AN EVALUATION OF RECRUITMENT INDICES FOR NORTHEAST ARCTIC COD (*GADUS MORHUA* L.)

by

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Abstract

Indices of the abundance of Northeast Arctic cod (*Gadus morhua* L.) for various life stages were compared in order to determine the earliest stage at which year-class strength is established. The indices considered are: VPA estimates of spawning stock biomass; an egg abundance index; an early juvenile (approximately three-months old) abundance index; 0-group (age four to five months) abundance indices; bottom trawl and acoustic survey abundance indices for one, two and three- year-old cod and VPA estimates of the abundance of three-year-old cod. Based on a regression analysis, the relative abundance of early juvenile cod was the first life stage that was correlated with their relative abundance as three year olds. Since the correlation between the estimates of spawning stock biomass or total egg production and the relative abundance of three-year-old cod was weak, it is concluded that considerable yearly variation in mortality occurs before cod reach the early juvenile stage.

Keywords: Barents Sea; Northeast Arctic cod; Recruitment indices; Stock development; Early life stages

Introduction

It has often been stated that the year-class strength of marine fish populations is mostly determined by mortality during the egg and larval stages (Sundby et al., 1989). Other studies claim that variable year-class strength is chiefly a result of variable mortality during the late larval and juvenile stages (Myers and Cadigan, 1993). Variation in year-class strength has also been attributed to variation in the reproductive potential of the spawners, which would influence total egg production (Marshall et al., 1998).

Such divergent views about when and how recruitment variation is generated highlight the need to determine whether there is a specific life history stage at which strong year-classes become clearly distinguishable from weak ones (ICES, 1997). Isolating the stage at which year-class strength becomes more or less fixed is a prerequisite to establishing the relative importance of the various factors, such as climatic conditions, which influence recruitment (Ulltang, 1996).

The abundance of a cohort of Northeast Arctic cod (Gadus morhua L.) varies greatly from year to year (Ottersen, 1996). The amplitude, measured as the ratio between poor and strong year classes is about 1:70 at the early juvenile stage (Sundby et al., 1989) and 1:15 at the 3 year stage (ICES, 1999). In this paper we examine the indices of abundance at different life stages in order to determine the earliest stage at which year-class strength is established.

The Institute of Marine Research (Bergen, Norway) has produced over the years estimates of the absolute or relative abundance of Northeast Arctic cod at various stages of development throughout the life span of a cohort. These include estimates of total egg production, and indices of the relative abundance of a cohort as early juveniles, at the 0-group stage, and as one-, two- and three-year olds. An overview of all available indices for Northeast Arctic cod, including those constructed by the Russians, is given in ICES (1998). Some of these indices were excluded from our analysis because detailed documentation on how they were obtained is unavailable, the time series were too short, or the surveys covered only a minor portion of the areal extent of the particular life stage.

In order to estimate the mortality from one life stage to the next, it is necessary to have estimates of the absolute abundance at the two stages. The indices considered here are based on bottom trawl, pelagic trawl or acoustic surveys that may track trends in abundance if the indices are proportional to the actual population size, but these surveys at present do not generate estimates of absolute abundance. Much research is being directed toward determining the proportionality constant for marine surveys (i.e., the "catchability" of the gear) though currently such estimates are fraught with uncertainties and at best quite variable (Godø, 1994).

Since there does not exist estimates of the absolute abundance of Northeast Arctic cod at each life stage of a cohort, a regression analysis of the indices was done to determine the earliest life stage for which the relative abundance was most highly correlated with the relative abundance at subsequent stages. Also included in this study were estimates of the absolute size of the spawning stock and estimates of the

abundance as three-year-olds from a virtual population analysis based on commercial catch statistics (VPA, see ICES, 1965). It is concluded that the relative abundance of cod as early juveniles appears to have the highest correlation with the relative abundance of later stages and thus the most significant yearly variation in mortality likely occurs before the early juvenile stage, which supports the findings of Sundby *et al.* (1989).

Materials and methods

General information about the surveys and the period in which they were conducted are given in Table 1, and the indices included in the analysis are given in Table 2. A general description of the areas covered by the surveys is shown in Figure 1.

Spawning stock biomass
The estimates of spawning stock biomass (SSB) are from the 1998 ICES stock assessment based on commercial catch statistics (ICES, 1999). It should be noted that for 1982 and earlier years, constant values of weight and maturity at age were used in calculating the spawning biomass. Ulltang (1996) presented an alternative set of SSB values using maturity ogives derived by Jørgensen (1990). However, revised values of weight at age for all years are not yet available.

