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# Development of a hydroacoustic abundance index for mackerel in Cabot Strait

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## Abstract

During the pre-spawning migration, the Atlantic mackerel (*Scomber scombrus*) Canadian stock is concentrated in time and space in Cabot Strait, the southern entrance to the Gulf of St. Lawrence. In this document, we summarize work on the development of a temporal hydroacoustic abundance index for estimating mackerel stock size as it migrates through Cabot Strait. The hydroacoustic survey consists of repeated surveys of a single transect line using a vessel equipped with a Simrad EK-500 echosounder. Although Cabot Strait is 57 nautical miles wide, migratory activity of pelagic fish is restricted to the first 1.2 nautical mile of shallow (< 160 m deep) nearshore waters on the southern side of the strait. Herring and gaspereau also occur in this area during the mackerel migration. We found that occurrence of echoes was maximum at flood and high tides, suggesting that migratory activity is linked to the tidal cycle and that mackerel and other pelagic species use selective tidal stream transport as a migratory mechanism. Current-meters moored in Cabot Strait show that currents flow into the Gulf at flood tide and that the nearshore waters are very tidally energetic, with currents as strong as 4 knots. The effect of tides on migration will need to be taken into consideration for the estimation of mackerel swimming speed, which is a required parameter to calculate an absolute abundance index from a survey consisting of a single transect line. Various problems that need to be addressed are discussed, the most important ones being the variable duration of the migratory period and the variability of migration timing.

## Résumé

Durant la migration pré-reproductrice, le stock canadien de maquereau bleu (*Scomber scombrus*) est concentré dans le temps et l'espace dans le détroit de Cabot, l'entrée sud du golfe Saint-Laurent. Dans ce document, nous résumons les travaux accomplis visant à développer un nouvel indice d'abondance hydroacoustique du stock au moment de sa migration dans le détroit de Cabot. Le relevé hydroacoustique consiste en une série de passages au-dessus d'un même transect avec un navire équipé d'une échosondeuse EK-500 de Simrad. Bien que le détroit de Cabot ait 57 milles nautiques de largeur, l'activité migratoire des poissons pélagiques est limitée au 1.2 mille nautique d'eau peu profonde (<160 m) près de la rive sud du détroit. On retrouve aussi du hareng et du gaspareau dans cette région durant la migration du maquereau. L'occurrence des échos est maximale à marée montante et à marée haute, ce qui suggère que les poissons pélagiques utilisent le transport par courant de marée comme mécanisme de migration. Des courantomètres déployés dans le détroit de Cabot démontrent que le courant de marée entre dans le Golfe à marée montante. Des courants jusqu'à 4 noeuds ont été mesurés du côté sud du détroit. L'effet des marées sur la migration des poissons devra pris en considération pour estimer la vitesse de migration, paramètre requis pour calculer un indice d'abondance absolu à partir d'un relevé en un même endroit. Plusieurs problèmes qui doivent être résolus avant qu'un relevé utile ne soit mis sur pied sont discutés, les plus importants étant la durée variable de la période migratoire et la variabilité dans le synchronisme migratoire.

## Introduction

At the August 1988 CAFSAC Pelagic Subcommittee meeting on hydroacoustic survey design, a proposal was presented to develop an acoustic index of Atlantic mackerel (*Scomber scombrus*) stock size as mackerel enter Cabot Strait in their annual pre-spawning migration towards their spawning grounds in the southern Gulf of St. Lawrence. Commercial catch statistics in NAFO Subdivision 4Vn indicated that mackerel migration through Cabot Strait is concentrated in time. Although Cabot Strait is 57 nautical miles (nm) wide, it was hypothesized that the mackerel migration would be concentrated on the southern side of the strait, between Cape North and St. Paul Island (Fig. 1), as previous work had shown that water is warmer on the southern side of the strait at that time of the year (El-Sahb 1977).

The proposal was to develop a temporal hydroacoustic survey to assess the biomass of the Canadian mackerel stock. The survey would consist of repeated passes over a single survey line with a vessel equipped with a scientific echosounder. It was argued that the spatial distribution of the mackerel stock was too vast for a standard spatial hydroacoustic survey to be feasible. Instead of space, the sampling design would have the dimension of time, with migration period, days, and crossings of the migration channel being equivalent to distribution area, strata, and sampling units, respectively. It was pointed out at the meeting that estimation of the migration speed was necessary to derive absolute abundance index from a temporal survey.

The objectives of this document are (1) to summarize work that has been accomplished on the development of a temporal hydroacoustic abundance index for mackerel and (2) to present problems that need to be addressed before a useful abundance index can be developed.

## Literature Review on Mackerel Target Strength and Swimming Speed

### Target Strength

The absence of a swimbladder in mackerel is responsible for its low target strength. What follows are target strength (TS) values for mackerel from the literature, expressed as either decibels (dB) per fish or dB per kg:

| Authors | Freq. (kHz) | TS (dB) | Fish | method |
|---|---|---|---|---|
| a | 120 | -41.9 /fish | 16 fish<br>29-34 cm | cage, max dorsal aspect |
| b | 38 | -50.0 /kg<br>-54.4 /kg | ? | cage, daytime<br>cage, nighttime |
| c | 120 | -151.3+67log(L)<br>L=length in cm | 5 fish<br>36-43 cm | dead, wire suspended |
| d | - | -77+20log(L)<br>L=length in cm | | Best guess: 6 dB down from herring |

[a] Nakken and Olsen (1977); [b] Edwards and Armstrong (1984); [c] Rose and Leggett (1988); [d] Degnbol et al. (1988).

According to J. Simmonds (Department of Fisheries and Agriculture, Marine Laboratory, P.O. Box 101, Victoria Road, Aberdeen, AB9 8DB Scotland; pers. comm.), "Mackerel TS must be regarded as still a little uncertain. The papers by Edwards and Armstrong (1984) ... are the most comprehensive cage fish experiments." Therefore, values of -50.0 dB/kg for daytime and -54.4 dB/kg for nighttime appear to be the best estimates available. The TS change between day and night was probably due to a more pronounced tilt angle at night (Edwards and Armstrong 1984).

Swimming Speed

He and Wardle (1988) measured the maximum sustained swimming speed of mackerel in a 10-m diameter annular tank to be 3.5 body lengths per second. A typical 35 cm mackerel swimming continuously at that speed would cover 106 km per day. However this is probably exaggerated, as fish activity at Cape North appears to be affected by tides (see below). Mackerel burst swimming speeds as high as 18.5 body lengths per second have been measured (Wardle and He 1988). This represents a speed of 16 knots for a large 45 cm mackerel.

## Review of Preliminary Surveys for a Mackerel Acoustic Index

1989: CARIBOU ship of opportunity survey

The ferry MV CARIBOU was used as a ship of opportunity from May 29 to June 5, 1989, to survey transects through Cabot Strait from Sydney, Nova Scotia to Port-aux-Basques, Newfoundland (D'Amours and Castonguay 1992). The thermal structure of the strait was constructed from XBT profiles (Fig. 2) which showed warmer water on the southern side of the strait. The echos observed on the ship sounder were located on the southern side of the strait and occurred during the week of peak mackerel landings in 4Vn for that year.

1990: Purse Seiner Charter Survey Vessel

A large commercial purse seiner was chartered between May 29 and June 5, 1990 to conduct exploratory fishing and oceanographic measurements in Cabot Strait (D'Amours and Castonguay 1992). A total of four seine sets collected 45 t of mackerel and 35 t of herring (*Clupea harengus*) which were located with a 150 kHz CH-14 Furuno sonar. Mackerel were caught in water as cold as 3°C (see Fig. 2). The occurrence of mackerel 4°C colder than its previously reported lower tolerance limit indicated that the development of the 7°C isotherm is not required for the springtime appearance of this species. We argued that during the pre-spawning migration, the thermal preferences of mackerel are subordinate to the reproductive requirements.

