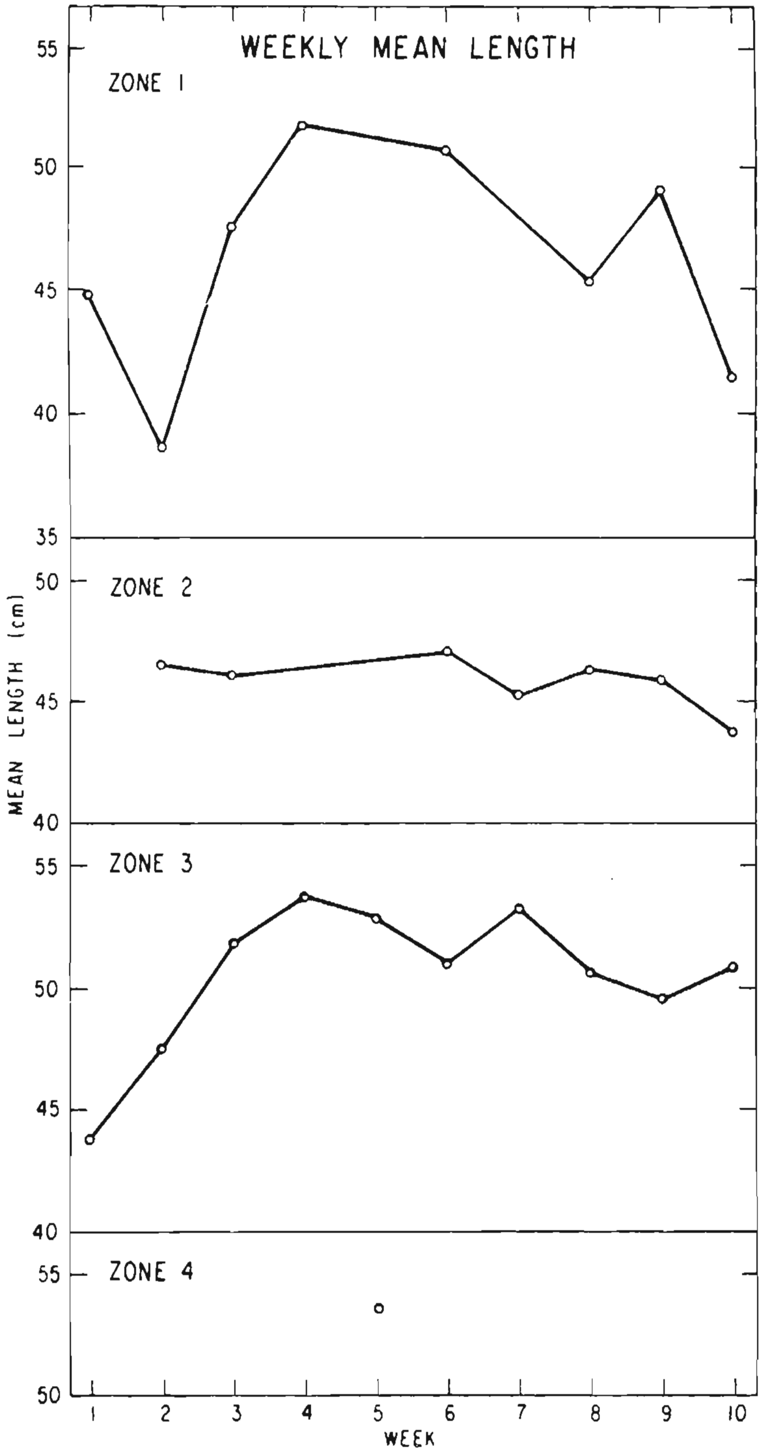

Figure 13. Mean length, by week, for samples of cod taken in each zone from June 9-16 (week 1) to August 12 to 18 (week 10).

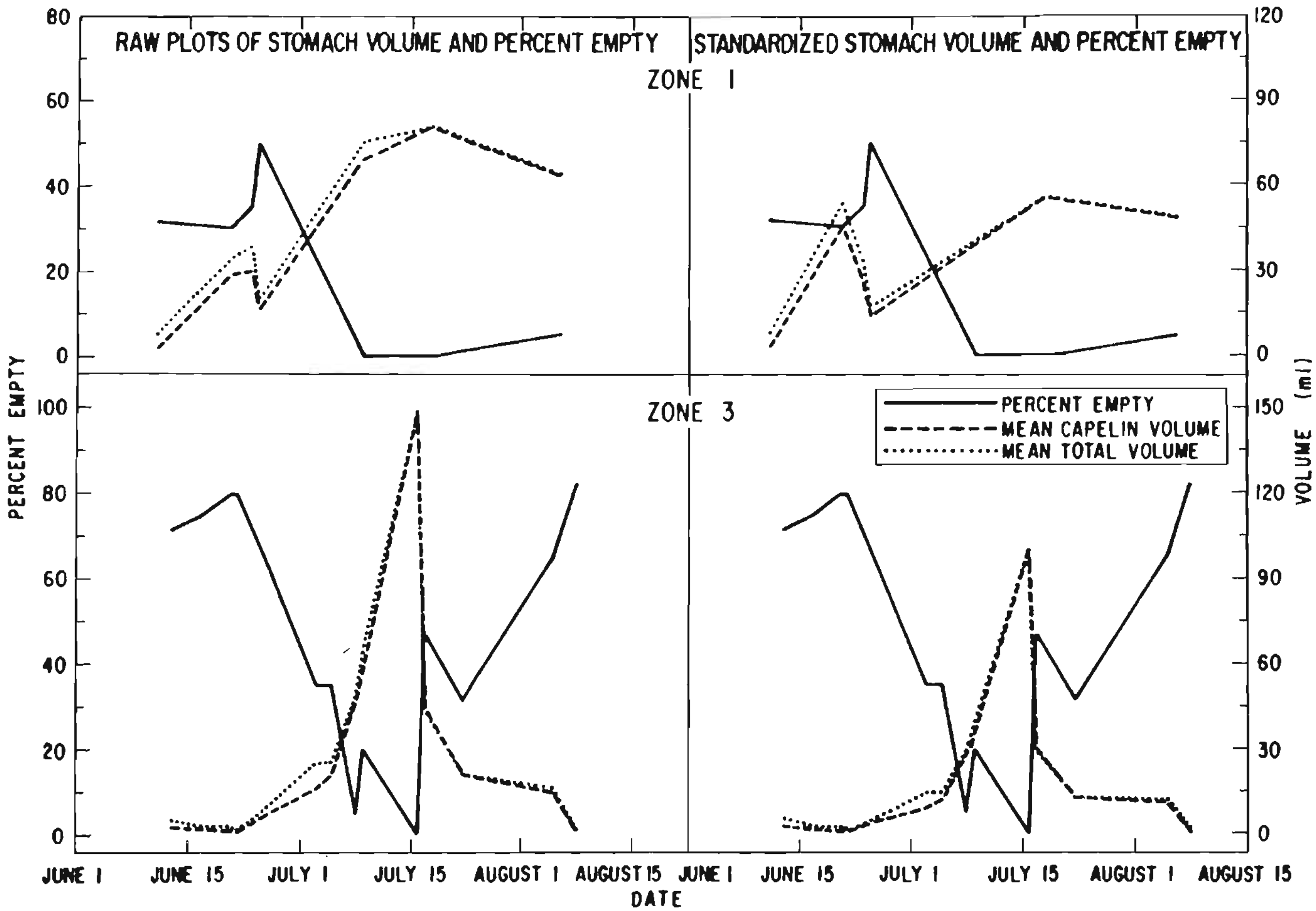

Figure 14. Percent of empty stomachs, and volumes of non-empty stomachs, for samples collected in Zone 1 (upper) and Zone 3 (lower). Note that dates of collection of stomach samples were irregular, and not the same in the two zones.