Total egg production
Total egg production (TEP) was estimated for 1985 through 1996 using acoustic estimates of total abundance and demographic information from trawl sampling during the Barents Sea (Jakobsen *et al.*, 1997) and Lofoten (Korsbrekke, 1997) surveys combined together with year-specific fecundity-length relationships (Marshall *et al.*, 1998). These estimates represent potential total egg production because they correspond to the total number of vitellogenic oocytes in the pre-spawning ovaries of all mature females. To account for differences between first-time (or recruit) and repeat spawners in the rate of egg mortality prior to hatching (Solemdal *et al.*, 1995) estimates of total egg production were partitioned into the number of eggs produced by recruit and repeat spawners using standard values of the proportion of repeat spawners by length (Table 8 of Marshall *et al.*, 1998).

Early juvenile cod
Early juvenile cod surveys were conducted by the Institute of Marine Research from 1978 to 1991 in June and July. The purpose of these surveys was to generate an abundance index and to determine the yearly spatial distribution of the juveniles. The survey was designed to adapt to changes in the geographical distribution, and therefore the surveyed area varies slightly from year to year. In order to have a relatively uniform survey region over time, only stations north of 67°N and in offshore waters are included in the calculation of the abundance index (Helle and Pennington, 1999). The abundance index was calculated using methods described in Pennington (1996).

The early juveniles were sampled using a mid-water trawl whose cod end contained a 4 meter long inner net with a 5 mm mesh size inner net. The trawl was towed at three

different depths: 40 m, 20 m and at the surface. For details on trawl configuration during tows see Bjørke and Sundby (1987).

0-group survey
The international 0-group survey which is a co-operation between Norway and Russia (until 1976 also UK) has been conducted from 1965 to the present in late August to early September with only a few days variation from year to year. The aims of the survey are to map the spatial distribution and to determine the abundance at the 0-group stage of the important commercial fish species in the Barents Sea and adjacent waters. Until 1980, the fishing depth of the trawl was selected based on acoustic observations. From 1980, a standard trawling procedure recommended by ICES has been used (Anon., 1983; Nakken and Raknes 1996)). The same trawl is used for the 0-group survey as was employed by the early juvenile fish survey. Two indices of abundance, an area index and a logarithmic index, produced by the 0-group survey are taken from the yearly ICES 0-group report (ICES, 1996). The methods used for calculating these indices are given in respectively Haug and Nakken (1977) and Randa (1982, 1984).

Bottom trawl and acoustic surveys
Bottom trawl and acoustic abundance indices for 1981 through 1999, based on the Norwegian winter (January-March) survey in the Barents Sea, revised indices for one, two and three-year-old cod are taken from Mehl (1999). For a description of the survey design, methodology and gear, including past changes in the implementation of the surveys, see Mehl (1999) and Jakobsen et al. (1997).

Estimates of the abundance of three-year-old cod
Estimates of the absolute abundance of three-year-old cod are taken from the ICES Report of the Arctic Fisheries Working Group (ICES, 1999). These estimates, which depend heavily on commercial catch statistics, are from a virtual population analysis (VPA) of the stock.

Statistical methods
Regression techniques were used to determine if the relative abundance of a cohort at a life stage is proportional to its relative abundance at an earlier stage. Since the residuals from these regressions are a time series and positively serially correlated residuals can cause the significance of regression estimates to be greatly exaggerated, the Durbin-Watson test was used to detect first-order serial correlation in the regression residuals (see, e.g., Draper and Smith, 1981). Positive correlation is most common for serial data and since these series are relatively short, a one-sided test was applied to test if the serial correlation is positive rather than zero.

There are three possible outcomes of the Durbin-Watson test: not significant and thus do not reject that the correlation is zero; significant and hence reject the null hypothesis; and inconclusive, which is taken as a warning that the correlation may be significant (again, see Draper and Smith, 1981, for details). If positive serial-correlation was detected or the test was inconclusive, this was taken as an indication that the estimated significance of the regression was likely overstated.