1991: E.E. PRINCE and Chartered Seiner Acoustic Survey

A first survey with a scientific echosounder was carried out on board the CSS E.E. Prince (a 130-foot scientific trawler from DFO Scotia-Fundy) from May 29 to June 7, 1991 whose objectives were to determine the width of the mackerel migration channel, to validate echos with fishing, and to calculate a preliminary estimate of surveyed biomass. The acoustic work was carried out using a 120 kHz single beam Datasonics echosounder coupled to the Femto HDPS acquisition and analysis software. The transducer was towed in a V-fin behind the vessel at 6 knots. The transect surveyed ran from the Cape North lighthouse, Nova Scotia (Fig. 1) to the Cape Ray lighthouse, Newfoundland. As the following text table indicates (mile 0 is at Cape

North and Mile 52 is at Cape Ray), surveying effort was more intense on the Nova Scotia side of the strait. Temperature and salinity cross-sections of Cabot Strait in May/June 1991 during the migration period are presented in Fig. 3.

The following text table also shows that almost all occurrences of fish echoes were within 1.2 nautical mile (nm) of Cape North, indicating that migratory activity is restricted to nearshore waters. For example, we passed 85 times over the transect section 1.2 - 3 nm (from Cape North) but fish schools were acoustically detected only three times. This data allow us to reject the null hypothesis that fish echoes are distributed at random in Cabot Strait ($\chi^2=36.77$; $P<0.001$). In the 1.2 nm of nearshore waters, the bottom first slopes gently to about 75 m then drops off quickly to 160 m (Fig. 4).

| Part of transect (nm) | number of passes | number of passes with fish |
|---|---|---|
| 0 - 1.2 | 82 | 29 |
| 1.2 - 3 | 85 | 3 |
| 3 - 6 | 36 | 0 |
| 6 - 12 | 15 | 1 |
| 12 - 22 | 8 | 1 |
| 22 - 52 | 2 | 0 |

A 50-foot commercial vessel equipped with a mackerel purse seine was chartered to validate echoes but was successful for only two sets that were made outside the survey line. The E.E. Prince also attempted fishing with an Engel pelagic trawl but was unsuccessful. Indirect validation of echoes was provided by catches from a trap fishery that is conducted in Aspy Bay, only a few nm from the survey area (Fig. 1). Trap catches show that mackerel, herring and gaspereau (*Alosa pseudoharengus*) were present simultaneously in the study area during the survey period (Table 1), which was a typical occurrence at that time of the year (K. Fitzgerald, Aspy Bay Fisheries, P.O. Box 44, Dingwall, N.S. B0C 1G0; pers. comm.).

As pointed out above, migration speed through Cabot Strait should be estimated in order to integrate biomass measured on the transects. On June 6 and 7, 1991, surveying effort was concentrated in the 0 - 3 nm section of the transect. The following text table shows that occurrence of echoes was almost exclusively at flood and high tide. Tide tables from Bay St. Lawrence, located 3 nm from Cape North, were used.

The null hypothesis that schools occur regardless of the tidal cycle is rejected ($\chi^2=8.17$; $P<0.05$), indicating that, at least at Cape North, the pelagic species synchronize their migratory activity with the tidal cycle. Hence, tidal cycle probably affects migratory speed which, as pointed out before, must be incorporated in the development of an absolute abundance index.

| Part of tidal cycle | number of passes | number of passes with fish |
|---|---|---|
| Low (±1.5 hour) | 11 | 1 |
| Flood | 14 | 7 |
| High (±1.5 hour) | 11 | 8 |
| Ebb | 9 | 1 |

On the basis of the above evidence, we hypothesized that the pelagic species exhibit selective tidal stream transport (STST) to enter the Gulf of St. Lawrence. STST is a migration mechanism by which fish synchronize their vertical movements in the water column to the tidal streams to achieve transport (reviewed by Arnold 1984). The essential features of STST are that fish leave bottom at or shortly after slack water, are carried downstream for the duration of the transporting tide and return to the bottom at the next slack water, remaining there for the duration of the opposing tide. STST has been shown to be energetically advantageous (Weihs 1978) and authors have also argued that it lessens the need for precise orientation on the part of the fish. If confirmed, this would be a first report of STST in pelagic fishes. STST has been previously reported in plaice, sole, cod, dogfish, and eels.

1992: F.G. CREED and CALANUS II Acoustic Survey (May 28 - June 8)

Because migratory activity at Cape North is very much concentrated in the nearshore area, acoustic surveying needs to be carried out with a vessel smaller than the E.E. Prince which could get closer to shore than a large vessel could. The CSS F.G. CREED, a 66-foot scientific SWATH (small waterplane area twin hull) vessel, was identified for future acoustic assessment work by DFO-Québec.

The 1992 cruise had three major objectives:

1) Produce a surveyed biomass estimate for mackerel using TS information from the literature and echo validation with a pelagic trawl.

2) Determine whether mackerel use selective tidal stream transport with acoustic sampling scheduled according to tides, current-meter information, and individual fish ultrasonic tracking with depth-sensitive ultrasonic transmitters.

3) Determine where mackerel leave the shores of Cape Breton to cross the Gulf of St. Lawrence on their way to the spawning sites. The comparison of monthly commercial catches (all fishing gears pooled) from Aspy Bay and Chéticamp (Fig. 1) illustrates this point well as it shows that mackerel are not caught on the Gulf coast of Cape Breton Island during their pre-spawning migration (Table 2).

An acoustic survey was carried out on board the F.G. CREED from May 28 to June 8, 1992 in the nearshore area (0 - 3 nm) with a newly acquired 120 kHz 7° split beam Simrad EK-500 echosounder which was coupled to the HDPS acquisition and analysis software which runs on a DOS based personal computer. The transducer was in a tow fish installed between the ship's twin hulls. Immediately prior to the cruise, a ball calibration of the system had been performed. The echosounder was used in single beam mode. While we could not get closer than 1 nm to shore with the E.E. PRINCE in 1991, we were able to survey as close as 0.3 nm with the F.G. CREED in 1992. However the vessels were restricted to a 12-hour per day schedule.

The lack of success with echo validation by the small charter seiner and by the E.E. Prince in 1991 prompted the development of a mackerel pelagic trawl suitable for the CALANUS II, a 65-foot scientific trawler from the DFO-Québec fleet. The trawl, built by NORDSEA, was tested in Cabot Strait in June 1992 and in Chaleur Bay in August 1992.

Unfortunately, 1992 was an odd year for many fish stocks in Atlantic Canada, including mackerel, which had never been so late in reaching the tip of Cape Breton (K. Fitzgerald, Aspy

Bay Fisheries, P.O. Box 44, Dingwall, N.S. B0C 1G0; pers. comm.; Table 1). Oceanographic conditions in the nearshore area for that year are presented in Fig. 5. Sea temperatures nearshore in 1992 (Fig. 5a) were about the same as in 1991 (Fig. 3a) and in 1990 (Fig. 1c), years for which migration timing was normal. Because of the unusual migration timing in 1992, very little mackerel biomass was surveyed and no echoes were validated at Cape North, although four successful trawl sets were made outside the survey area. The cruise was a technical success: the trawl appeared to fish properly although it caught few fish (four sets caught 1.5 t of pelagic fish, mostly herring) and the EK-500/HDPS system performed satisfactorily using a preamp gain of 30 dB. However, we could not meet the scientific objectives.

Two moorings with two current-meters each were set for two weeks during the survey period. Due to high velocities of currents near Cape North, current-meters were not moored properly and only 30 % of the data were valid. This scanty data nevertheless show that currents flow into the gulf at flood tide (a prerequisite for selective tidal transport to operate here) and that the nearshore waters around Cape North are very tidally energetic, with currents as strong as 4 knots.