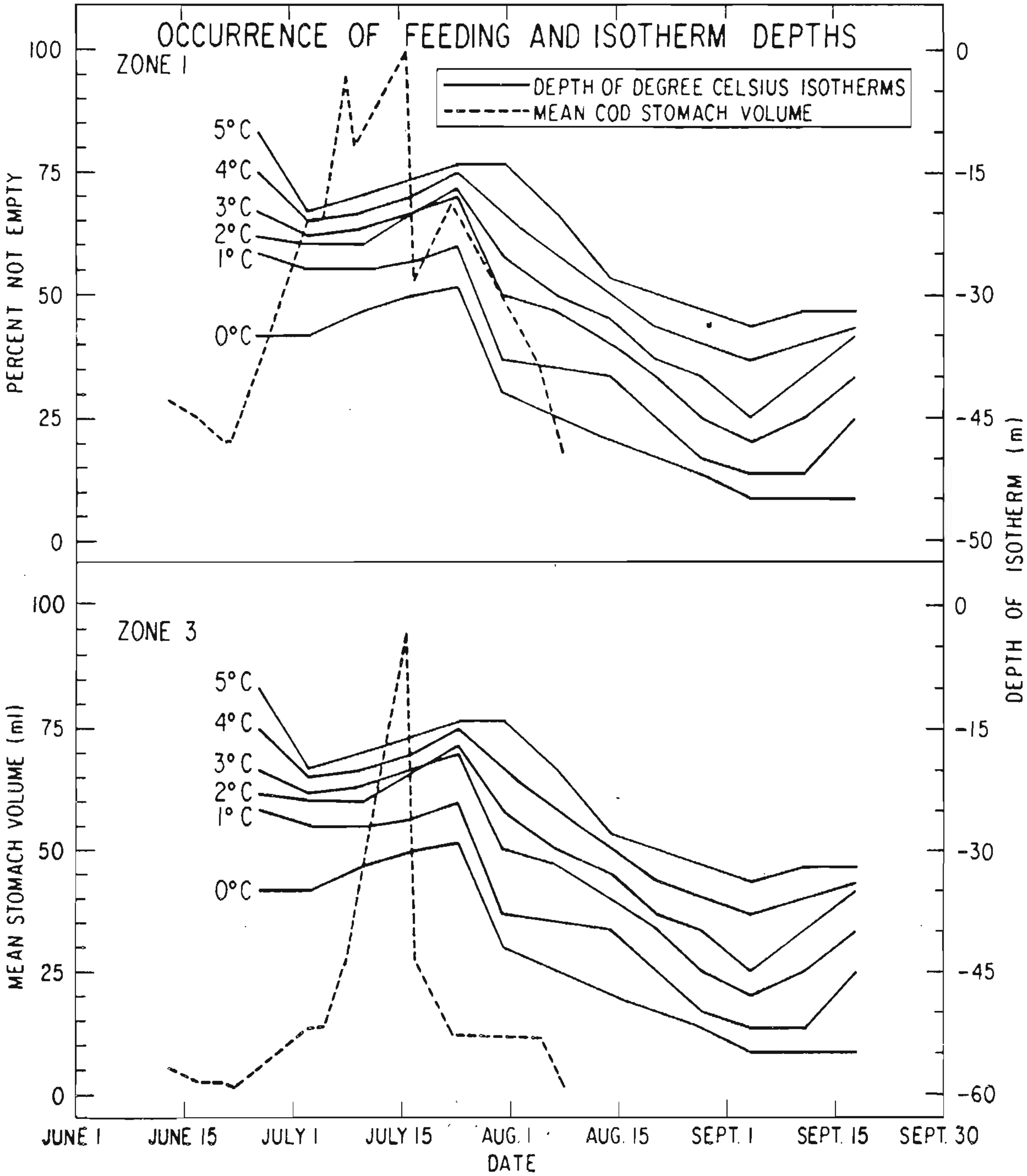

Figure 15. Percent of stomachs containing prey (usually capelin), and depth of the 0 to 5°C isotherms, from June to September, for Zone 1 (upper) and Zone 3 (lower).

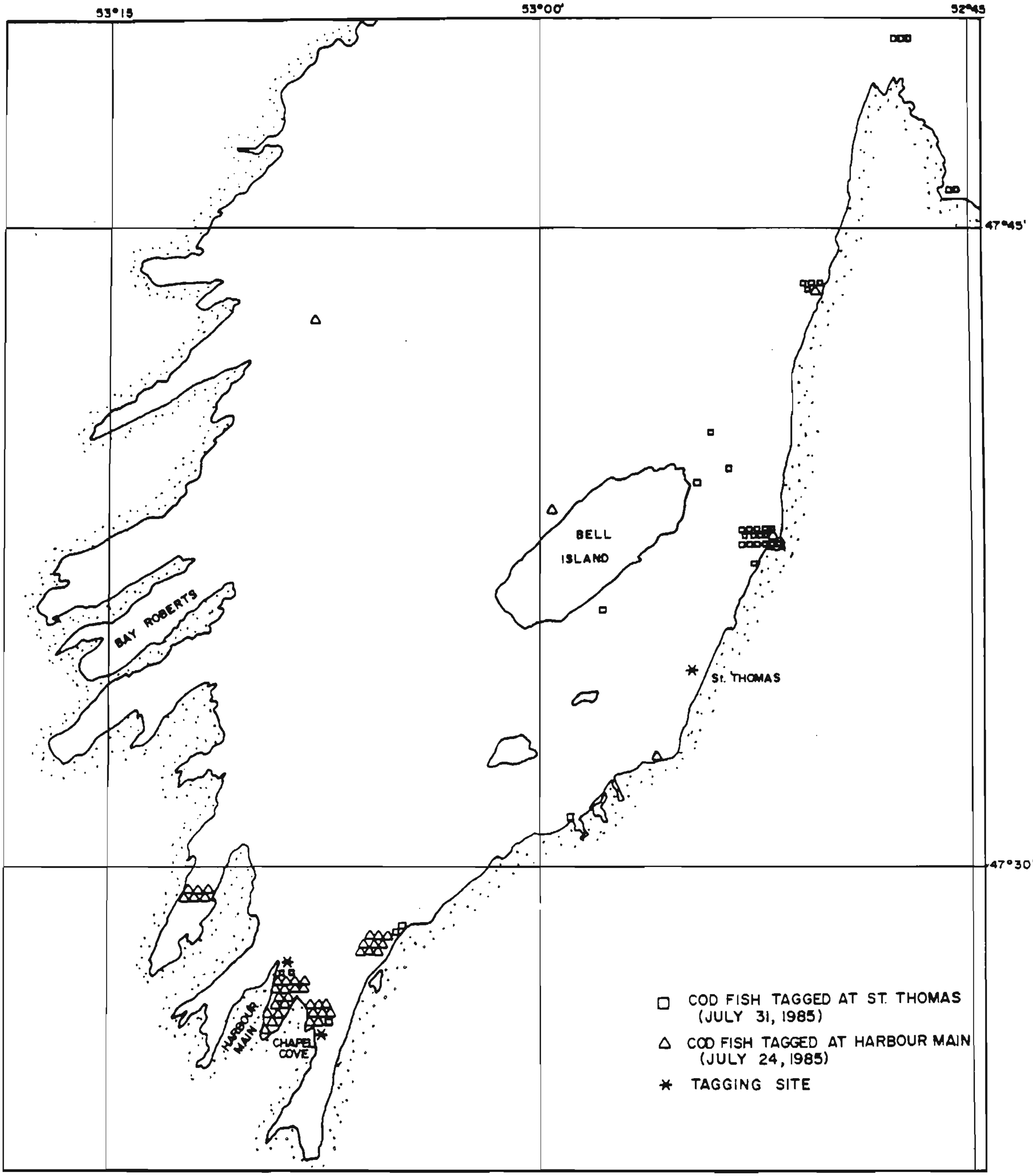

Figure 16. Tagging sites, and locations of tag recoveries, for fish tagged in Conception Bay in the summer of 1985.

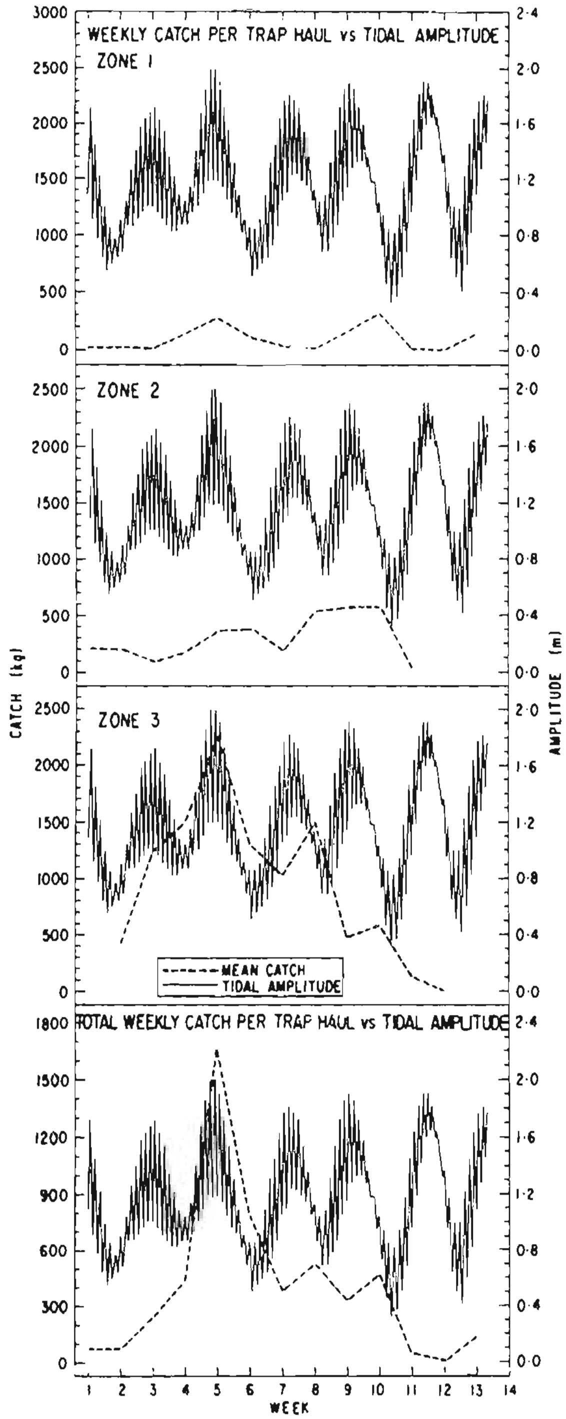

Figure 17. Weekly mean catch per trap for all zones, and daily tidal amplitude for Conception Bay in summer 1985.