The value of the squared correlation coefficient, r^2, (multiple correlation coefficient, squared) and whether the intercept was significantly different from zero were used as indicators of the strength and goodness of the relation between the two stages. A large value of r^2 indicates that the relation between the abundance at an earlier stage with that at a later one is relatively strong. A low r^2 may mean the relation is weak or that the correlation is reduced because of measurement error and biases in the indices. That is, the relative sizes of the r^2's may also be a measure of the relative accuracy of the indices. Likewise, a zero intercept implies a 'reasonable' relation (e.g., no egg production implies no juveniles), while a positive intercept may occur because either the relation between the two stages is non-linear or there is large measurement error in the independent variable which will cause the estimator of the intercept to be positively biased (Draper and Smith, 1981).

Results

Table 3 contains the estimated r^2 for the regression of an abundance index at one stage versus its abundance at an earlier stage. For example, r^2 equals 77% for the relative abundance of early juvenile cod (EJC) and total egg production (TEP) two to three months earlier. The estimates in Table 3 are based on all available data and it is noted in the table if the intercept for the regression is significantly different from zero and if the one-sided Durbin-Watson statistic for positive serial correlation is significant, both at the 5% level.

Total egg production (TEP) appears to be more closely related to the abundance of early cod juveniles than does the estimate of spawning stock biomass (SSB). For both series the intercepts are not significantly different from zero and the Durbin-Watson tests were not significant.

The early juvenile cod index is fairly strongly correlated with previous and subsequent life stages, though its relation with the 0-group indices (0-gr. log and 0-gr. area) appears to be inconsistent. The intercepts for the 0-group indices versus the EJC index are significantly different from zero and the EJC series appears to be more strongly related to the indices for later life stages than are the 0-group indices (Table 3), which implies that the EJC survey is more precise and less biased than the 0-group indices.

The relation between the abundance of cod as early juveniles and their abundance as two year olds (BT_2 and AC_2) is stronger than its association with the one-year-old indices (see Table 3). For example, r^2 between EJC and BT_1 equals 43%, r^2 for EJC and BT_2 equals 68% and between EJC and BT_3, r^2 equals 66%. This may indicate that BT_1 and AC_1 are less accurate than the indices for ages two and three.

The worst performing index appears to be the estimates of the abundance of cod as three year olds from a virtual population analysis of the stock (VPA_3). The correlations with VPA_3 and the indices for earlier stages are lower than those using the index of the abundance of three-year-old cod based on the bottom trawl survey (BT_3) or the acoustic survey (AC_3). In addition, the intercepts for all the regressions of the VPA_3 index versus the indices for earlier stages are positive and significantly different from

zero, while the intercepts for the survey based estimates are not significantly different from zero. A comparison of the VPA estimates and the survey based estimates of three-year-old cod is shown in Figure 2, which contains plots of BT_3, AC_3, and VPA_3 versus the early juvenile cod index.

In order to check whether the varying time periods covered by the indices caused the comparison of the indices to be biased, estimates of r^2 and associated statistics for the cohorts (1980-1991) that are covered by all the indices, except for total egg production which is available from 1985 onwards and is not included in this analysis, are given in Table 4. The results are similar to those given in Table 3, though for this period the early juvenile index appears to have performed much better than the 0-group indices when compared with their relative performance over differing time spans (Table 3).

Conclusions and Discussion

Taking into account the value of r^2, whether the intercept was significantly different from zero and if the Durbin-Watson test detected serial correlation, it appears that the most reliable relations between the index of the relative abundance at one stage versus that at a later stage are the following:

1) The total egg production index is a good indicator of the relative abundance of juveniles.
2) The juvenile stage is most consistently related to the relative abundance of two year olds based on the survey estimates (BT_2 and AC_2).
3) The survey estimates of the relative abundance of two-year-old cod are consistent with the survey estimates of their relative abundance at age three (BT_3 and AC_3).

The relative abundance of early juvenile cod appears to be a better predictor of year-class strength than the estimates of spawning stock size or total egg production. Given that the early juvenile stage is more closely related to later stages than are the earlier ones, then this implies that there is considerable year-to-year variation in mortality previous to the juvenile stage.

Since this study was based on indices of relative abundance, nothing can be inferred about the absolute size of the mortality between life stages. To estimate mortality, it is necessary to have estimates of the actual abundance at each stage. Because of the large uncertainty in estimates of the proportionality constant relating a survey index to absolute abundance, the resulting estimates of mortality would be very unreliable.