1992: F.G. CREED and CALANUS II Trials (August 20 - 24)

Further trawl trials were conducted on board the CALANUS in Chaleur Bay from 20 to 24 August 1992 with a SCANMAR net positioning system rented from NORDSEA. Seventeen sets for which we had echoes were made, which caught 9 t of mackerel and 4 t of herring (Beaulieu et al. 1993). Two thirds of herring catches were made at night. Mackerel were larger on average in daytime than at night, suggesting that visual net avoidance by faster swimming larger mackerel was not a problem. These trials provided our first direct validation of echoes with catches. To our knowledge, this is the first time in North America that mackerel were caught with a pelagic trawl rigged on a small vessel.

Individual fish tracking was also carried out during the August 1992 cruise. Individual mackerel > 35 cm were captured with barbless hooks and were placed in a MS-222/seawater solution. After two minutes in the solution, a previously calibrated Vemco depth-sensitive transmitter was inserted into the fish stomach. The fish was then gently returned to the sea. The whole procedure lasted less than five minutes. The transmitters, 62 mm long by 16 mm diameter, powered by silver oxide batteries, operate on frequencies from 66 to 77 kHz and weigh 9.8 g in seawater.

Two of the three tagged mackerel appeared to survive the procedure well. The other one expired quickly on the sea bottom. We were not able to follow either of the two survivors for more that one hour. M. Greer Walker (Ministry of Agriculture, Fisheries and Food, Fisheries Lab, Lowestoft, Suffolk NR33 0HT England; pers. comm) informed us that he has made some unpublished attempts at tracking mackerel in the past, but was largely unsuccessful. He believes that for schooling species, the signal from the transmitter is attenuated by surrounding fish in the school. This brings into question the feasibility of the tracking method we are trying to develop to estimate swimming speed.

1993: Upcoming F.G. CREED and CALANUS Acoustic Survey

The objectives of the 1993 survey will be the same as last year (as they were not met). As opposed to 1992, the echosounder will operate in split beam mode and the transducer will be hull-mounted. The cruise will start a week later than in previous years, on June 4, instead of

May 28/29. Three moorings with two current-meters each will be deployed in Cabot Strait, 1, 3, and 6 nm from Cape North from June to October 1993.

In order to provide additional, although indirect echo validation, Mr. Fitzgerald's trap catches in Aspy Bay (Fig. 1) will be monitored intensively with daily random samples of 50 mackerel and length frequencies of 250 mackerel, herring, and gaspereau for the duration of the mackerel migratory period.

## Problems that need to be addressed

### Migratory speed

In order to derive an absolute abundance index from a temporal survey (similar to extrapolation in spatial surveys), estimation of the migratory speed is necessary to calculate the distance that the mackerel surveyed in a given day covered for that day. Individual ultrasonic fish tracking may not be possible with schooling species because of signal attenuation produced from surrounding individuals in the school. Although literature values could be used, it would be best to develop swimming speed estimates specific for mackerel in Cabot Strait. If individual fish tracking proves not to be feasible, other means might have to be devised to accomplish this (e.g. either directly through acoustics or indirectly using commercial trap catches at other sites in Nova Scotia).

Alternatively, the abundance index could be used as a relative one by focussing on interannual variations of surveyed mackerel biomass without extrapolating using the swimming speed. The advantage of using the index in this manner is that we would not need to incorporate the imprecise swimming speed parameter into the calculation of the index.

### Variable duration of the migratory period

Although the beginning of migration, as determined from Dingwall trap catches, varies little from year to year, the duration of the migratory period does varies substantially, from 12 to 51 days (Table 3; Fig. 6). Obviously, in most years the survey cannot cover the whole migration period. One way to address this problem would be to calculate a relationship between Aspy Bay trap catches per day and amount of biomass acoustically surveyed at Cape North per day that could be used to estimate biomass for the part of the migration period not covered by the survey. Furthermore, a relative abundance index could be calculated from Aspy Bay trap catches using the multiplicative model (Gavaris 1980) which could be scaled up to an absolute abundance index using this hydroacoustic survey.

### Migration timing

A fundamental aspect of this survey is precise migration timing. Although the timing, as indicated by commercial trap catches, seems very precise in most years (Table 3), this was not the case in 1992. If poor timing occurs more commonly than expected, we will have to question the usefulness of the survey.

Echo validation

Echo validation is of utmost importance in a multispecific environment such as ours, where the species of interest has a much lower backscatter than the other species present. We were successful in developing a pelagic trawl that can catch mackerel and herring and gaspereau. The commercial traps in nearby Aspy Bay provide a backup echo validation, although an indirect one. Preliminary echo analysis based on target strength indicates that although most schools appear to be monospecific, multispecific schools sometimes occur. However, species within such schools are arranged in discrete layers, which makes possible echogram edition in preparation for echointegration. Therefore, we believe that we have the capability to resolve the echoes by species.

Target strength

According to J. Simmonds (Department of Fisheries and Agriculture, Marine Laboratory, P.O. Box 101, Victoria Road, Aberdeen, AB9 8DB Scotland; pers. comm.), mackerel TS is still somewhat uncertain. To our knowledge, no laboratory is currently working on this subject. Data collected with our split beam echosounder in 1993 may allow calculation of representative *in situ* mackerel TS.

S.A. Iversen (Institute of Marine Research, P.O. Box 1870, N-5024, Bergen, Norway; pers. comm.) stated that "due to distribution, behavior and the fact that our mackerel are lacking swimbladder, the traditional acoustic method is for the time being not considered appropriate and therefore little experiments have been carried out." With our temporal survey, we may have an advantage over the Norwegians regarding distribution, but we share with them the lack of swimbladder problem.

Assessing immature fish biomass

Grégoire (1992) determined that mackerel caught in Aspy Bay traps were smaller and younger towards the end of the migratory period. Hence, the proportion of immature fish probably also increases. This raises the question of whether or not this survey should assess immature biomass. We suggest that the survey should address only the estimation of spawning biomass. Proper fish sampling should allow the estimation of the proportion of mature biomass entering the Gulf during the survey period. This would make this index consistent with the other index for this stock, the egg production index, which only estimates spawning biomass.

## Conclusion

We have presented a progress report of work completed toward developing a temporal acoustic survey for mackerel as it migrates through a narrow corridor during the prespawning migration. We have also discussed problems that need to be addressed before a useful biomass index can be developed. The validation, target strength, and immature fish problems should not prove too difficult to solve. Interactive analysis of trap catches and hydroacoustic survey data may permit addressing the more difficult issue of estimating mackerel biomass for the part of the migratory period outside of the survey. Once that accomplished, a relative abundance index could be developed. If a proper estimate of migratory speed can be measured, an absolute abundance index could then be calculated. Such an index, either relative or absolute, will represent a first example of a temporal hydroacoustic survey at sea. To our knowledge, there is no other such example in the literature.