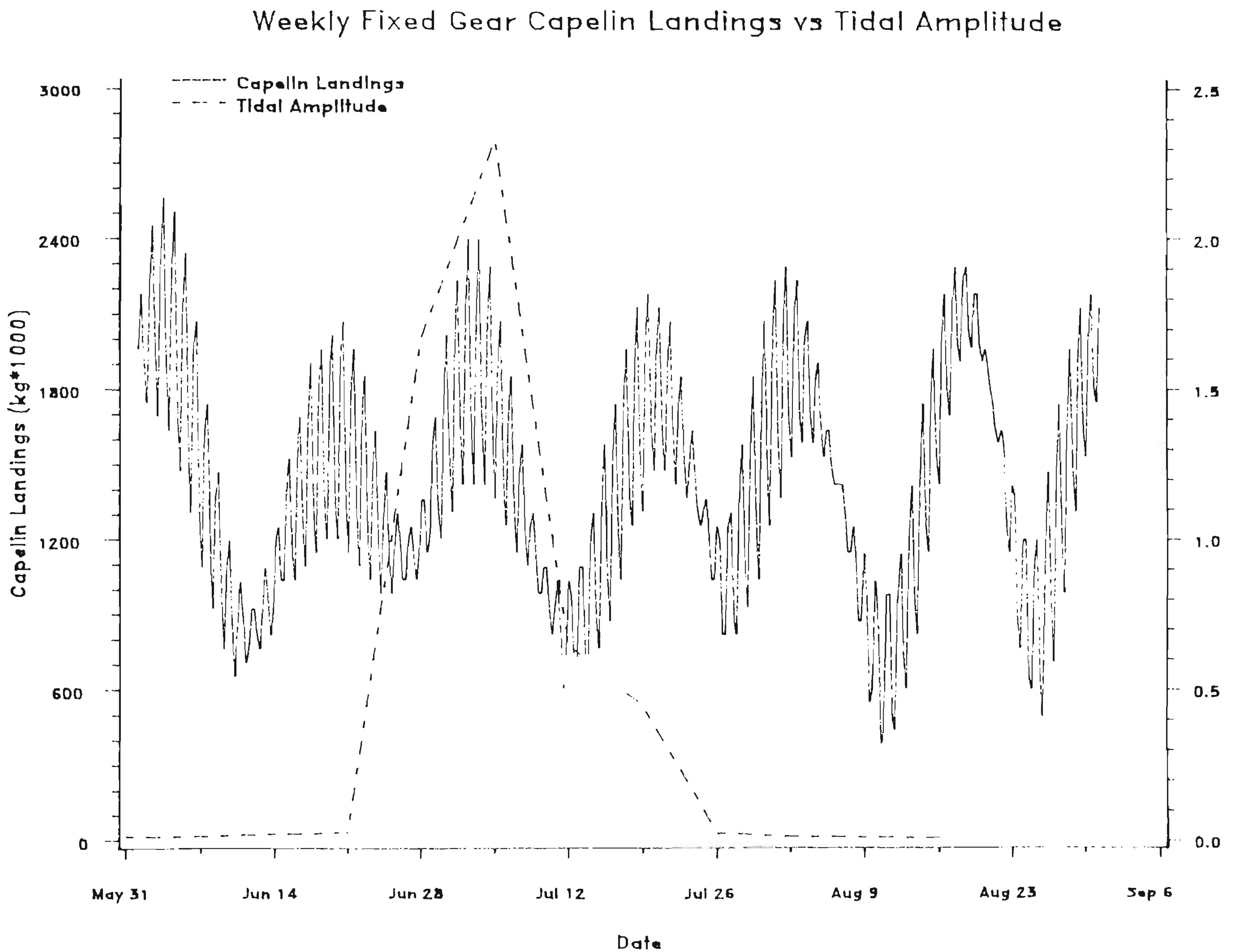

Figure 18. Weekly fixed gear capelin landings vs tidal amplitude for Conception Bay in summer of 1985.

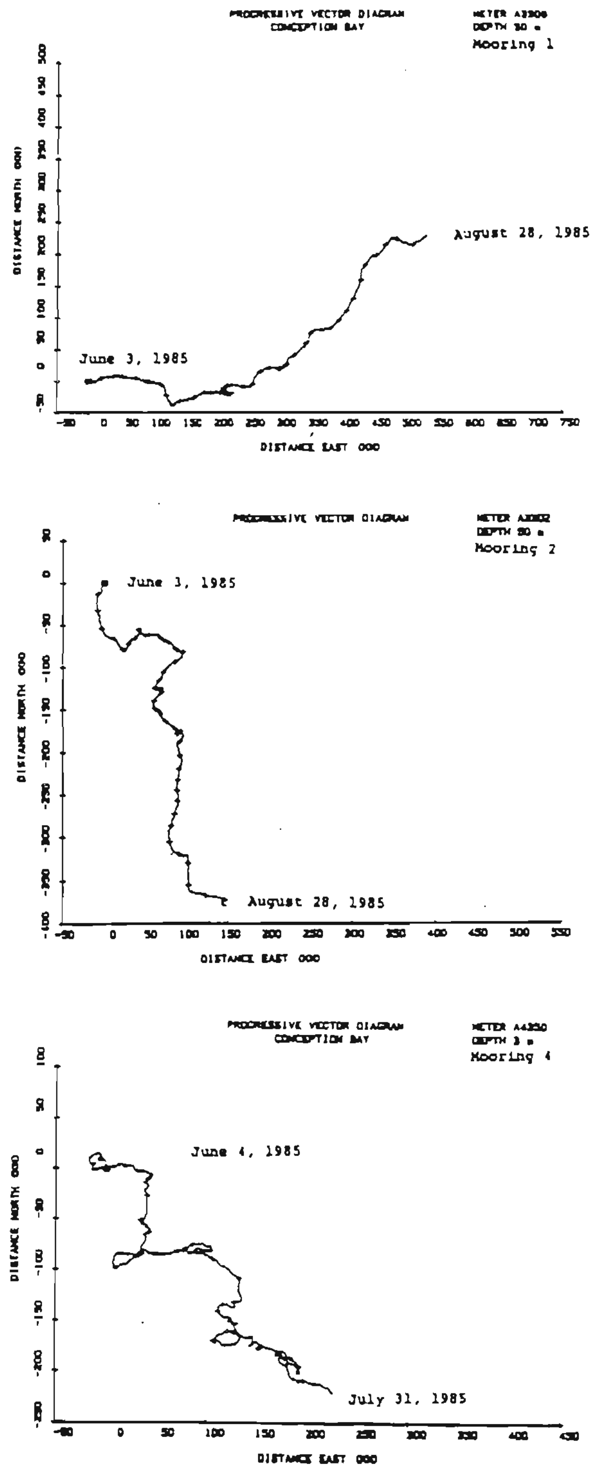

Figure 19. Progressive vector diagrams showing distance and direction a particle would travel, given the flow over the period of the recording. Hatch marks denote 2 day intervals.

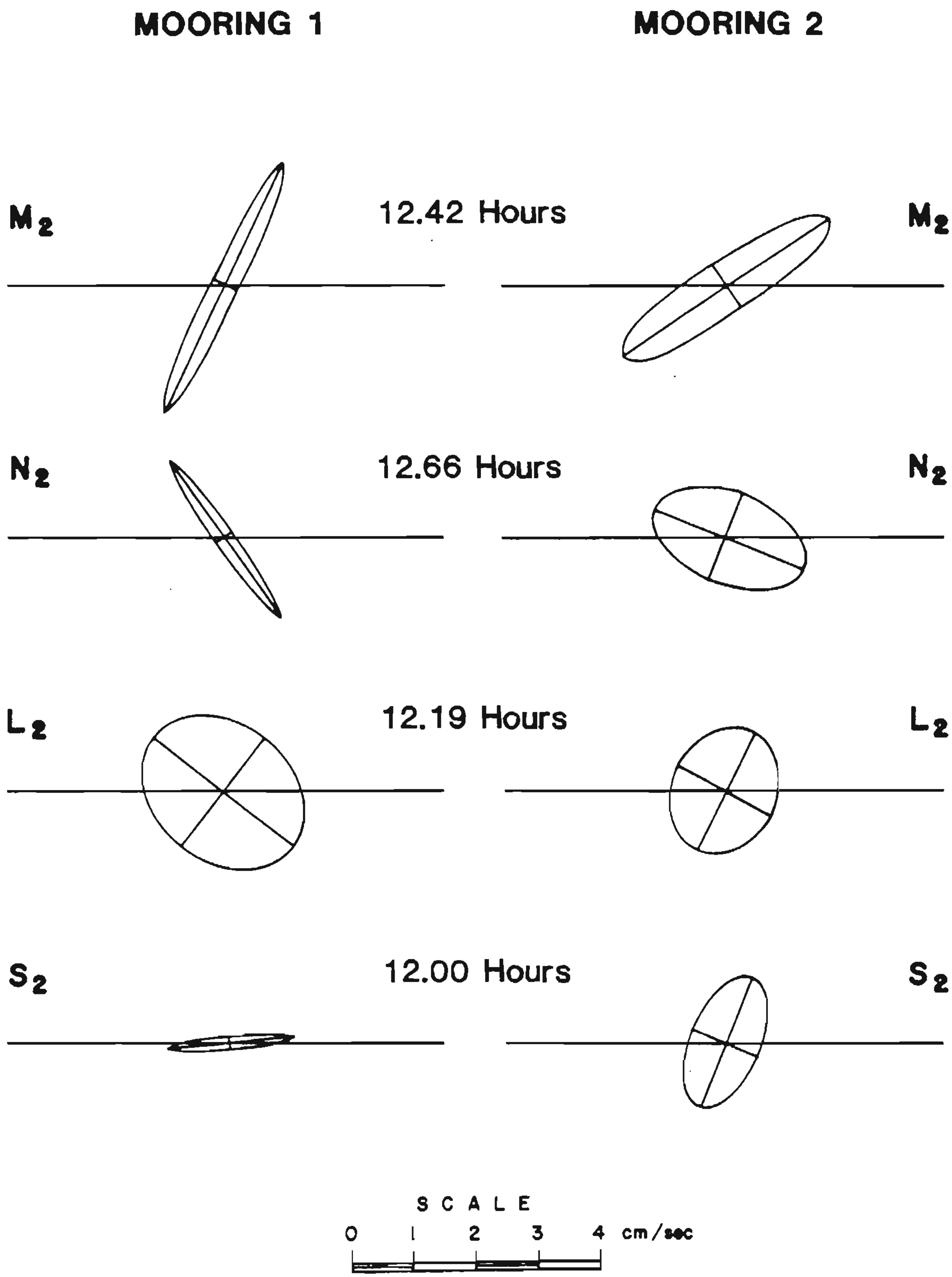

Figure 20. Tidal hodographs for currents at 50 m for Moorings 1 and 2.

