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Year-Class Strength of Northern Cod (2J3KL) Estimated from Pelagic Juvenile Fish Surveys in the Newfoundland Region, 1994, 1995 and 1996

by

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Abstract

Pelagic juvenile fish surveys were carried out in August-September 1994-1996 to index the year-class strength of Atlantic cod (*Gadus morhua*) in the NW Atlantic ocean (NAFO Div. 2J3KL). The abundance of pelagic juvenile cod decreased by a factor of eight from 1994 to 1996. This decline occurred first in the offshore in 1995 and occurred both inshore and offshore in 1996. Year-class estimates from these surveys predict that recruitment at age three of the 1996 year-class will be extremely low. Growth rates of 0-group cod estimated from micro-otoliths averaged 0.57 mm d^{-1} in 1994, 0.67 mm d^{-1} in 1995 and 0.55 mm d^{-1} in 1996. Mean survey lengths were 45.1 mm, 45.3 mm and 41.2 mm, respectively. When lengths were adjusted to a common date based on measured growth rates, cod were larger in 1994 than in 1995 or 1996. Peak hatching dates were June 1994 and June–July in 1995 and 1996, indicating that spawning occurred primarily in May and June of these three years. The observed decline in abundance coincided with the disappearance of spawning cod offshore. There is some evidence of declining abundance and reduced spawning of cod inshore, in Trinity Bay. There is no evidence of poor survival in 1996, based on the abundances of larval capelin and pelagic juvenile Arctic cod (*Boreogadus saida*) sampled in these surveys. The decline in abundance and geographical contraction in the range of pelagic juvenile cod is consistent with declining production associated wtih depensation for an extremely low spawning population.

Introduction

Pelagic juvenile fish surveys have been carried out in the eastern north Atlantic ocean for many years by ICES countries. These surveys have spanned approximately 30 years for the NE Arctic (Arcto-Norwegian) cod stock, 25 years for the Icelandic cod stock and 15 years for the Faroe Plateau cod stock. In each case, year-class strength estimates from these surveys have predicted subsequent recruitment to the fisheries, in most years (Sundby et al. 1989, Assthorsson et al. 1994, Jakupsstovu and Reinert 1994). Failures to predict recruitment have always resulted in over estimates. For the Arcto-Norwegian cod stock, failure to predict three year-classes in the mid-1980's was related to increased cannibalism on one and two year old cod following the collapse of the Barents sea capelin stock (Anon 1995). For the Icelandic cod stock, failure to predict two large year-classes in 1973 and 1984 resulted from a large scale advection of eggs and larvae to West Greenland (Anon 1996). However, these year-classes subsequently returned to spawn in Iceland, thereby showing up as spawners but not as recruits.

A research program to develop a multi-species, pre-recruit fish survey was carried out during 1991-1993, as part of the Northern Cod Science Program (Anderson and Dalley 1997a). Beginning in 1994, a two-ship survey was initiated to measure pre-recruit abundances of cod (*Gadus morhua*) and capelin (*Mallotus villosus*) throughout NAFO Divisions 2J3KLNO, including both inshore and offshore areas (Figure 1). A mid-water trawl and plankton gear are used to sample the upper water column for the abundance of pelagic juvenile fish. The survey has been carried out in August and September, timed to sample pelagic juvenile cod, before they settle to the bottom and larval capelin released from beach and bottom sediments.

The purpose of this paper is to report on abundances, distributions, length frequencies, ages and hatch dates of Atlantic cod (*Gadus morhua*) for the northern cod stock (NAFO Div. 2J3KL) from the 1996 survey, and to compare these results to those of the 1994 and 1995 surveys. Multi-species results from these surveys were presented during recent environmental and fisheries oceanography assessment meetings (Anderson and Dalley 1997b, Dalley and Anderson 1997). Capelin year-class strength estimates were presented during the Newfoundland Region Capelin Assessment meeting in March 1997 (Anderson and Dalley 1997c).

Materials and Methods

The surveys capture plankton (0.3 - 10 mm) and nekton (10 - 200 mm) across almost three orders of magnitude in size, as a broad-scale measure of these communities in late summer, following the spring and summer spawning periods. The surveys have been carried out in August and September, with the mid-date occurring approximately two weeks later in 1995 (Table 1). The survey design is based on a systematic survey grid at 55 km (30 nm) station spacing. This design is equivalent to a systematic stratified sampling design, where the first station was selected randomly from one 55x55 km stratum (Snedcor and Cochrane 1967). Within the bays stations were positioned approximately 55 km apart through the center of each bay.

At each station a SeaBird 25 CTD with a fluorometer was lowered to a maximum depth of 500 m, followed by a plankton tow (0-100 m) and finally a mid-water trawl (20-60 m). Plankton were sampled using a bongo sampler (61 cm, 0.333 mm mesh) towed at 1.25-1.5 m s^{-1} using a double oblique haul 0-100 m with payout and retrieval rates of approximately 0.8 and 0.4 m s^{-1}, respectively. Beginning in 1996, 0.232 mm and 0.505 mm mesh nets were used on each side of the bongo sampler to measure invertebrate zooplankton and ichthyoplankton, respectively. The bongo sampler was instrumented and transmited data in real time to the ship, including sampler speed, volume filtered, distance towed, sampling time, salinity, temperature and depth. The IYGPT (International Young Gadoids Pelagic Trawl) is a pelagic mid-water trawl designed to catch pelagic juvenile gadoids with an effective opening of approximately 10x10 m, (Anderson and Dalley 1997a). The IYGPT trawl was towed at 1.25-1.5 m s^{-1} for 30 minutes, slowly oscillating the head rope between 20-50 m depth through two complete cycles, such that the trawl sampled the 20-60 m depth stratum. The trawl depth and configuration were monitored using acoustic net sensors (Scanmar) to measure net depth, net opening, wing and door widths. For both samplers, the net performance data were used to estimate the volume of water (m^3) filtered during the tow to standardize catch rates.