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Table 1. Commercial trap catches in Aspy Bay during the acoustic survey period in 1991 and 1992.

| | | Weight (kg) | |
|---|---|---|---|
| Date | Species | 1991 | 1992 |
| May 29 | mackerel | | 2100 |
| | gaspereau | 3000 | 20000 |
| May 30 | gaspereau | 9000 | 0 |
| May 31 | mackerel | 24300 | 3600 |
| | gaspereau | 7000 | 4500 |
| June 1 | mackerel | 34500 | 900 |
| | herring | | 1400 |
| June 2 | mackerel | 21400 | 0 |
| June 3 | mackerel | 43900 | 3400 |
| | gaspereau | 3500 | |
| | herring | 8000 | |
| June 4 | mackerel | 17800 | 2300 |
| | gaspereau | 5700 | 500 |
| | herring | 5700 | |
| June 5 | mackerel | 11000 | 19000 |
| | gaspereau | 11000 | |
| | herring | 11000 | |
| June 6 | mackerel | no fishing | 3200 |
| June 7 | mackerel | 24000 | no fishing |
| | herring | 6800 | |
| June 8 | mackerel | 13000 | 25500 |

Table 2. Comparison of monthly commercial catches (t): Chéticamp (left) versus Dingwall (right).

| | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|
| April | 0/0 | 0/0 | 0/0 | 0/0 | 0/0 |
| May | 0/156.3 | 0/57.5 | 0/49.1 | 0/0 | 0/24.4 |
| June | 0/111.5 | 0.5/54.9 | 0/141.5 | 0/144.1 | 0/305.4 |
| July | 4.5/4.5 | 2.1/2.4 | 7.3/0 | 10.2/15.2 | 18.2/43.2 |
| August | 10.5/0 | 15.7/0 | 3.1/0 | 11.1/0 | 2.0/0 |
| September | 9.1/0 | 18.7/0 | 19.0/0 | 23.6/0 | 18.7/0 |
| October | 14.4/0 | 2.5/0 | 8.0/0 | 9.9/0 | 34.5/0 |
| November | 0.01/0 | 4.8/0 | 0/0 | 0/0 | 0/0 |

Table 3. Descriptive statistics of the mackerel trap fishery conducted each year in Aspy Bay, near the survey area. Dates are expressed as day and month.

| Year | Start date | End date | Duration 95% (days) | Median date | Date 50% | Duration 50% (days) | Catch (t) |
|---|---|---|---|---|---|---|---|
| 1983 | 30-05 | 05-07 | 37 | 17-06 | 22-06 | 23 | 270.8 |
| 1984 | 26-05 | 26-06 | 32 | 11-06 | 01-06 | 5 | 297.5 |
| 1985 | 28-05 | 22-06 | 26 | 10-06 | 31-05 | 4 | 200.9 |
| 1986 | 24-05 | 17-06 | 25 | 05-06 | 02-06 | 9 | 202.4 |
| 1987 | 25-05 | 05-06 | 12 | 31-05 | 30-05 | 5 | 272.3 |
| 1988 | 24-05 | 24-06 | 32 | 09-06 | 29-05 | 5 | 114.7 |
| 1989 | 24-05 | 07-06 | 15 | 31-05 | 02-06 | 9 | 141.6 |
| 1990 | 01-06 | 03-07 | 33 | 17-06 | 12-06 | 9 | 159.3 |
| 1991 | 30-05 | 05-07 | 37 | 17-06 | 11-06 | 10 | 373.0 |
| 1992 | 29-05 | 18-07 | 51 | 22-06 | 12-06 | 14 | 254.5 |

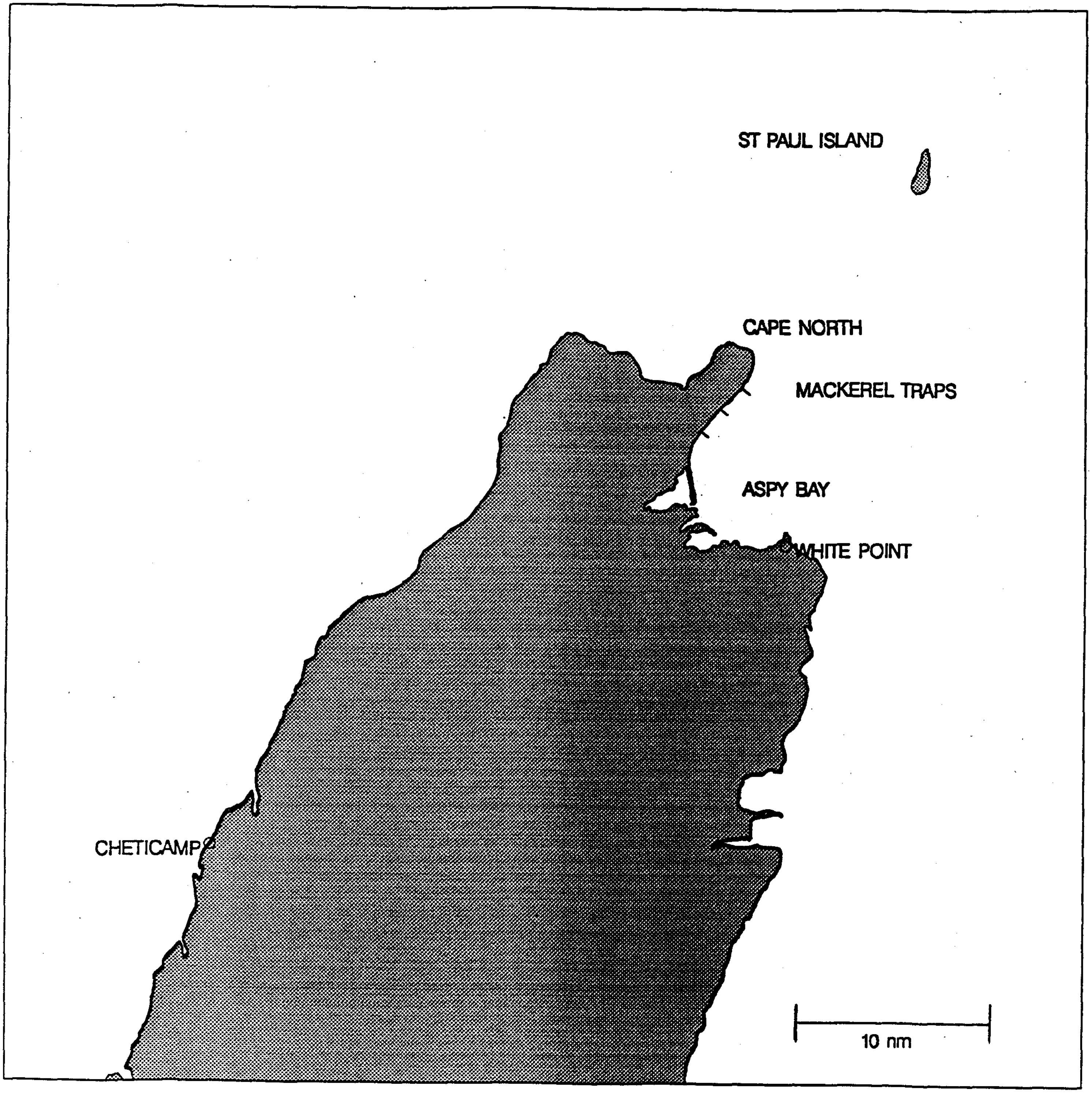


Figure 1. Map of study area showing the tip of Cape Breton Islans and southern Cabot Strait which separate the Atlantic Ocean to the east from the Gulf of St.Lawrence to the west. The transect line surveyed is located between Cape North and St.Paul Island.