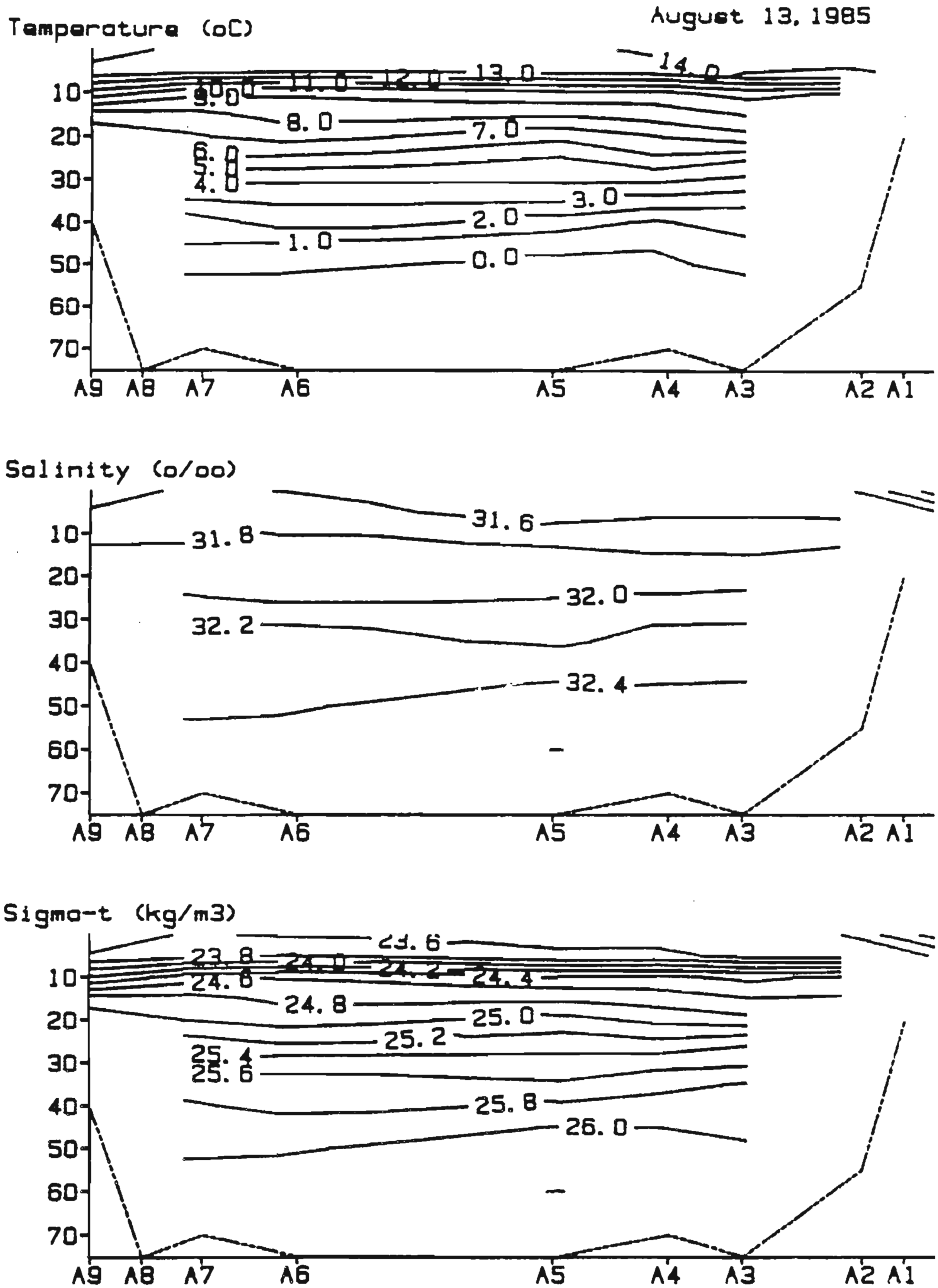

Figure 21. Temperature, salinity, and sigma-t values from CTD profiles along Transit A on August 13, 1985.

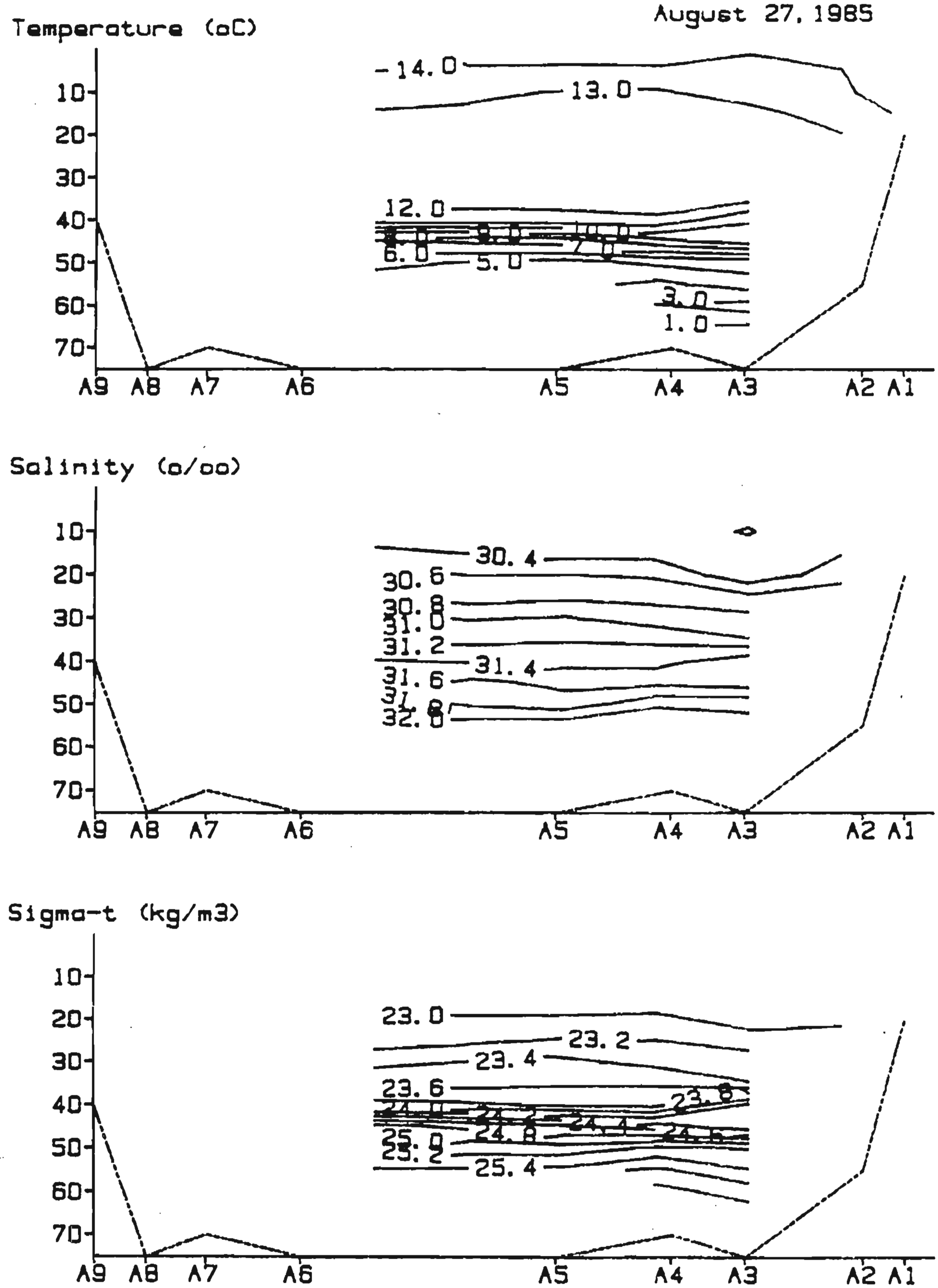

Figure 22. Temperature, salinity, and sigma-t values from CTD profiles along Transit A on August 27, 1985.