The IYGPT trawl catches were processed at sea, identifying all fish to species level, where possible, and recording total length for dominant fish species. Sorted samples of Atlantic cod (*Gadus morhua*) and Arctic cod (*Boreogadus saida*) were preserved in alcohol (1994) or frozen (1995) while all other species were preserved in 5% buffered formalin. Total trawl wet weight was also estimated (g). In 1994 this weight included jelly fish, whereas in 1995 and 1996 the jelly fish were weighed separately from the remainder of the catch. Wet weight was also determined for the dominant species sorted from the catch. Squid were counted and weighed but not speciated. Samples of squid were preserved in formalin and returned to the laboratory for taxonomic identification.

Samples from one side of the bongo were subsampled at sea for identification and measurement of capelin and herring, without replacement. Sorted samples were preserved in alcohol. The remainder of the sample was processed in the laboratory, following standard procedures. From the other bongo sample, the plankton was split into two equal halves using a Motoda plankton splitter. One half of this sample was divided into three size categories (< 1 mm, 1-2 mm, > 2 mm), dried for 24 h at 55-60°C and weighed to the nearest milligram. Selected zooplankton samples from 1994 (n=29) and 1995 (n=29) were processed for full taxonomic classification following standard laboratory procedures.

Atlantic cod were preserved in 95% ethanol or frozen and returned to the laboratory where the otoliths (sagittae and lapillae) were removed and mounted on microscope slides using "crystal bond". Otoliths were polished to their central plane using different grades of lapping film. In most cases lapillae were aged under a light microscope at magnifications of 400 to 1000 times with the assistance of an Optimus image analysis system. Replicate readings of daily rings were made to ensure consistency of the age estimates. When age estimates of replicate readings differed by more than 10% then the otolith was discarded. Samples for otolith age analyses were stratified across all length groups and for different geographic areas. Hatch date was estimated as the difference between the age of the fish subtracted from the date of capture.

An abundance index was developed based on a number of selected areas, following the method of Randa (1982). These Index Areas were chosen to represent different regions for inshore and offshore locations (Figure 1). The index is dependent on all stations being sampled within each area for a given year. When two or more areas have been sampled, an area weighted overall index of abundance can be derived. The basic index for a unit area is calculated as,

$$I_j = \overline{X}_j \cdot p_j$$

where, I_j is the index of abundance for area$_j$, $\overline{X}_j$ is the geometric mean abundance (log_e *number* $10^4 m^{-3}$) and p_j is the proportion of non-zero catches. The geometric mean abundance is calculated for each Index Area as,

$$\overline{X_j} = \frac{1}{N_{lj}} \cdot \sum_{i=1}^{N_{lj}} \cdot ln(X_{ij})$$

where N_{lj} is the number of non-zero catches and the variance of $\overline{X_j}$ is calculated as,

$$S_j^2 = \frac{1}{N_{lj} - a} \cdot \sum_{i=1}^{N_{lj}} \cdot (ln(X_{ij}) - \overline{X}_j)$$

where a is the number of zero catches. Finally the Index Area is weighted by the size of each area as,

$$P_j = a_j \cdot I_j$$

where a_j is area of each Index Area (km^2).

An overall index for several commonly sampled areas can be estimated as the sum of the weighted Index Area values

$$SUM_{P_j} = \sum_{j=1}^{k} P_j$$

where k is the total number of commonly sampled Index Areas.

Results

Year-Class Abundance

The abundance of pelagic juvenile cod has decreased significantly from 1994 to 1996 (Figure 2). The decline in abundance occurred first in the offshore, in 1995. Inshore, abundance remained high in 1995, comparable to that of 1994. By 1996, offshore abundance declined to zero and inshore abundance decreased significantly in all bays compared to 1994 and 1995. Overall, the abundance of pelagic juvenile cod has declined by a factor of 8 during the last two years (Table 2).

Distributions

Pelagic juvenile cod occurred throughout the inshore area in 1994 and they were also distributed widely offshore over the Northeast Newfoundland Shelf (2J3KL, Figure 3). Only a few cod occurred on the southern portion of the Northeast Newfoundland Shelf and on the northern Grand Bank. In 1995, juvenile cod only occurred sporadically offshore over the Northeast Newfoundland Shelf although they remained widely distributed throughout the inshore. In 1996, only a very small number of pelagic juvenile cod were found at three stations in Bonavista Bay, one station in White Bay and at one station off the northern peninsula. None occurred in Notre Dame Bay, Trinity Bay or Conception Bay and no juvenile cod were observed offshore.

Pelagic juvenile cod have been observed on the southern Grand Bank (3NO) each year, but in relatively low abundances (Figure 3).