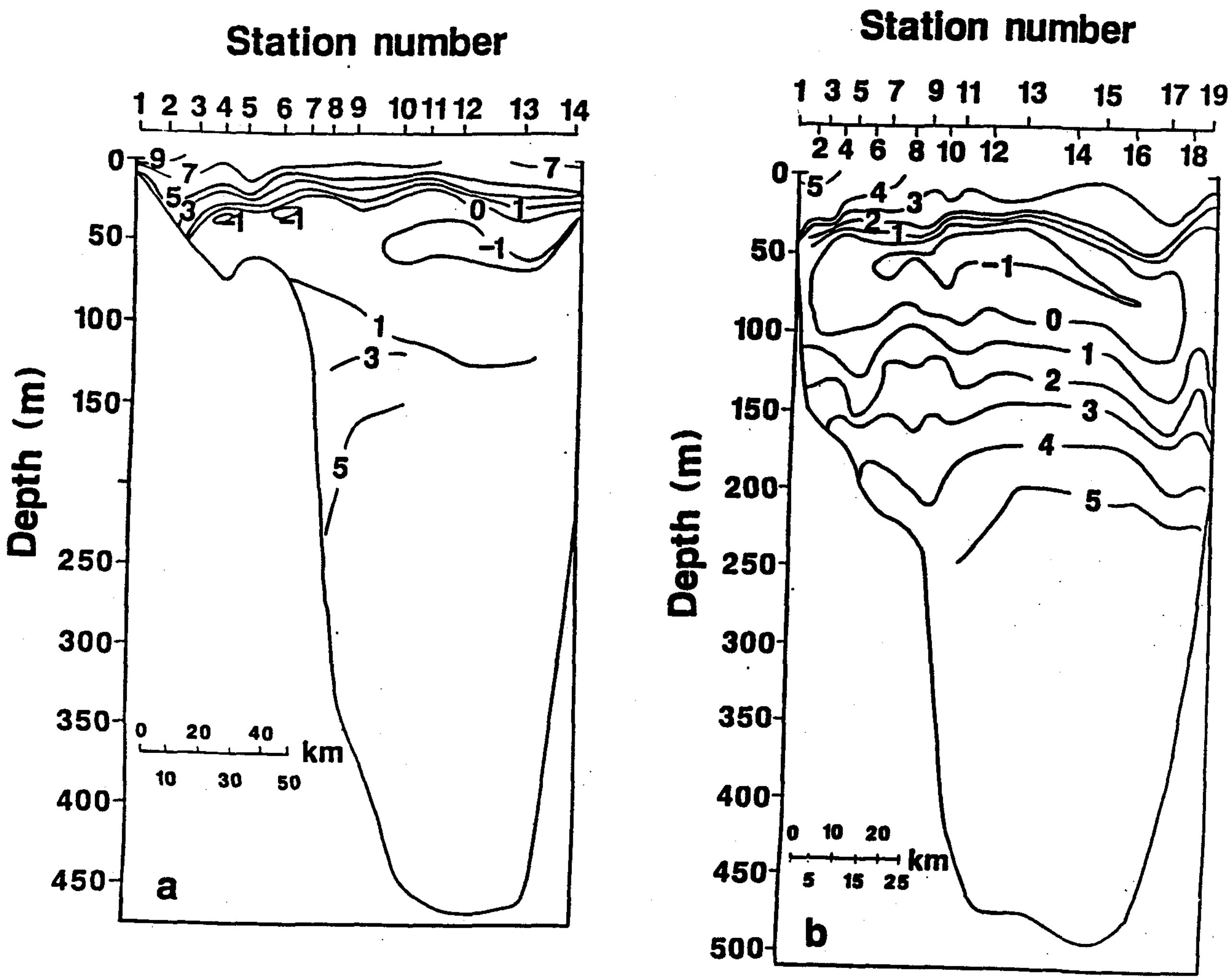


Figure 2. Temperature profiles across Cabot Strait on June 2, 1989 (a), and on June 2, 1990 (b). The Figure is reproduced from D'Amours and Castonguay (1992).

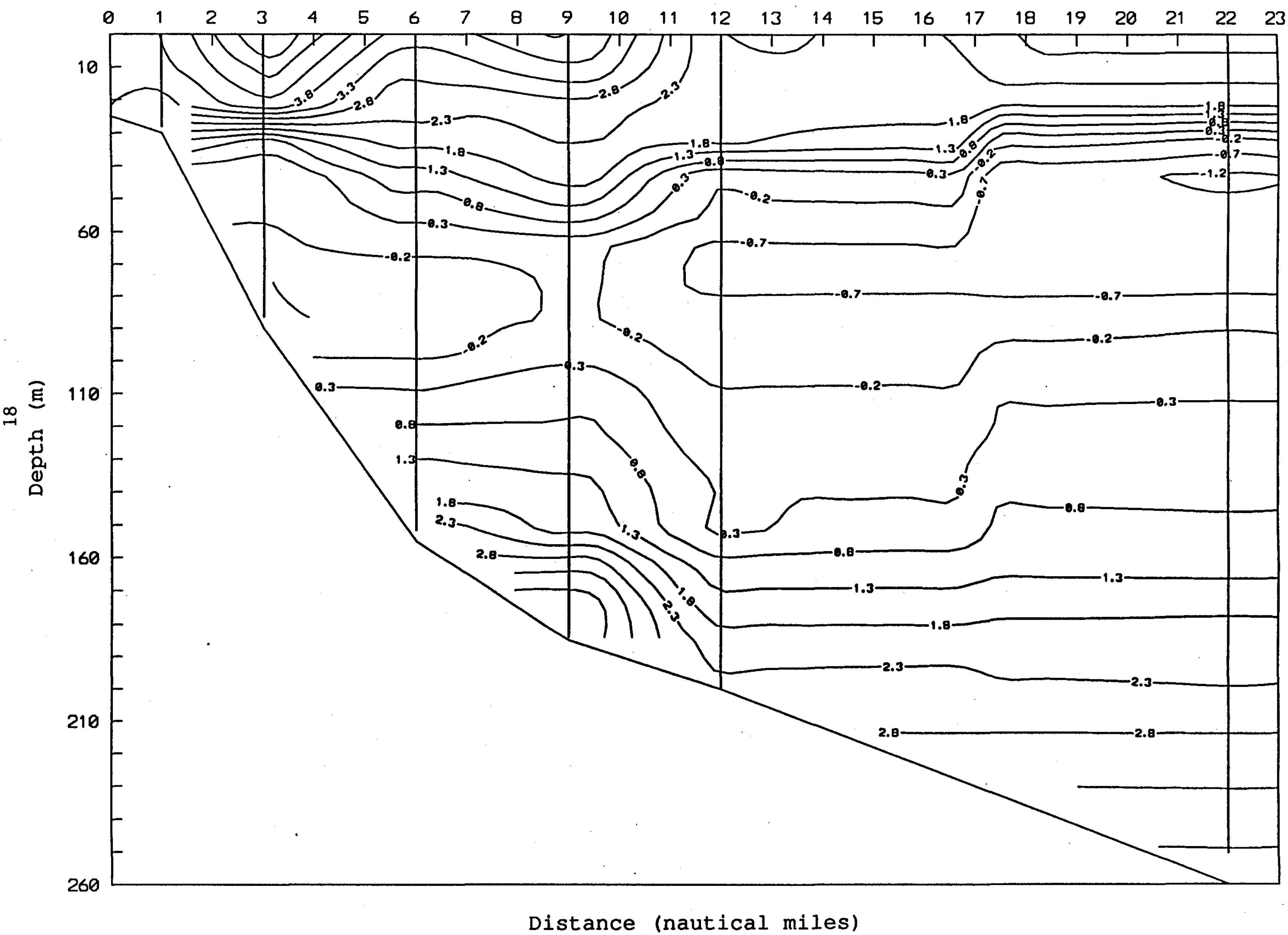


Figure 3a. Temperature profiles across the southern half of Cabot Strait of May 29, 1991.