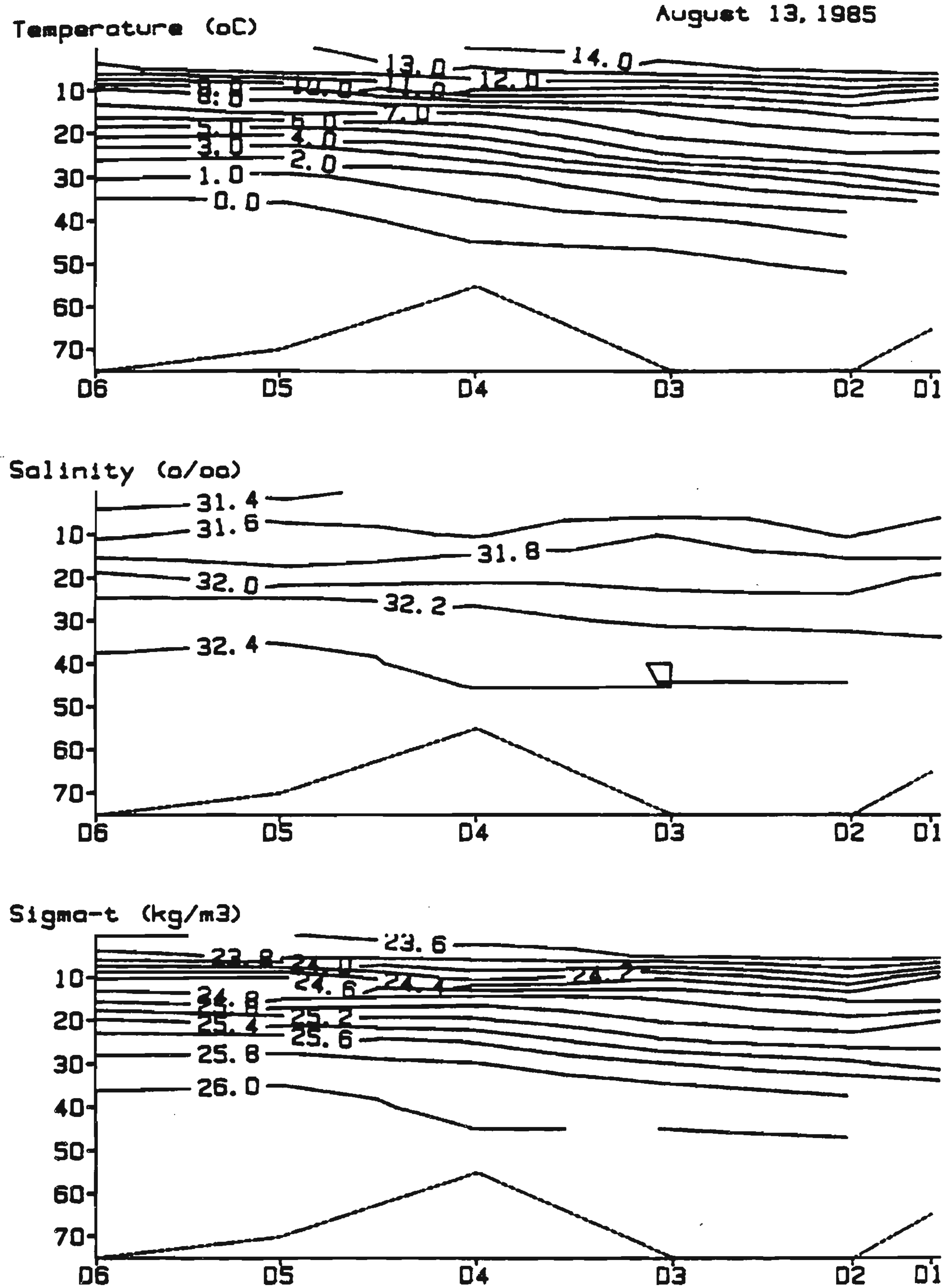

Figure 23. Temperature, salinity, and sigma-t values from CTD profiles along Transit D on August 13, 1985.

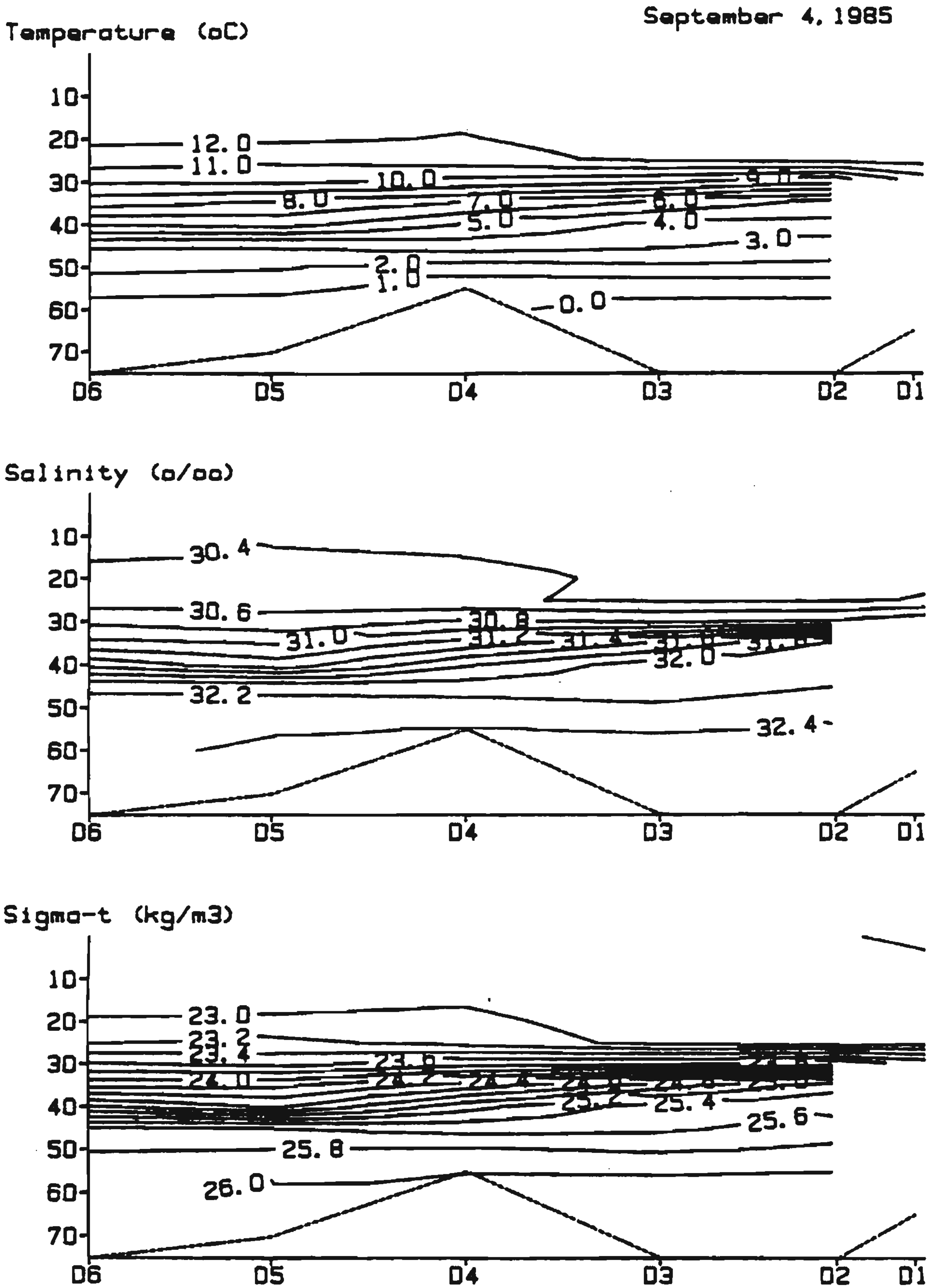

Figure 24. Temperature, salinity, and sigma-t values from CTD profiles along Transit D on September 4, 1985.

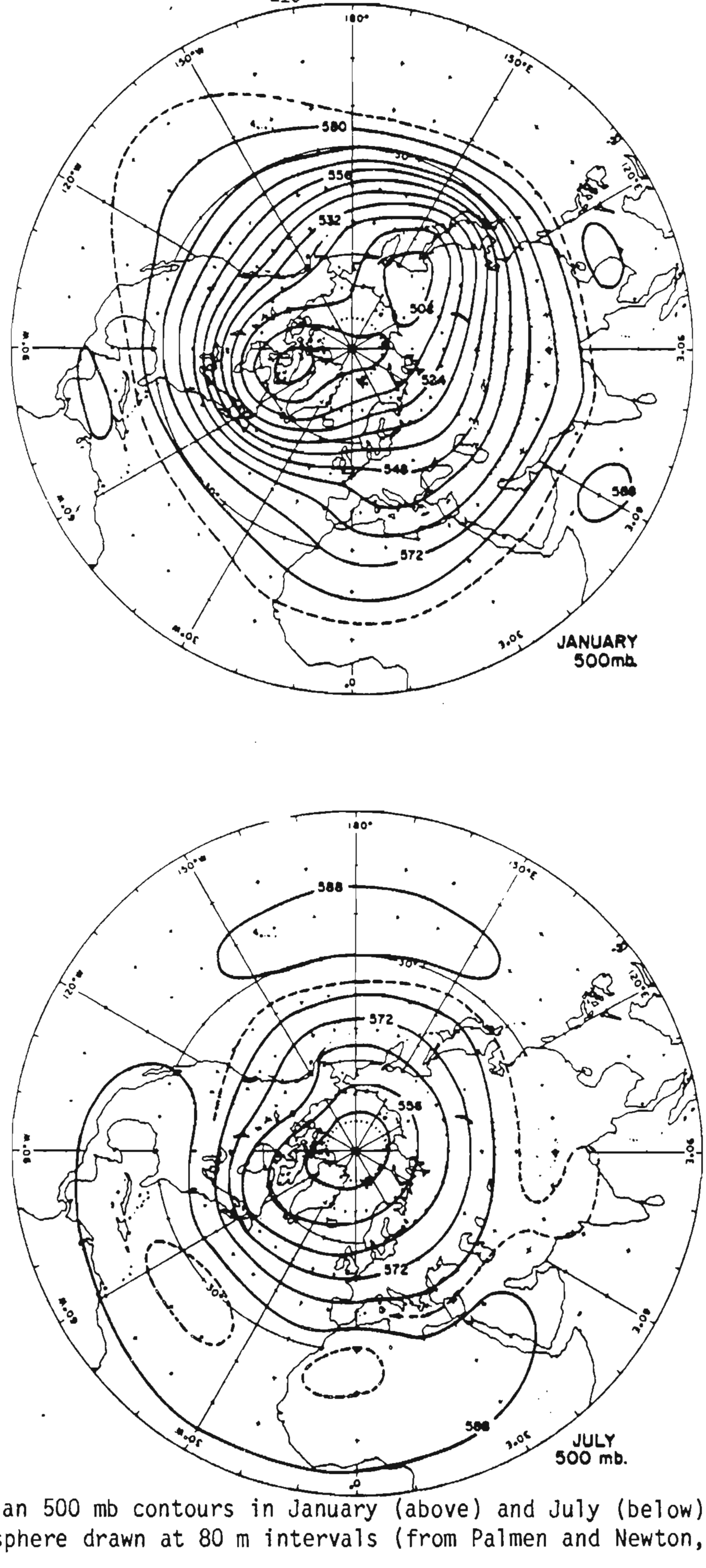

Figure 25. Mean 500 mb contours in January (above) and July (below) for the northern hemisphere drawn at 80 m intervals (from Palmen and Newton, 1969).