Length, Age and Growth

In the 1996 survey, pelagic juvenile cod averaged 41.2 mm in length, ranging from 26-62 mm. This compares with cod which averaged 45.1 mm (30-101 mm) and 45.3 mm (27-71 mm) during the 1994 and 1995 surveys, respectively. These average sizes can be projected forward to a common date, based on measured growth rates. For example, for a common date in mid-September (Day 258) cod would have averaged 54.7 mm in 1994, 46.0 mm in 1995 and 50.5 mm in 1996. Settlement is thought to occur sometime in October through to early November (Anderson et al. 1995, Anderson and Dalley 1997a). Projecting lengths to mid-October, cod would have averaged 72.2 mm, 66.7 mm and 67.5 mm, respectively. Due to the higher growth rate in 1995 compared to 1996, the size difference between these years disappears with time. Therefore, it appears that juvenile cod were larger in 1994 than in the following two years.

All pelagic cod caught in 1996 were sampled for age, including a number of cod sampled in Bonavista Bay during several experimental tows. Cod in 1996 averaged 35.2 mm in length and 64 days of age (Table 3). There was a highly linear relationship between size and age (Figure 4). Cod were smaller and younger in 1996 compared to 1994, for survey times which occurred at the same time of year (Table 1). In 1995, cod were approximately 10 mm larger but only averaged 4.5 days older, for a survey that occurred about two weeks later in the year compared to 1996 (Table 1). Therefore, average growth rate in 1995 was higher, at 0.67 mm d^{-1}, compared to 1994 and 1996 when growth rates averaged 0.57 and 0.55 mm d^{-1}, respectively (Table 3). The higher growth rate measured in 1995 was comparable to those measured in the 1992 and 1993 surveys (Table 3).

Hatching and Spawning Times

Pelagic cod sampled in 1996 hatched from the middle of May through to the end of August (Figure 5). The data indicate a bi-modal distribution, with one mode in June and a second in July. However, these modes are only separated by 10 days and come from a relatively small sample size (n=61). These cod were spawned primarily in May and June of 1996 although the earliest spawning occurred in April; based on egg development times of approximately 25-30 days for June and July water temperatures (Anderson and deYoung 1995).

Hatching and spawning times in 1996 were similar to 1995 but occurred slightly later than 1994 (Figure 5). Compared to 1993, hatching and spawning times were earlier but overlapped. Spawning in 1992, however, occurred later than in 1994-1996 (Figure 5). Over the five years in which we have collected samples, there has been a shift in spawning time from relatively late in 1992 and 1993 to approximately 1-2 months earlier during 1994-1996. Examination of bongo samples for the presence of cod eggs and larvae indicated there was no spawning which occurred during June-August of 1994-1996. If spawning occurred early in the year in 1992 and 1993 then either these fish had died or they had settled to the bottom and were not available to the mid-water trawl.

Discussion

There has been a significant decline in the abundance of pelagic juvenile cod during the period 1994-1996. This decline in abundance has been accompanied by a severe contraction in their geographic distribution. These data indicate there will be a significant decline in recruitment to the northern cod population over these three years, which will have severe implications for stock recovery.

These patterns in distribution and abundance can be explained by differential survival of eggs and larvae among areas or by changing dynamics in the distribution and fecundity of spawners. Based on a single survey, it is difficult to distinguish between these different casual mechanisms which would explain the differences we have observed in pelagic juvenile cod. However, there is some information to indicate that the differences may be a function of a decline in spawning.

Offshore acoustic surveys have been conducted in June each year since 1994 (G. Rose, Marine Institute, Memorial University of Newfoundland, St. John's, NF, per. comm.) These surveys measured a significant concentration of spawning cod offshore in 1994, immediately south of Hamilton Bank, which coincides with the broad distribution of pelagic juveniles we measured offshore in 1994. As many of the cod sampled during the spring acoustic survey were spent, it was concluded that spawning occurred primarily in May and June of 1994. In 1995, only a small concentration of spawners was found in this area, which coincides with the sporadic distribution of pelagic juveniles we sampled offshore in 1995. In 1996, only juvenile fish were observed offshore in the spring by the acoustic survey, which coincides with the total absence of pelagic juveniles sampled offshore in 1996. These observations indicate there has been a decline in the abundance of offshore spawners during the period 1994-1996.

There is limited information on the spawning of cod within the inshore area during the 1990's. Spawning has been observed within one area of Trinity Bay in recent years. Spawning cod were observed from May to August during 1991-1993, with peak spawning occurring from mid-June to mid-July (Smedbol and Wroblewski 1997). A large concentration of spawning cod was observed in Smith Sound, Trinity Bay during April 1995 (Rose 1996). However, this large concentration of spawning cod was not found during a similar survey in April 1996 (Brattey and Porter 1997). In both 1995 and 1996, cod were in spawning condition in April, with peak spawning probably occurring in May and June (Brattey 1996, Rose 1996). In addition, some of the adult cod sampled in 1996 had very low levels of fecundity, where in some areas approximately 34% of cod > 60 cm were not going to spawn that year (Brattey 1996).

The spring observations on the timing of spawning both offshore and inshore during the period 1991-1996 coincide with our observations on the spawning and hatch dates of pelagic juvenile cod sampled 1992-1996. Therefore, there appears to have been a shift in spawning from June–July in 1991-1993 to an earlier spawning which occurred primarily in May–June in 1994-1996. The earlier spawning in 1994-1996 coincided with warmer water temperatures which were close to the long-term mean, whereas the later spawning in 1991-1993 coincided with extremely low water temperatures (Colbourne et al. 1994, Drinkwater et al. 1995, Colbourne 1996).