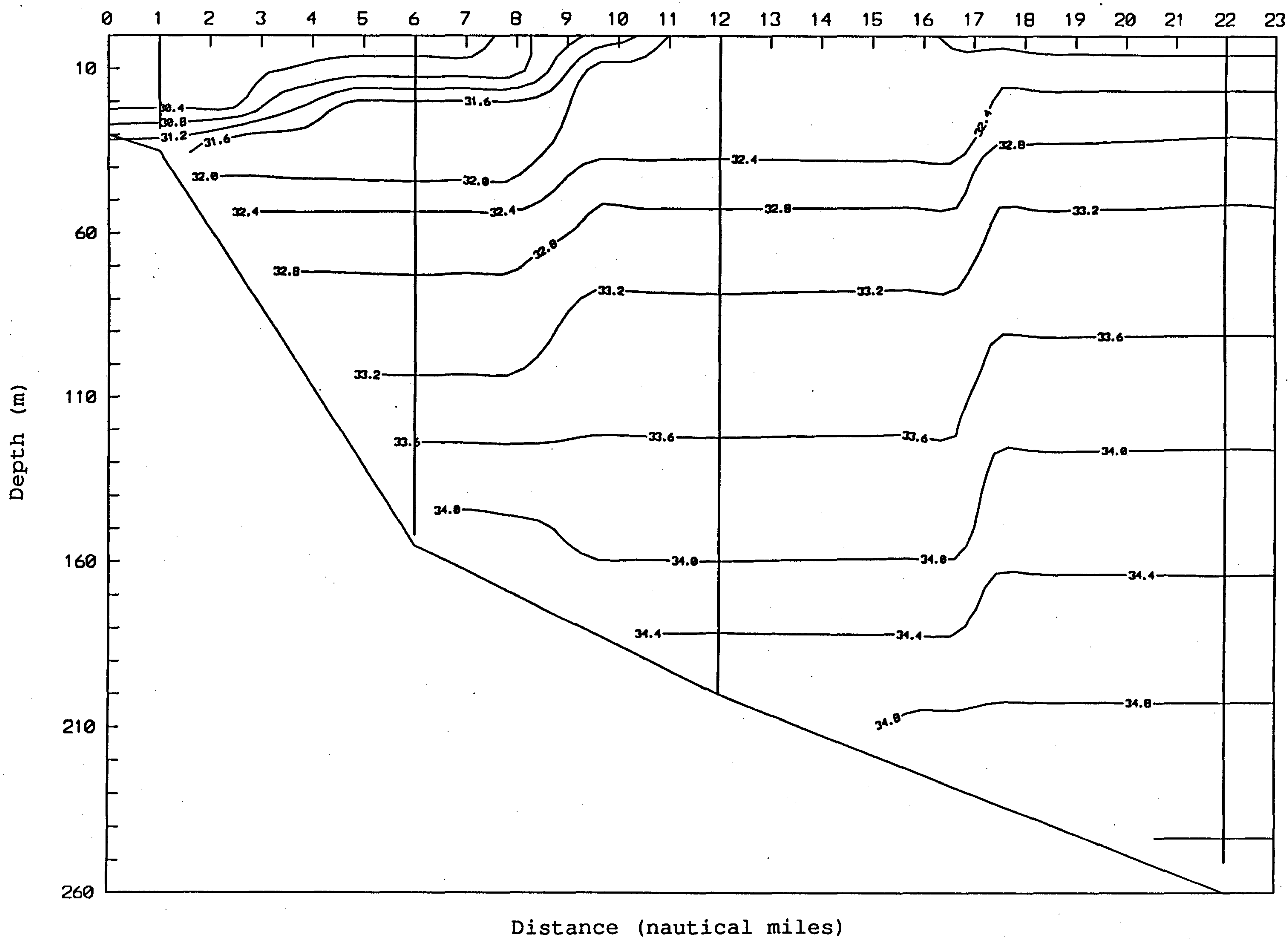


Figure 3b. Salinity profiles across the southern half of Cabot Strait on May 29, 1991.

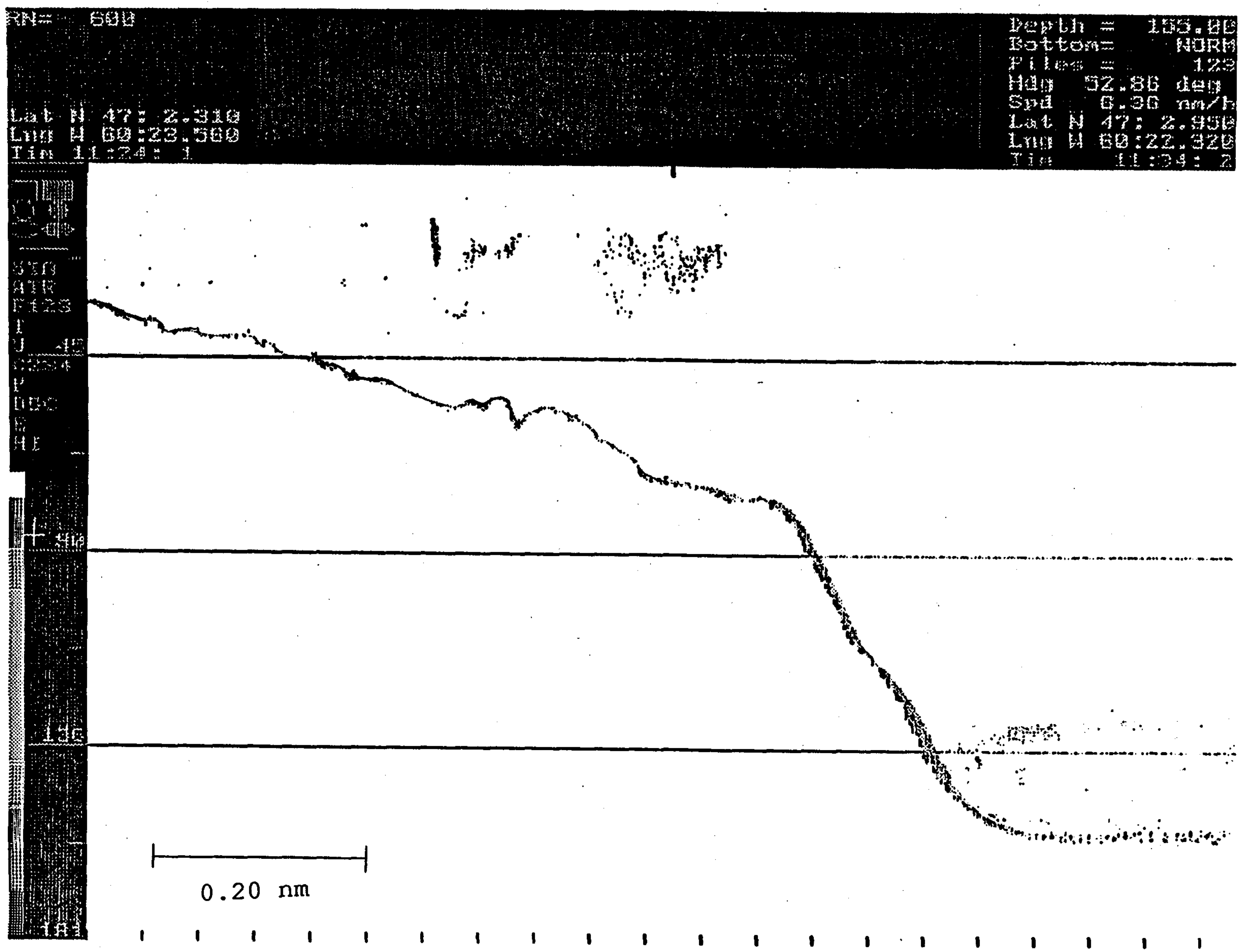


Figure 4. Bottom profile of the mackerel migratory corridor, near Cape North, Cape Breton.