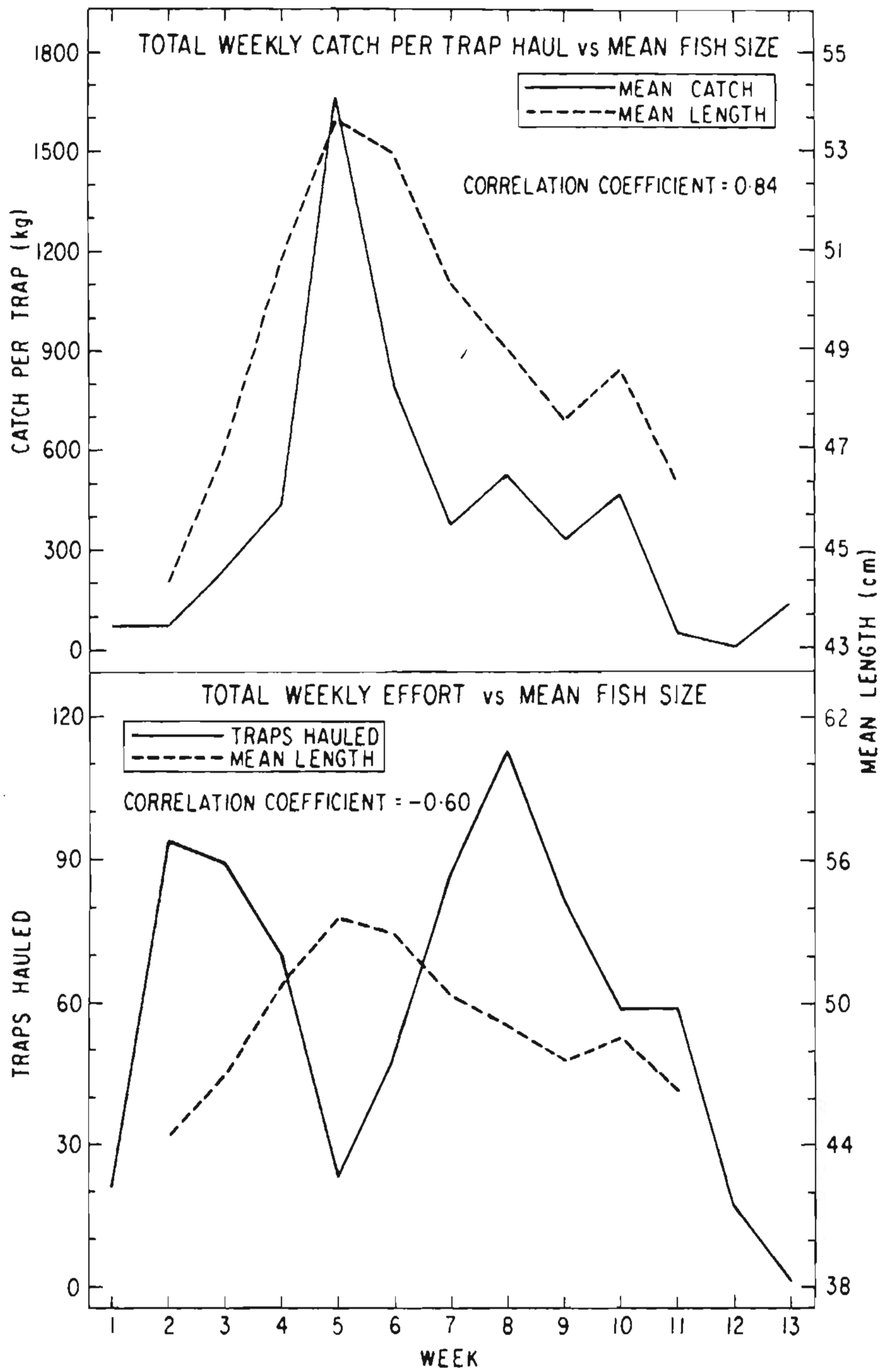

Figure 26. Mean catch per trap and mean fish size by week for Conception Bay, from early June to late August in 1985.

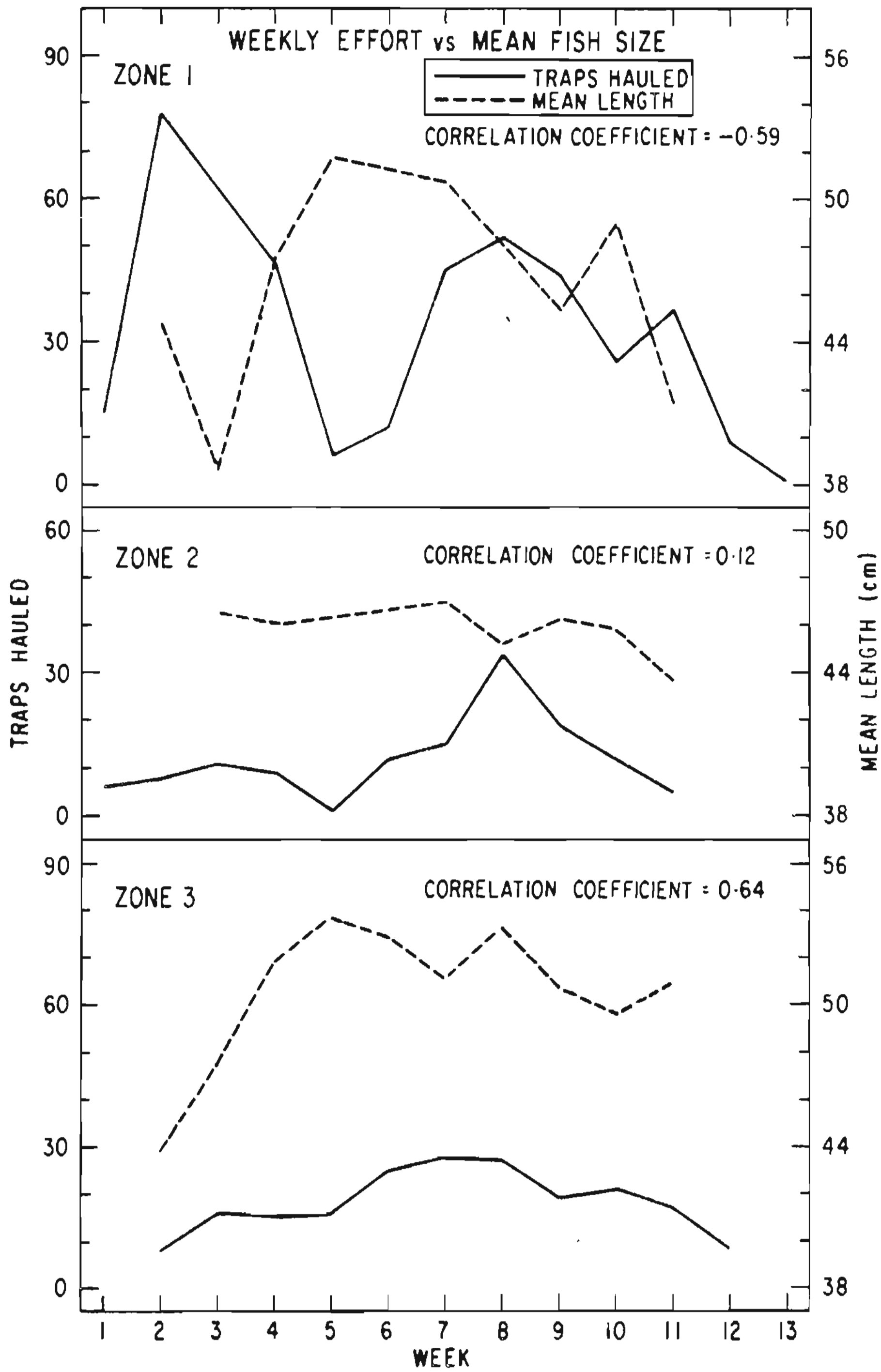

Figure 27. Weekly effort vs mean fish size for Zones 1, 2, and 3 in Conception Bay for summer of 1985.