There is no indication of low survival by fish eggs and larvae during the 1994-1996 period. Spring ice conditions and water temperatures have been close to normal during these three years (Colbourne 1996). Arctic cod (*Boreogadus saida*) have occurred abundantly in our samples each year, being distributed widely over the Northeast Newfoundland Shelf and throughout the inshore (Anderson and Dalley 1997b, Dalley and Anderson 1997). Pelagic juvenile Arctic cod occur in the water column with Atlantic cod and were similar in size (op. cit.). In addition, capelin larvae and age one and two year old juveniles have been increasing in abundance since 1993 (Anderson and Dalley 1996, 1997c). While there may be resource competition between the two gadoid species, there is no indication of poor ocean conditions for survival of small planktivores in the pelagic environment during the years 1994-96.

Taken together, these observations indicate there may have been a significant decline in the amount of spawning by northern cod during the period 1994-1996. This decline would be manifest by a disappearance of spawning fish offshore and possibly a significant contraction of their distribution inshore, coupled with reduced spawning by the remaining adults inshore. These observations are consistent with depensatory mechanisms for a severly depeleted population, where a decline in spawning at low population abundance may occur. The consequences of depensation for stock rebuilding would be severe. The degree to which the remaining adult cod are spawning on an annual basis must be determined.

A possible explanation for our observations is that cod may have settled to the bottom earlier in 1996. However, there is no indication that this occurred. In offshore areas pelagic juvenile cod routinely average 40-60 mm in length (Assthorsson et al. 1994, Helle 1994). On Georges Bank juvenile cod did not settle to the bottom until 70-80 mm in length (Perry and Neilson 1988). Earlier settlement at a common size would occur from a much earlier spawning time or due to higher growth rates. If spawning had been earlier in 1996 and settlement had occurred earlier, then we should have sampled larger juvenile cod at the end of their pelagic phase. However, pelagic juvenile cod were both smaller and growth rates were lower in 1996, compared to 1994 and 1995. Simulations predicting the sizes of pelagic juvenile cod for different spawning times demonstrated that spawning in mid-March would result in juvenile cod ~50 mm in length during mid-August (J. Anderson, unpubl. data). Similarly, based on average growth rates observed in this study, cod that may have been spawned in March–June would not reach 50 mm in length until mid-August through to mid-September. These estimates are based on egg developement times ranging from 30-60 days (Page and Frank 1989, Pepin et al. 1997), depending on the assumed month of spawning, and a size at hatch of 4 mm.

Beach seine surveys measuring the abundance of settled 0-group cod have been carried out since 1992. The indices of abundance of 0-group juvenile cod from these two surveys have agreed during the period 1992-1995 (Evans 1996). In 1996, the beach seine survey measured the lowest abundance of 0-group cod of the entire time series (Methven 1997), which agrees with our pelagic 0-group estimate in 1996. Both surveys indicate the lowest estimates of 0-group juvenile cod abundance during the period 1992-1996.

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Table 1. Summary of Pelagic Juvenile Fish Surveys conducted, 1994-1996, where DoY–Day of the Year; Bongo–bongo plankton sampler; IYGPT–International Young Gadoids Pelagic Trawl. The numbers below each gear type list the number of stations sampled each year by each gear type. Start, End and Mid refer to the starting, ending and mid-date of each survey.

YEAR	SHIP	DATES	DoY Start	DoY End	DoY Mid	Bongo	IYGPT
1994	TEM157/GAD247	22 Aug--3 Sep	234	246	241	99	99
1995	TEM175/TEL018	5 Sep--22 Sep	248	264	257	139	139
1996	TEM193/TEL034	19 Aug--6 Sep	231	249	241	147	147

Table 2. Abundance indices estimated for pelagic juvenile cod (*Gadus morhua*) for the different Index Areas sampled each year, 1994-1996. SUM IN–sum of all weighted Index Area values for the commonly sampled inshore areas (shaded); SUM OFF–sum of all weighted Index Area values for the commonly sampled offshore areas (shaded); TOTAL–sum of SUM IN + SUM OFF.

	Ln(NOM3)	10^11	
Area	1994	1995	1996
Inshore			
CB	0.83	3.52	0.00
TB	2.98	1.44	0.00
BB	10.29	2.31	1.11
NDB	11.45	24.78	0.00
WB	16.80	2.45	8.28
SUM IN	42.35	34.50	9.39
Offshore			
HB		0.22	
ISN	0.90	1.21	0.00
ISS	16.55	3.25	0.23
BIBI	14.33	0.22	0.00
BIBO			
FIBI	3.95	0.43	0.00
FIBO	0.31		
NGB	0.37	0.59	0.00
SA	0.33		0.00
SGB	3.10	0.38	1.13
NOSE			0.00
TAIL			
SGBO			
WD			
SUM OFF	39.20	6.08	1.36
TOTAL	81.55	40.58	10.75

Table 3. Summary of the ages (days), lengths (mm) and growth rates (mm d^{-1}) measured for pelagic juvenile cod (*Gadus morhua*) sampled each year, 1992-1996.