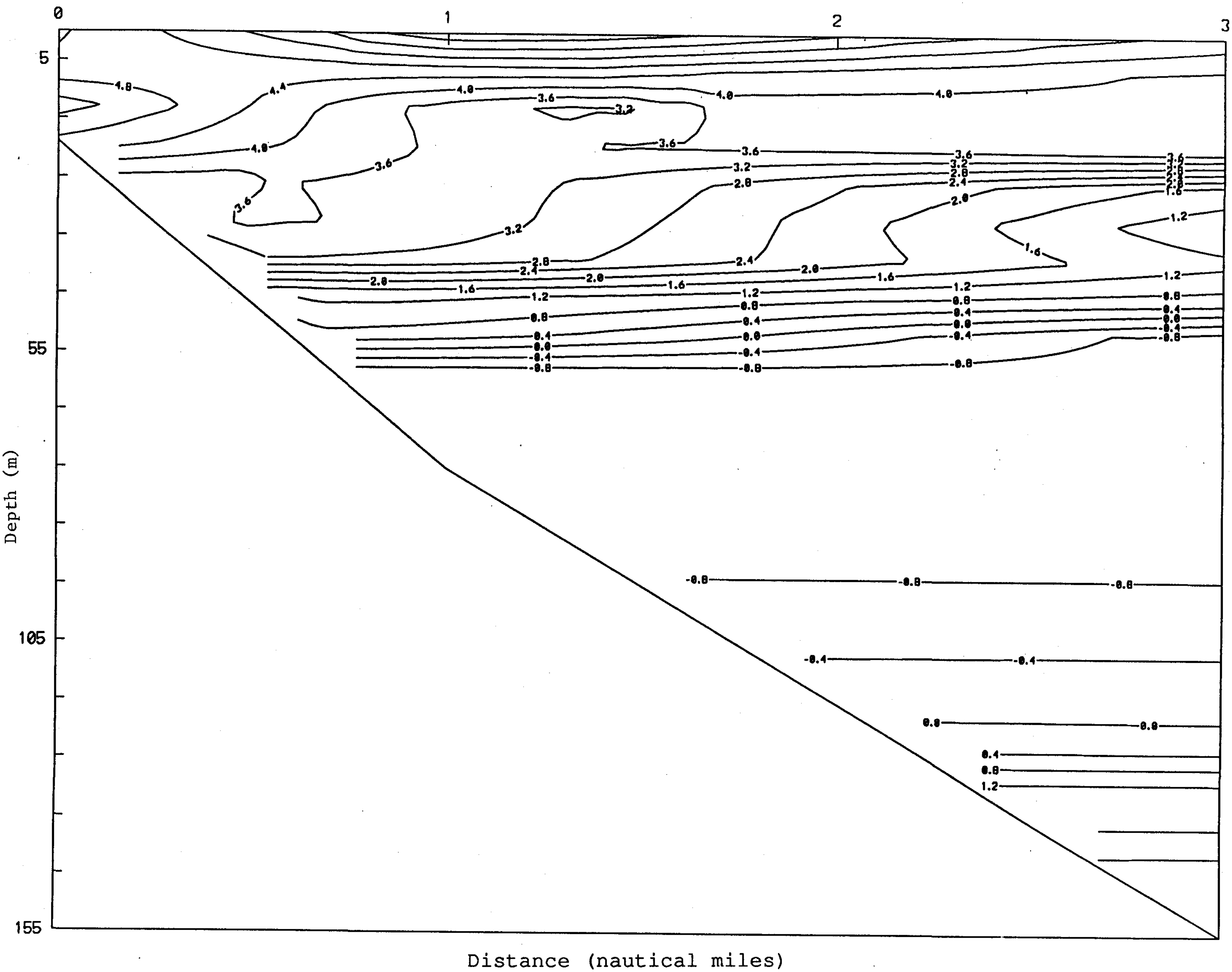


Figure 5. Temperature profiles from Cape North to 3 nautical miles offshore on June 3, 1992.

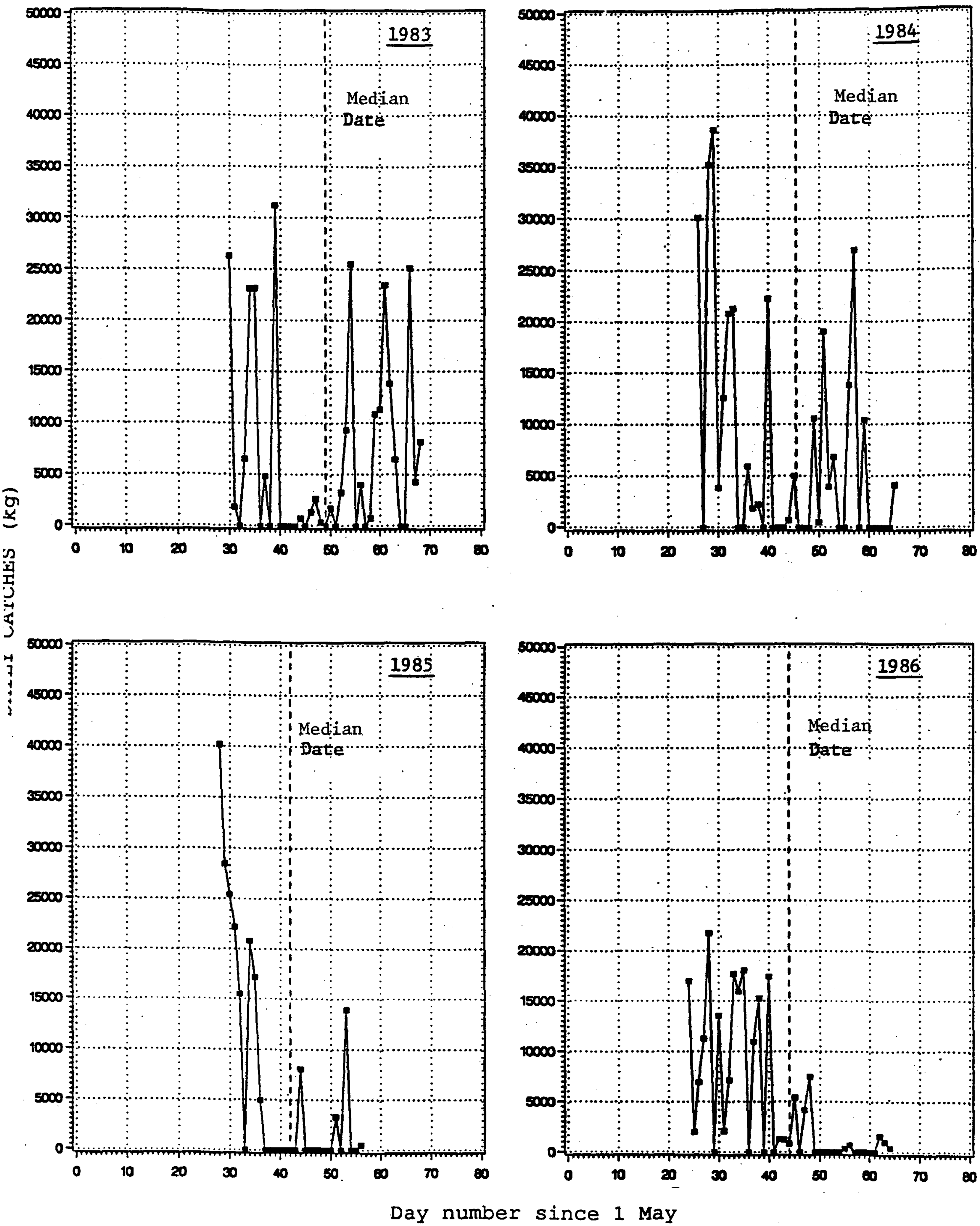


Figure 6. Total daily catch of three mackerel traps set in Aspy Bay. Daily catches from 1983 to 1992 are presented. Dates are presented as the number of days since May 1. Graphs from 1983 to 1991 are reproduced from Grégoire and Fitzgerald (1992). Zero catches at the beginning of fishing seasons are not indicated on the Figure.