There are several reasons why the early juvenile index was more highly correlated with subsequent life stages than were the 0-group indices. Northeast Arctic cod spawn chiefly in the area around the Lofoten. The eggs and larvae are transported by the currents north toward Spitsbergen and into the Barents Sea (Helle, 1994). The early juvenile fish survey was designed, based on the spreading pattern of the eggs and larvae from the spawning grounds, to cover completely the spatial distribution of the cod juveniles, (Bjørke and Sundby, 1984, 1987). Since the 0-group survey is a multi-species survey, it is not designed to optimally cover the distribution of 0-group cod.

Additional factors, such as schooling and an early settling to the bottom, can reduce the accuracy of the 0-group surveys, while for early juvenile cod such factors can be neglected (Sundby et al., 1989).

The early juvenile and 0-group indices were more highly correlated with the survey indices for the abundance of two-year-old cod than with the survey indices for age one cod. Changes in survey coverage and gear since the inception of the winter survey in the Barents Sea affected the survey catchability and coverage of the young cod more than the older fish and, hence, the survey indices for younger cod are less accurate than for older cod (Jakobsen et al., 1997). Based on this study, it appears as if the survey indices for two-year-old cod are fairly accurate and consistent with the other indices.

The most incompatible series appears to be the VPA estimates of the number of three year olds. Since a VPA is based on commercial catch statistics, its accuracy can be greatly reduced due to, for example, unreported catch and discards (Nakken, 1998). As was the case in this study, surveys appear often to produce more accurate assessments of abundance trends than do catch based assessments (see, e.g., Marshall et al., 1998; Pennington and Strømme, 1998).

The comparison of the survey indices for the early life stages indicate that the early juvenile index performs the best. Given the possible biases in the 0-group survey (Sundby et al., 1989), it may be more effective to conduct a survey of the early juveniles in June and July if the goal is to predict the future recruitment of cod.

Acknowledgement

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Table 1. Summary of data sets included in this study.

Index	Age months	Year class	Unit	Area covered	Sampling gear	Reference
VPA (1998) SSB	0	1978-1997	1 000 tonnes			ICES (1999)
Total egg production	0	1985-1996	million	Lofoten and Barents Sea survey combined	not applicable	Marshall et al. (1998)
Early juvenile cod	3	1978-1991	no/trawl hour	The coast of North Norway and the western Barents Sea	Midwater trawl	Helle and Pennington (1999)
0-group area index (corrected for opening)	5	1978-1997		The Barents Sea and the coast of Spitsbergen	Midwater trawl	Nakken and Raknes (1996) ICES (1996)
0-group log index	5	1978-1997		The Barents Sea and the coast of Spitsbergen	Midwater trawl	ICES (1996)
Bottom trawl and acoustic index age 1	10	1980-1997	million	Barents Sea	Shrimp trawl (Bottom trawl)	Jakobsen et al. (1997)
Bottom trawl and acoustic index age 2	22	1979-1996	million	Barents Sea	Shrimp trawl (Bottom trawl)	Jakobsen et al. (1997)
Bottom trawl and acoustic index age 3	34	1978-1995	million	Barents Sea	Shrimp trawl (Bottom trawl)	Jakobsen et al. (1997)
1998 VPA age 3	33	1978-1995	million			ICES (1999)

Table 2. Indices used in the regression analysis.