Year	n	Age Mean	Age Min	Age Max	Length Mean	Minimum	Maximum
1992	104	67.3	48.0	87.0	43.1	29.5	67.0
1993	92	72.8	54.0	101.0	46.8	31.5	69.0
1994	104	80.7	58.0	121.0	45.4	31.5	86.0
1995	100	68.5	48.0	96.0	45.8	30.0	69.5
1996	61	63.9	42	104	35.2	18	59.5

	Growth Rates					
Year	n	Mean	Min	Max	Std Dev	CV
1992	104	0.641	0.493	0.810	0.0688	10.7
1993	92	0.643	0.500	0.829	0.0661	10.3
1994	104	0.565	0.431	0.711	0.0555	9.8
1995	100	0.670	0.505	0.838	0.0698	10.4
1996	61	0.548	0.424	0.727	0.0694	12.7

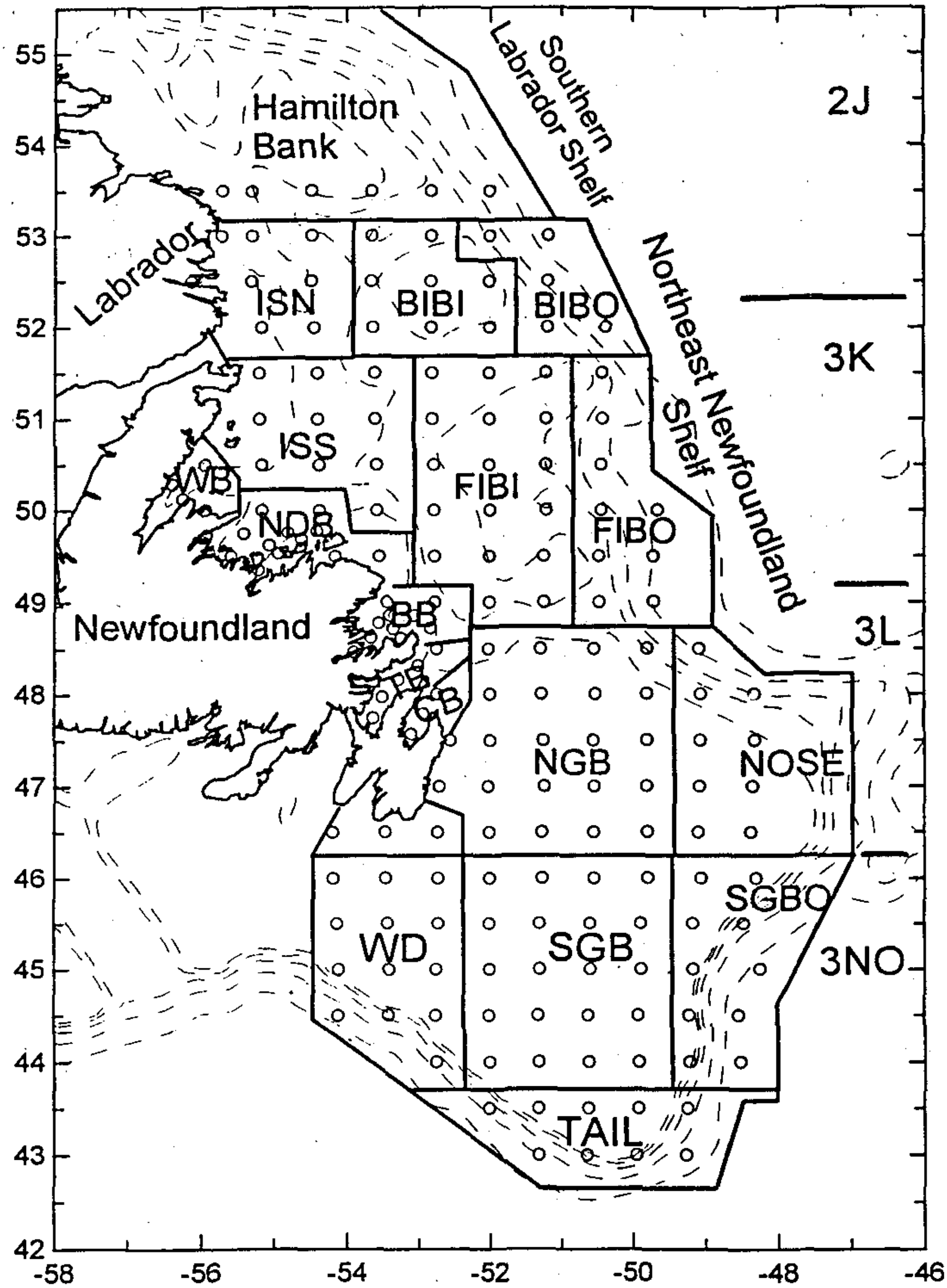

Figure 1. Pelagic Juvenile Fish Survey station locations (open circles) and Index Areas. The "inshore area" is represented by: WB - White Bay, NDB - Notre Dame Bay, BB - Bonavista Bay, TB - Trinity Bay, CB - Conception Bay. The open circles represent survey station locations. The isobath lines span depth from 100 m to 1000 m.