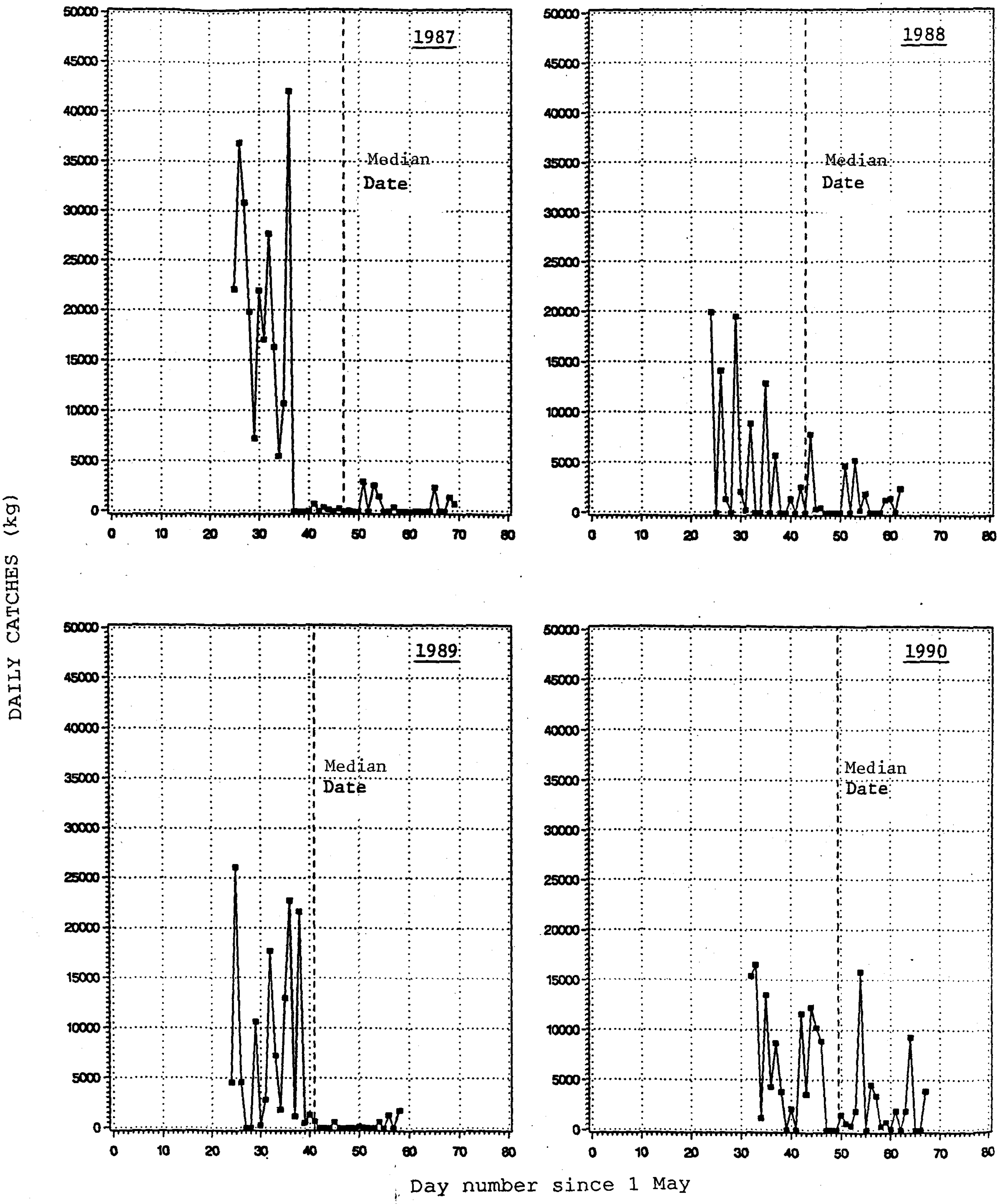


Figure 6 (cont.)

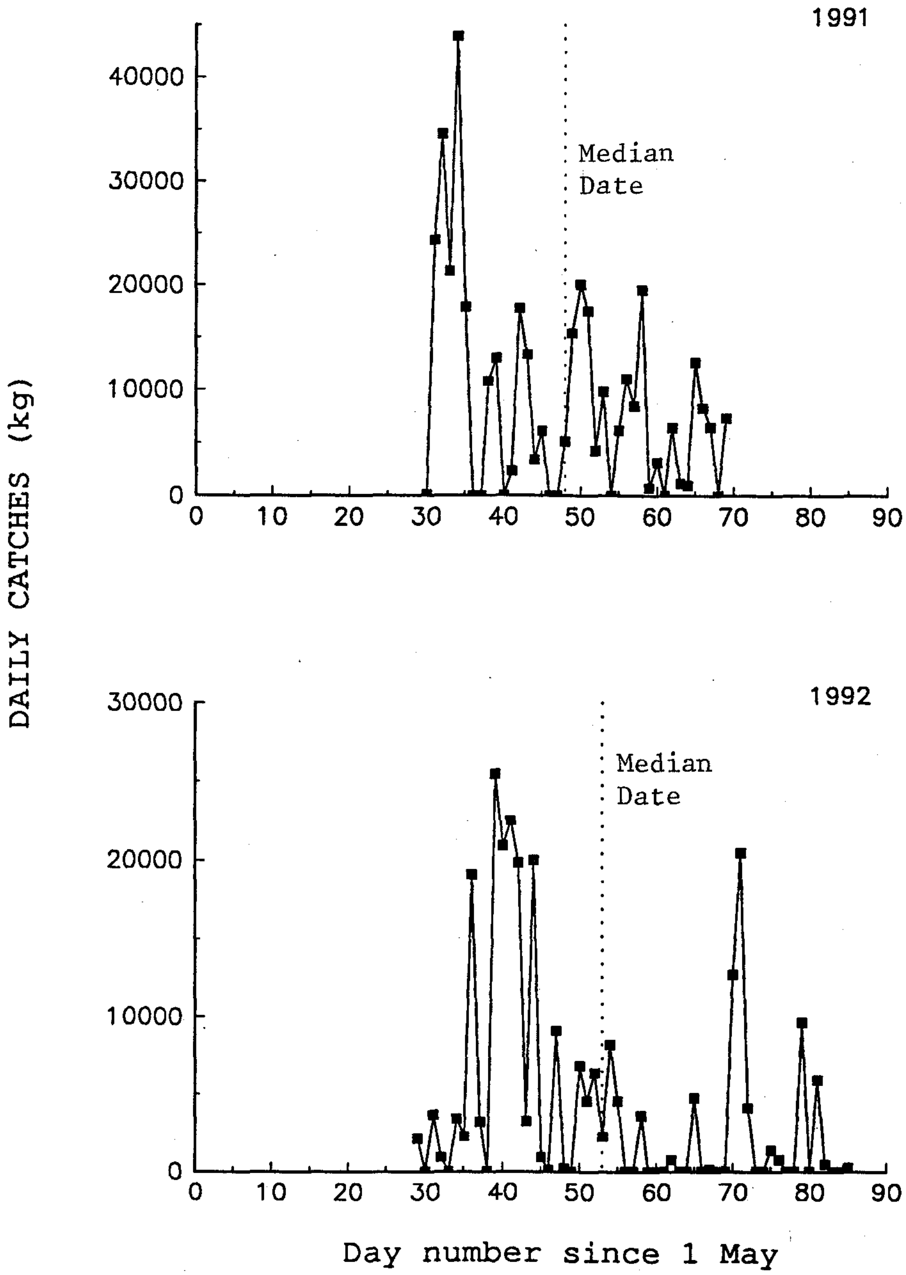


Figure 6 (cont.)