Indices / Cohort	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
VPA (1998) SSB	402	244	164	167	401	320	259	212	166	112	187	196	350	697	882	751	604	537	651	727
Total egg production $*10^6$								40.5	35.8	3.6	4.1	10.8	68.6	109.0	320.0	320.0	232.0	116.0	44.8	
Early juvenile cod	189.6	169.4	4.0	220.3	76.2	2007.0	226.2	1376.2	9.9	63.8	44.0	117.0	1648.8	1849.4						
0-group area index (corrected for opening)	192	129	61	65	136	495	559	742	434	102	133	202	465	766	1159	910	899	1069	1142	1077
0-group log index	0.22	0.40	0.13	0.10	0.59	1.69	1.55	2.46	1.37	0.17	0.33	0.38	1.23	2.30	2.94	2.09	2.27	2.40	2.87	1.60
Bottom trawl index age1 (BT$_1$)			4.6	0.8	341.9	2864.4	57.8	769.3	28.1	3.9	8.0	170.9	451.5	126.5	533.5	1034.3	5253.4	5771.7	5250.0	2816.7
Acoustic index age 1 (AC$_1$)			8.0	4.0	0.0	1807.0	69.1	350.0	0.6	1.0	7.5	81.9	180.1	240.7	1083.8	872.4	2619.2	2412.9	1516.0	3083.8
Bottom trawl index age 2 (BT$_2$)		34.3	2.9	19.0	393.2	624.8	363.2	441.8	70.6	14.9	51.1	214.5	554.2	420.2	537.4	540.9	679.7	1097.2	685.6	
Acoustic index age 2 (AC$_2$)		82.0	5.0	19.0	150.0	446.3	236.2	34.1	14.6	7.9	24.3	220.9	562.2	485.4	570.8	292.7	324.1	467.3	552.4	
Bottom trawl index age 3 (BT$_3$)	16.4	28.3	22.3	115.9	149.5	634.6	236.5	168.9	44.7	27.1	33.4	154.6	274.5	296.3	275.9	167.0	258.8	424.0		
Acoustic index age 3 (AC$_3$)	40.0	49.0	13.0	31.0	153.1	498.9	62.8	46.0	17.2	14.8	50.5	177.2	359.5	345.8	167.0	91.5	179.2	375.7		
1998 VPA age 3	158	158	169	382	496	1015	270	196	158	213	416	759	1024	831	713	467	786			

Table 3. Summary statistics for the regression analysis (stage versus earlier stage) using all available data since 1978. The first number in the upper row of a cell below the diagonal is the model p-value, the second is the result of the Durbin-Watson test if the model is significant at the 5% level (S, significant; NS, not significant; I, inconclusive). In the second row is the value of r^2 and in parentheses is the number of data points. The symbols in the cells above the diagonal indicate if the intercept is significantly different from zero (-) or not (0).

	SSB	TEP	EJC	0-gr. log	0-gr. area	BT$_1$	AC$_1$	BT$_2$	AC$_2$	BT$_3$	AC$_3$	VPA$_3$
SSB	x	0	0	0	0	0	0	0	0	0	0	-
Total egg production TEP	<0.01 I 69.9 (12)	x	0	-	-	0	0	-	-	-	-	-
Rel. abundance of early juvenile cod (EJC)	0.03 NS 32.7 (14)	0.01 NS 77.0 (7)	x	-	-	0	0	0	0	0	0	-
0-group log.index	<0.01 S 53.1 (20)	0.04 S 35.2 (10)	<0.01 I 57.6 (14)	x	x	0	0	0	0	0	0	-
0-group area index	<0.001 S 66.5 (20)	0.02 S 44.8 (12)	<0.01 NS 57.0 (14)	x	x	0	0	0	0	0	0	-
Bottom trawl 1 year old (BT$_1$)	0.05 S 22.1 (18)	0.5 3.9 (12)	0.02 I 43.1 (12)	0.01 S 32.9 (18)	<0.01 S 43.0 (18)	x	x	-	-	-	-	-
Acoustic index 1 year old (AC$_1$)	<0.01 NS 39.0 (18)	0.09 25.5 (12)	0.01 NS 46.7 (12)	0.02 I 31.4 (18)	<0.001 NS 53.5 (18)	x	x	-	-	-	-	-
BT$_2$	<0.01 I 46.2 (18)	0.1 21.6 (12)	<0.001 NS 67.7 (13)	<0.001 NS 62.5 (18)	<0.001 NS 67.6 (18)	<0.001 I 63.4 (17)	<0.001 NS 67.9 (17)	x	x	0	0	-
AC$_2$	<0.001 NS 59.7 (18)	0.1 21.8 (12)	<0.01 NS 62.0 (13)	0.001 S 50.9 (18)	<0.001 S 55.1 (18)	0.04 S 26.3 (17)	0.01 S 33.7 (17)	x	x	0	0	-
BT$_3$	0.083 17.6 (18)	0.2 20.2 (11)	<0.001 I 66.1 (14)	<0.01 NS 39.6 (18)	0.01 NS 34.4 (18)	0.01 I 37.0 (16)	<0.01 I 47.4 (16)	<0.001 NS 63.61 (17)	<0.001 NS 60.9 (17)	x	x	x
AC$_3$	0.1 15.9 (18)	0.7 2.4 (11)	<0.001 NS 69.6 (14)	0.05 I 21.6 (18)	0.07 19.1 (18)	0.04 I 26.9 (16)	0.03 I 30.5 (16)	<0.01 NS 52.8 (17)	<0.001 NS 68.8 (17)	x	x	x
VPA$_3$	0.06 21.5 (17)	0.4 9.4 (10)	<0.01 S 50.9 (14)	0.1 17.4 (17)	0.1 17.2 (17)	0.09 20.7 (15)	0.05 S 27.1 (15)	<0.01 I 50.4 (16)	<0.001 NS 73.5 (16)	x	x	x