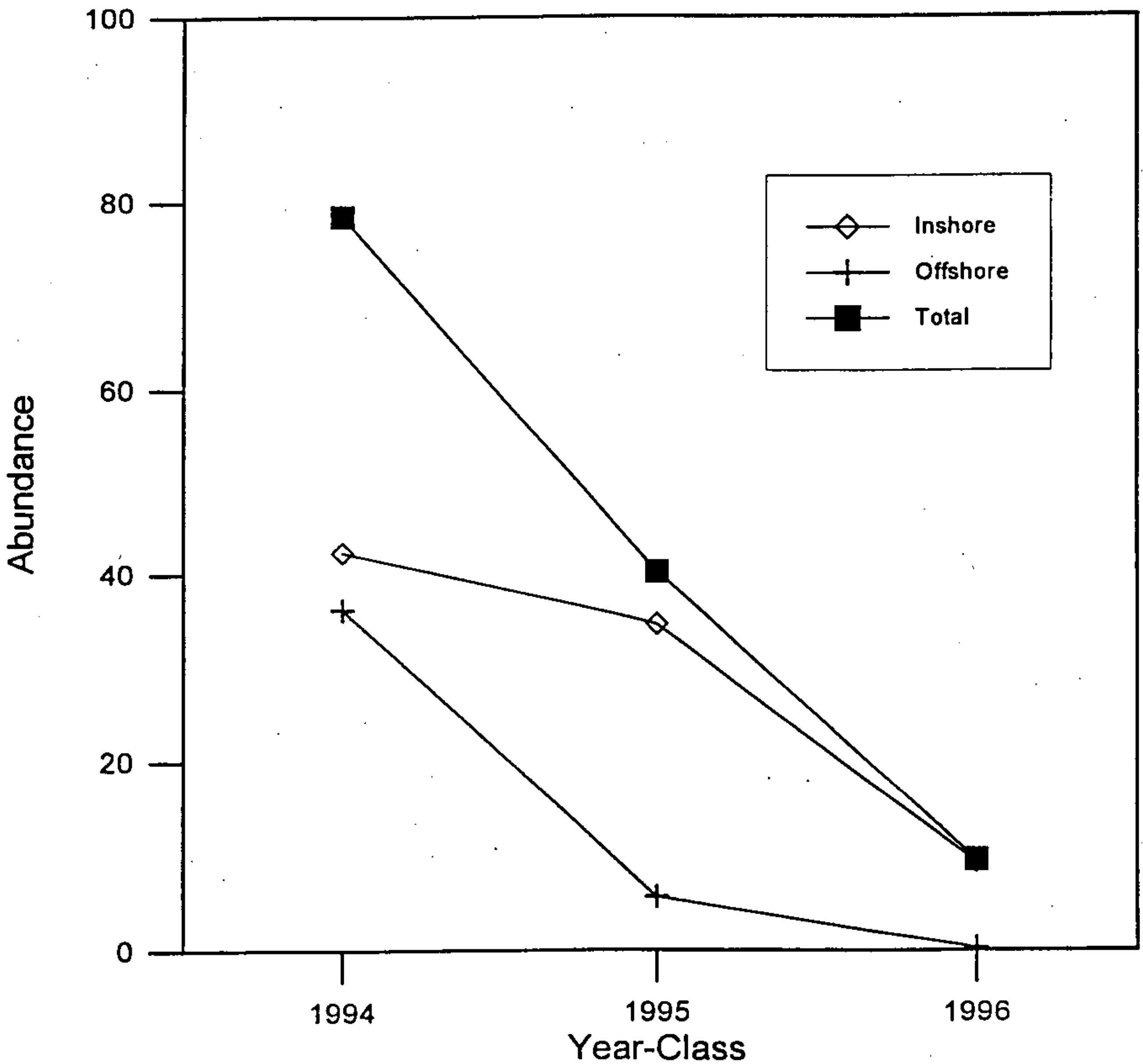

Figure 2. Abundance indices for inshore, offshore and the total for commonly sampled Index Areas, 1994-1996, for northern cod (2J3KL).