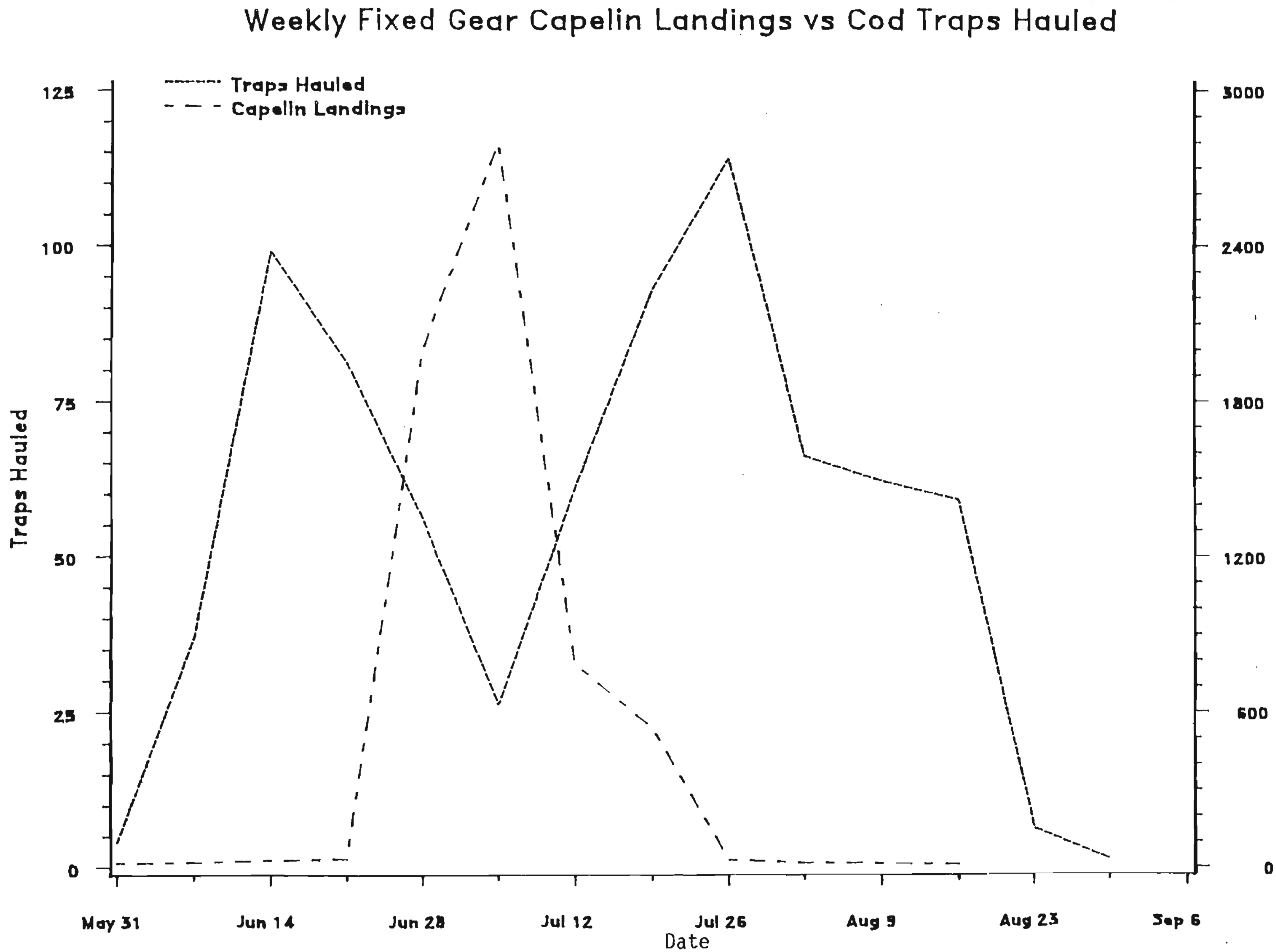

Figure 28. Landings of capelin from fixed gears, and numbers of traps hauled by week, for the study locations in 1985.

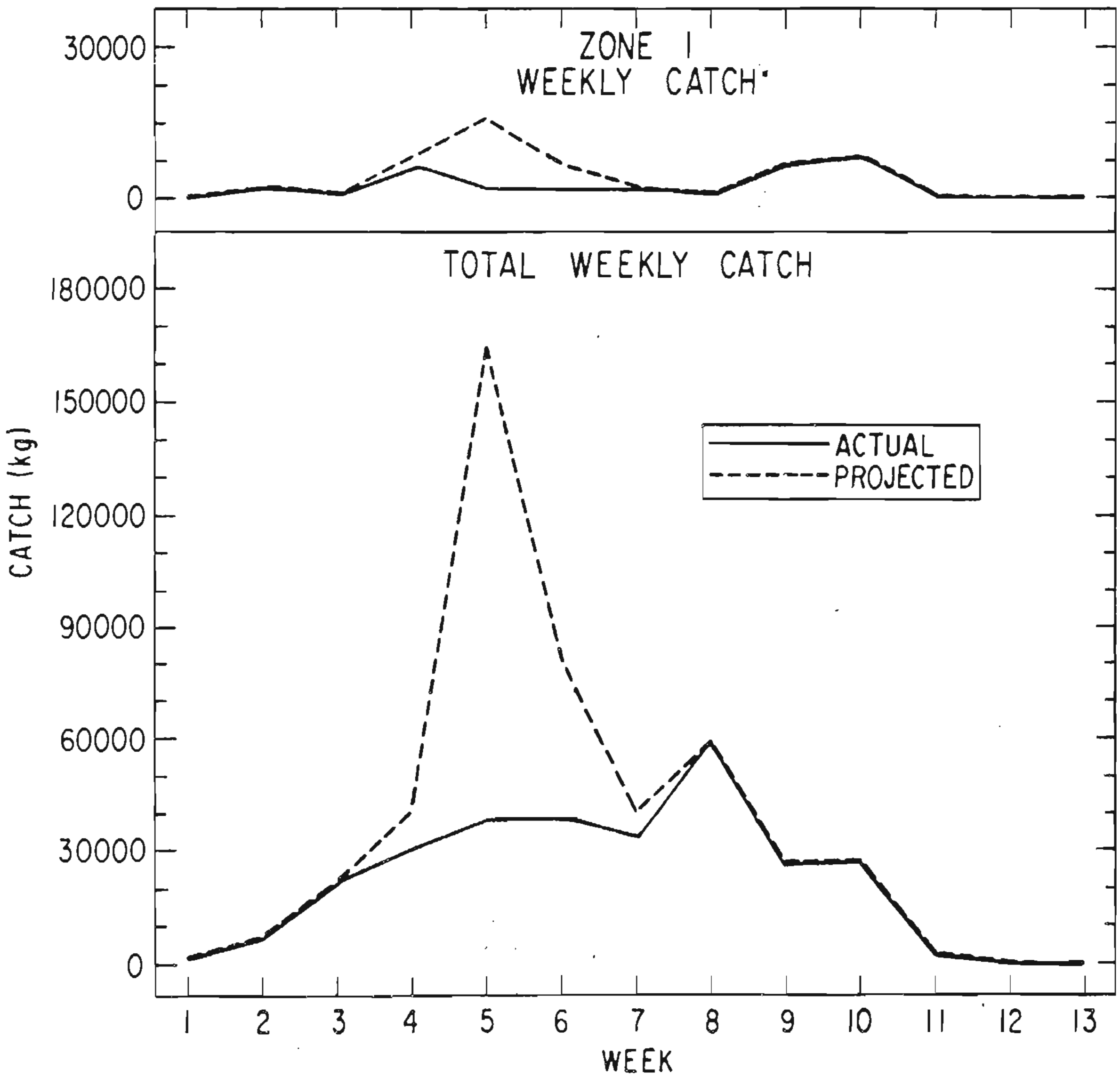

Figure 29. Weekly actual catch (kg) and catch projected if effort had shown a linear pattern from week 3 to 8 for Zone 1 (top) and for all zones (bottom).