Table 4. Summary statistics for the regression analysis of the 1980 through 1991 cohorts. The notation is the same as in Table 3.

|	SSB	EJC	0-gr. log	0-gr. area	BT₁	AC₁	BT₂	AC₂	BT₃	AC₃	VPA₃
SSB	x	0	0	0	0	0	0	0	0	0	0
Rel. abundance of early juvenile cod (EJC)	0.03 NS 40.3	x	-	-	0	0	-	0	0	0	-
0-group log.index	0.06 31.3	<0.01 I 55.7	x	x	0	0	0	0	0	0	-
0-group area index	0.06 31.8	<0.01 NS 55.0	x	x	0	0	0	0	0	0	-
Bottom trawl 1 year old (BT₁)	0.6 2.6	0.02 I 43.1	0.2 15.8	0.3 10.3	x	x	-	0	-	-	-
Acoustic index 1 year old (AC₁)	0.5 4.3	0.01 NS 46.7	0.2 17.7	0.3 12.9	x	x	-	-	-	-	-
BT₂	0.03 NS 39.1	<0.001 NS 67.3	<0.01 I 51.3	<0.01 NS 48.7	0.02 I 44.2	0.03 NS 39.2	x	x	0	0	0
AC₂	<0.01 NS 54.3	<0.01 NS 61.2	0.1 24.2	0.07 29.6	0.1 20.4	0.1 23.6	x	x	0	0	-
BT₃	0.09 25.7	<0.01 NS 64.9	0.06 30.9	0.07 28.6	<0.001 I 75.5	<0.001 I 79.7	<0.001 NS 70.5	<0.01 NS 60.6	x	x	x
AC₃	0.02 NS 44.8	<0.001 NS 68.1	0.2 19.3	0.2 19.5	<0.01 S 50.1	<0.01 S 53.5	<0.01 NS 64.9	<0.001 NS 84.5	x	x	x
VPA₃	0.04 NS 36.6	<0.01 I 48.8	0.5 5.7	0.4 7.4	0.07 28.7	0.06 30.3	<0.01 I 47.7	<0.001 NS 80.7	x	x	x
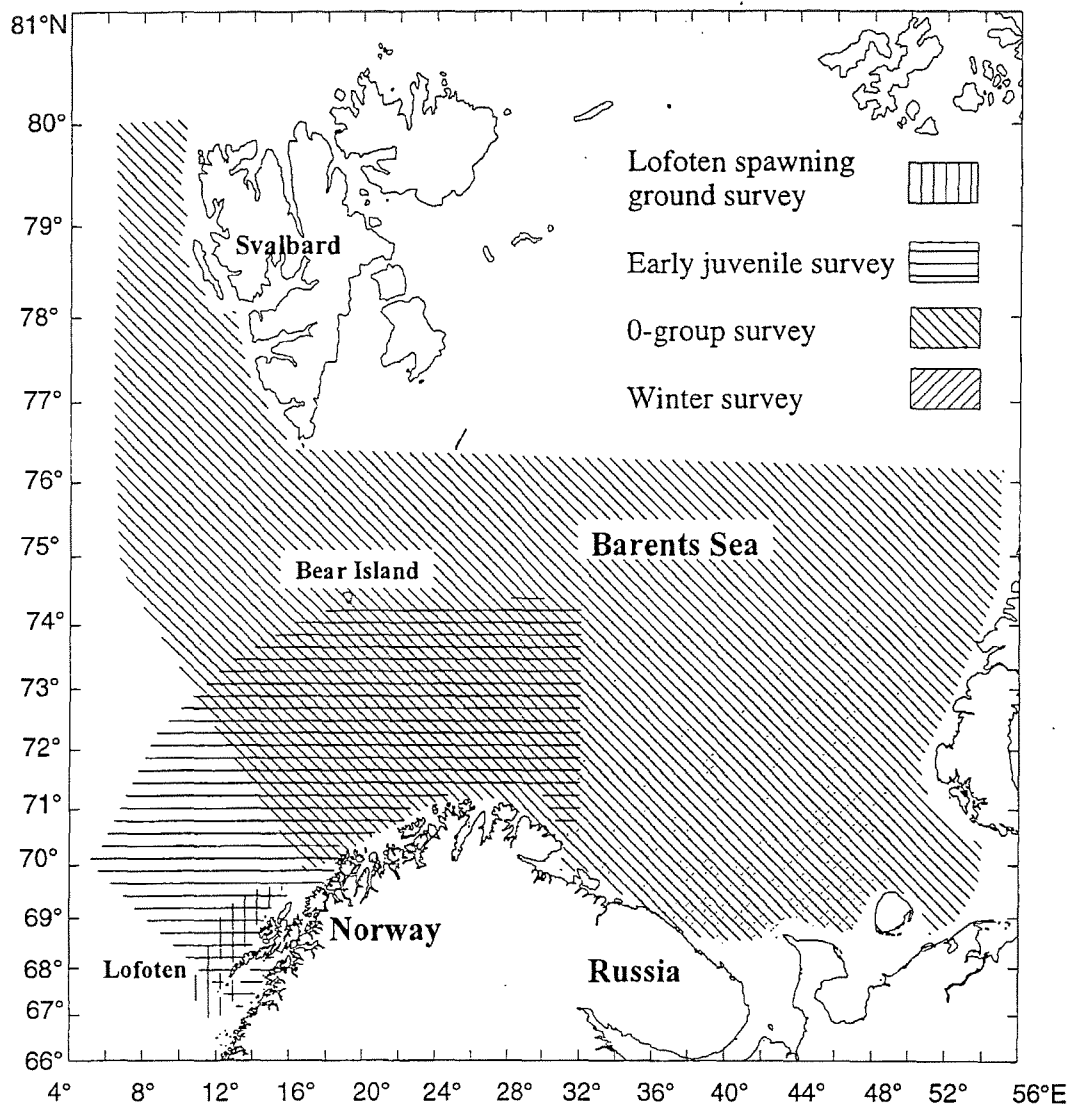
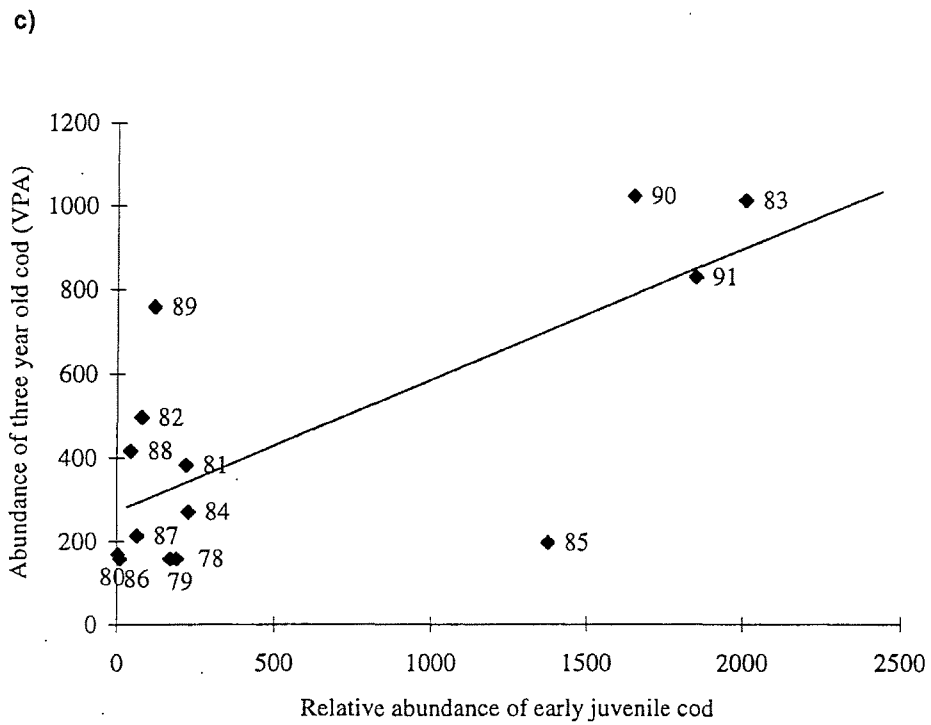Figure 1. The general areas covered by the four surveys.