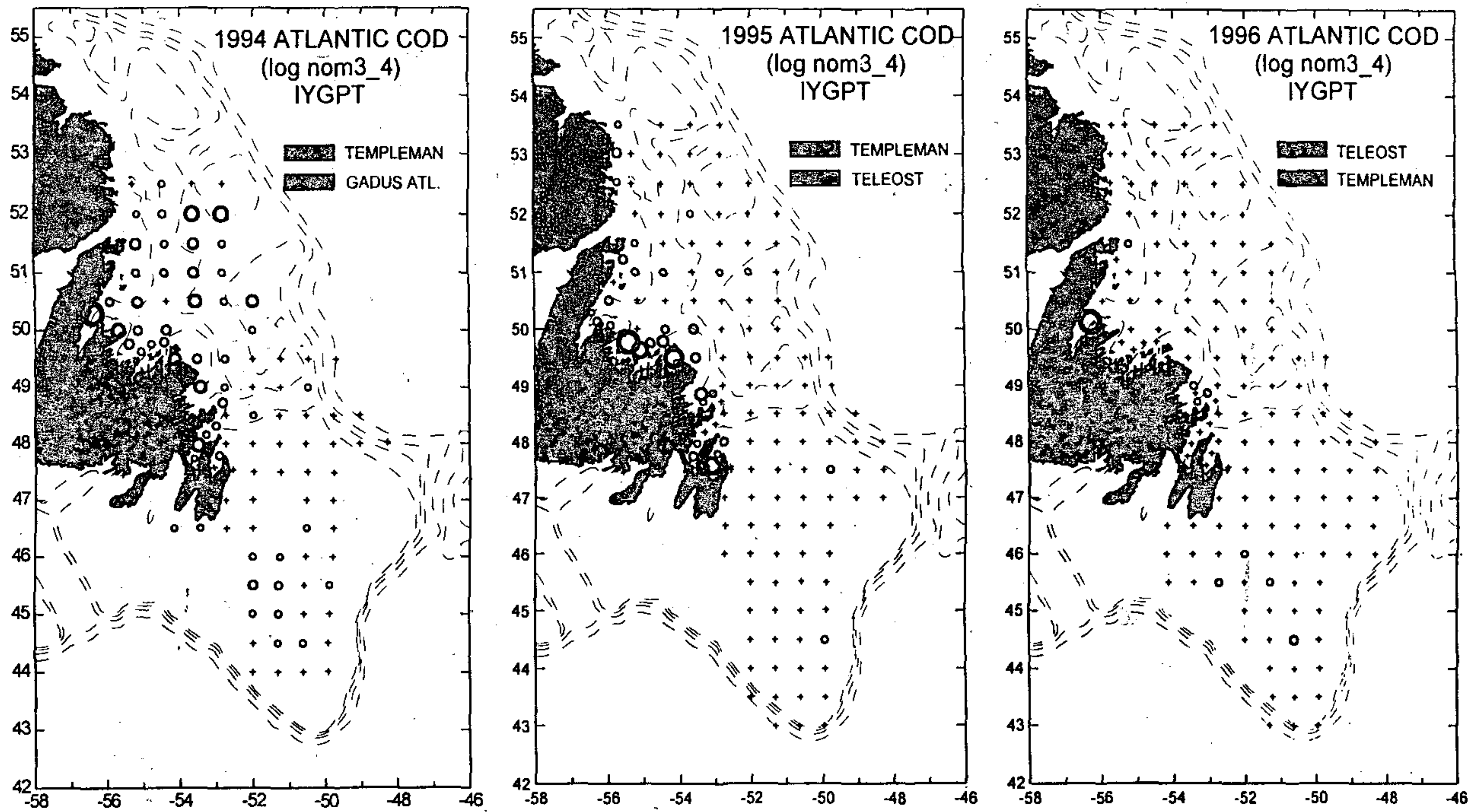

Figure 3. Distributions of pelagic juvenile cod (*Gadus morhua*) for 1994-1996. The expanding symbols represent abundances (log (number $10^4 m^{-3}$), scaled within each year. Stations sampled but cod were not caught are represented by a plus symbol.