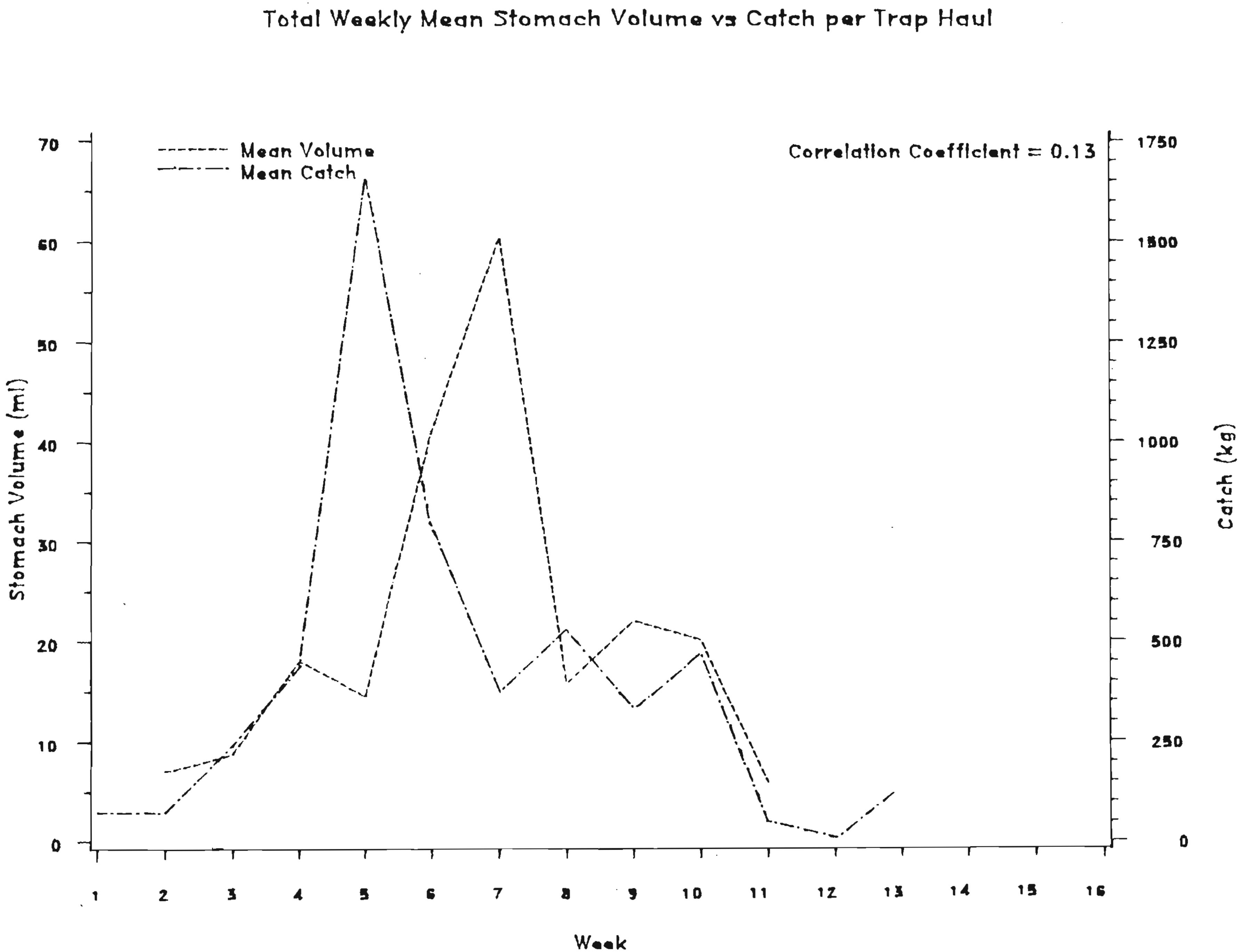

Figure 30. Weekly mean stomach volumes, and weekly mean catch per trap, across all zones from early June to late August.

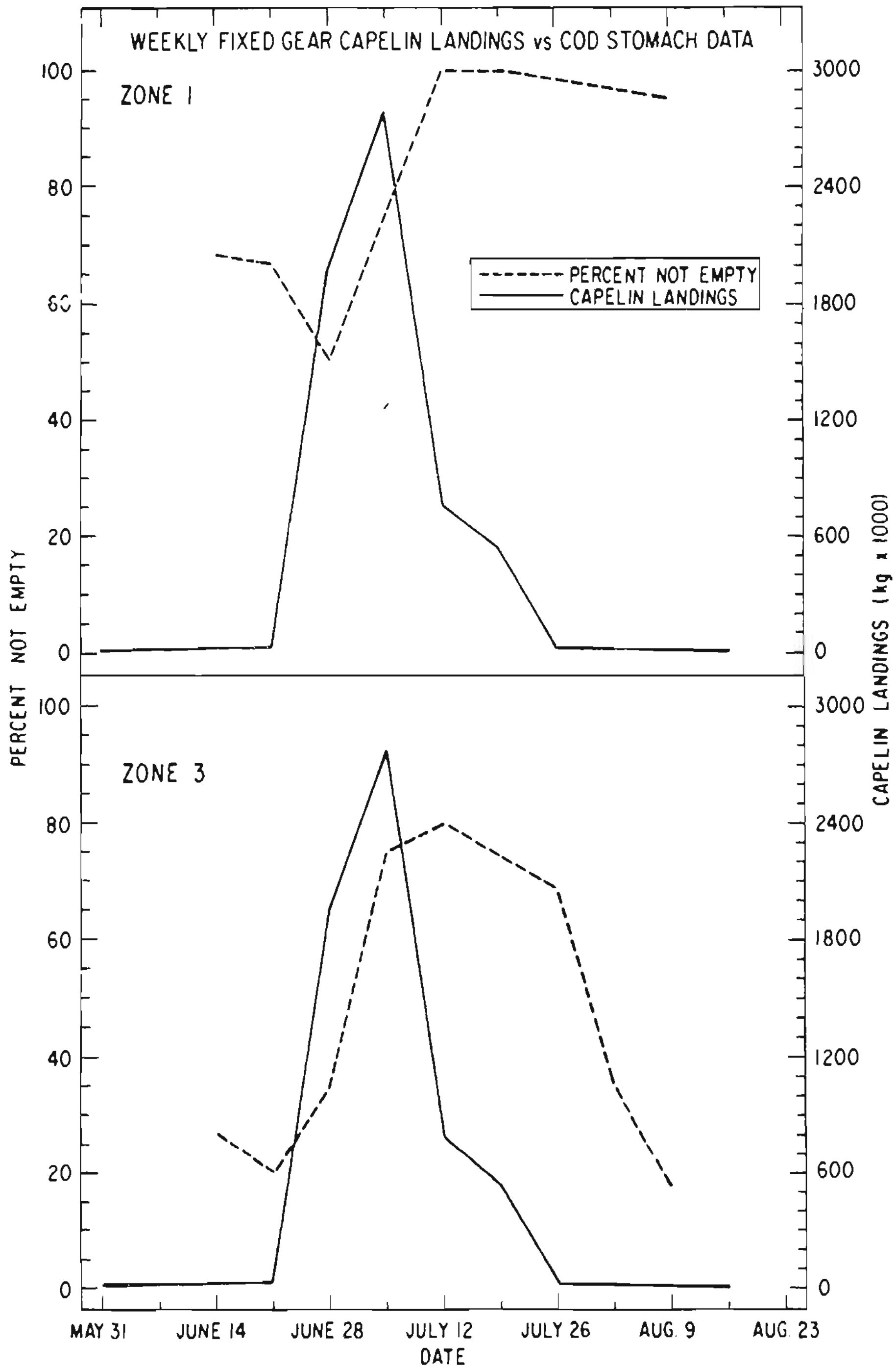

Figure 31. Percent of stomachs containing food from stomach samples taken in this study, and total capelin landings from fixed gear, by week for Zones 1 (top) and 3 (bottom).

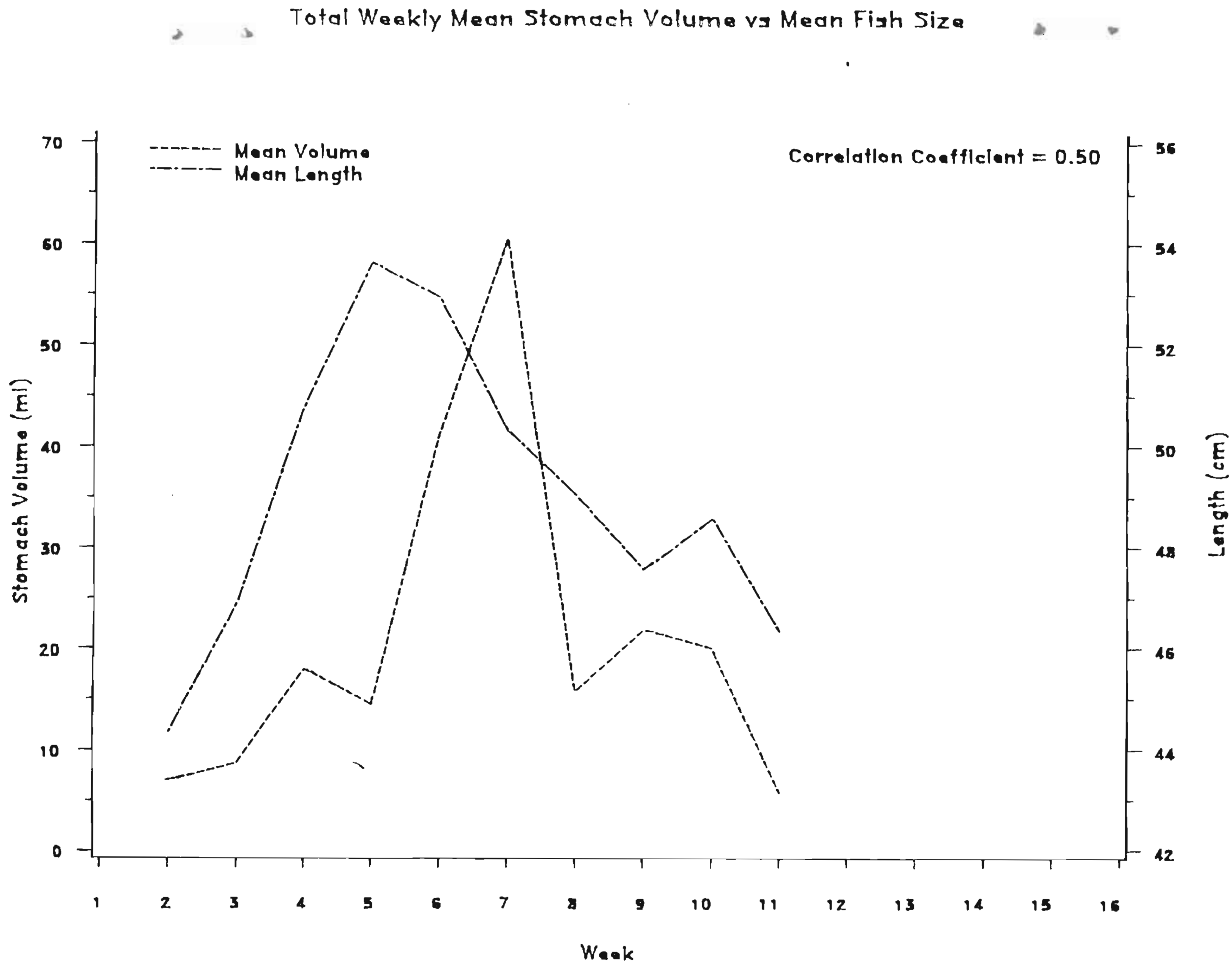

Figure 32. Weekly mean stomach volume, and mean length of fish taken in traps by week, for samples from all zones in Conception Bay.