a)

b)

c)
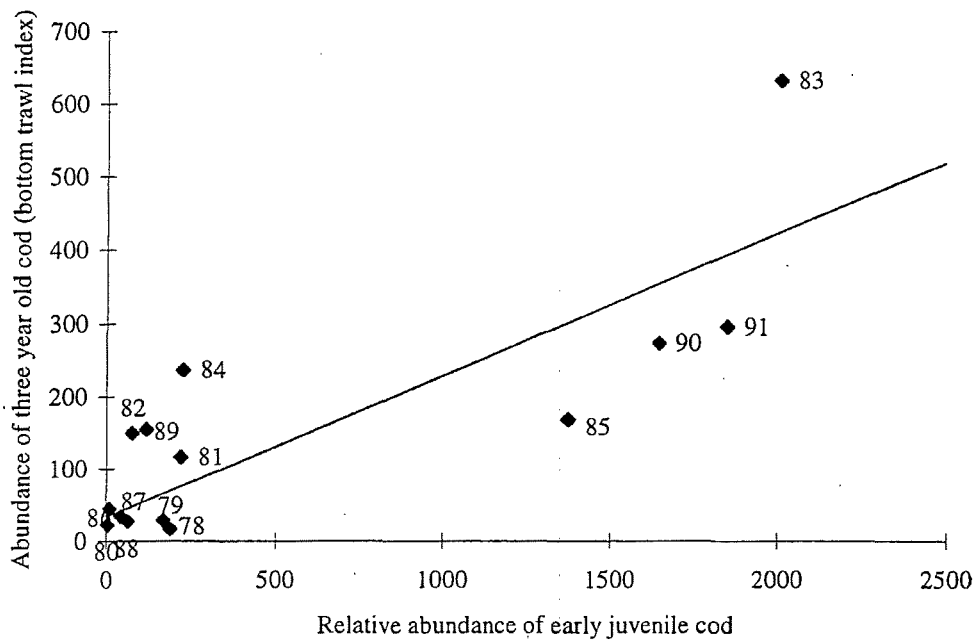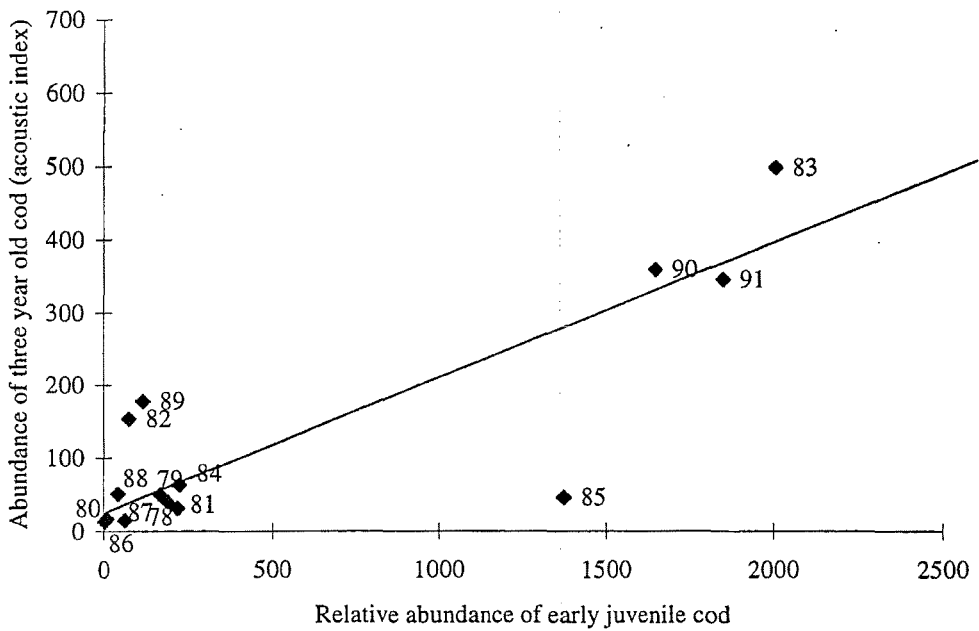
Figure 2. Plots of estimates of the relative abundance of three-year-old cod [(a) acoustic survey; (b) bottom trawl survey, (c) VPA estimates] versus their relative abundance as early juveniles. Next to each point is the year class. The intercepts in panels (a) and (b) are not significantly different from zero while the intercept in panel (c) is significantly different from zero.