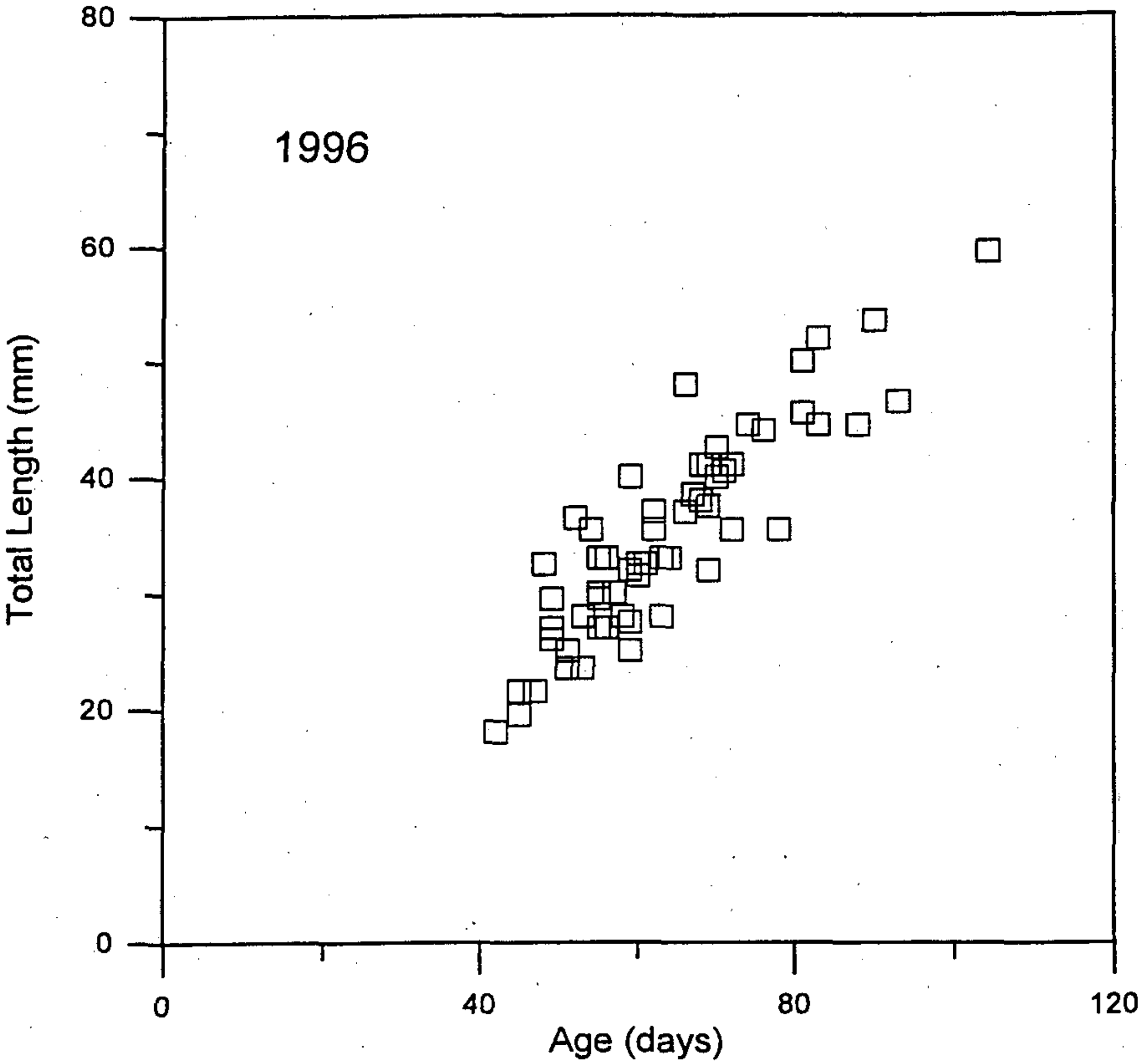

Figure 4. Length–age relationship for pelagic juvenile cod (*Gadus morhua*) sampled in 1996, based on micro-otoliths.

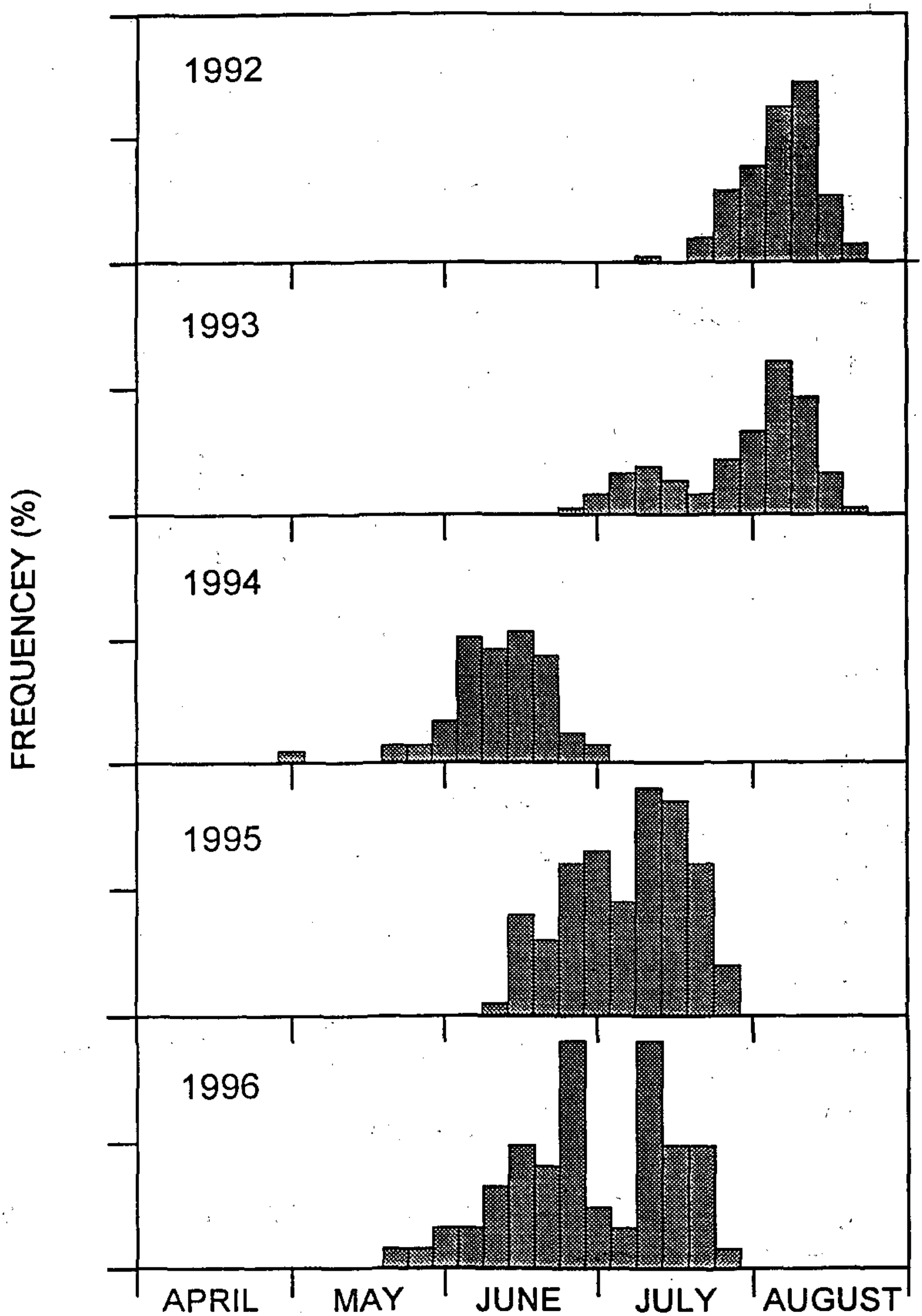

Figure 5. Larval hatch dates estimated from from the ages of pelagic juvenile cod (*Gadus morhua*) sampled each year 1992-1996, summarized into five day periods.