NAFO Sci. Coun. Studies, 29: 23–29

A Combined Recruitment Index for Demersal Juvenile Cod in NAFO Divisions 3K and 3L

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Abstract

Several indices have been developed to assess the relative abundance of pre-recruit cod (age 0 to 3 years) in NAFO Div. 3KL. A new analysis was undertaken to determine the homogeneity of catches across surveys based on the interaction term in a two-way classification of catch, by year and by survey. The interaction F-ratios tended to be small, often less than unity. This homogeneity in year-to-year change across surveys meant that a single composite index could be constructed by averaging across surveys within each year. However, a simple average gives undue weight to the series that has the largest mean value, which is an undesirable characteristic. In the absence of an acceptable weighting, and in light of the similarity in trends of the indices, a narrative index was constructed that reported the evolution of each year-class, as seen in the several surveys. This showed that two cohorts (1992 and 1993) began weakly but became somewhat stronger at age 1 and 2, with a strong offshore shift in distribution. Two cohorts (1994 and 1995) began more strongly. Two cohorts (1993 and 1994) suffered substantial weakening in 1995 (as age 2 and age 1, respectively). Only the 1995 year-class now appears promising.

Key words: cod, cohort strength, *Gadus morhua*, multiple surveys, northwest Atlantic, recruitment index

Introduction

A variety of indices have been developed using different survey data to assess the relative abundance of pre-recruit cod (age 0 to 3 years) in NAFO Div. 3KL. The surveys include:

1. An inshore pelagic juvenile survey (Anderson and Dalley, MS 1995).
2. An offshore pelagic juvenile survey (Anderson and Dalley, MS 1995).
3. A coastal survey using bottom seines in coastal nursery habitat (Schneider *et al.*, MS 1995),
4. An inshore demersal juvenile survey using campelen trawls (Dalley and Anderson, 1996),
5. An offshore demersal juvenile survey using campelen trawls (Dalley and Anderson, 1996).

During the 1995 stock assessment, these surveys were combined on an informal basis by comparing the ranking of each year-class within each age group. This analysis showed that in general the ranking was 1994 > 1993 > 1992 for first year (*LG*0 = length group 0+) fish. The ranking was 1994 > 1993 > 1992 for second year (*LG*1) fish. The ranking was 1994 > 1993 > 1992 for third year (*LG*2) fish. A multiplicative model of the same data set showed that the reliability of this index was as good as any index for cod in the North Atlantic. It was thus of interest to determine whether a composite index could be developed.

A series of analyses were undertaken. The first was to determine whether the cohort projection model (Ings *et al.*, 1996) used with the coastal survey (Schneider *et al.*, MS 1995) could be extended to the other surveys. As background for this, the coastal survey model was tested by adding the 1994 cohort and recomputing the parameter estimates for the model. The second analysis was to determine whether the observed pattern of similar rankings can be extended to a ratio scale: Is the change from year-to-year homogeneous across surveys? The third analysis looked at the problems associated with constructing a single numerical index. A narrative index of cohort evolution is presented in this report.

Methods

Data were taken from three sources: pelagic inshore and offshore surveys (Anderson and Dalley, MS 1996), coastal demersal survey (Schneider *et al.*, 1996), and inshore and offshore demersal surveys (Dalley and Anderson, MS 1996). Procedures for collection, including changes in protocol, are described in these documents. Statistical analyses were carried out within the framework of the Generalized Linear Model (McCullagh and Nelder, 1989) which has the advantage of permitting non-normal error structures.

Results

Can the cohort projection model used in 1994 be extended to 1995?

Data from the 1959–64 and 1992–95 coastal surveys were used to investigate whether a recruitment signal could be detected. These data for 1992–95 are shown in Fig. 1. A recruitment signal from one year to the next, on a ratio scale, was detectable when two successive years were used (Δ deviance = 6.474, df = 2, p = 0.04 gamma error structure were reported by Schneider *et al.*, MS 1995). An iterative weighting algorithm was used to estimate the parameters of the cohort projection model:

$$LG1 = \beta_{0\to1} LG0$$
$$LG2 = \beta_{1\to2} LG1$$

where, $\beta_{0\to1}$ is the product of two quantities, the loss due to natural mortality $e^{-\mu t}$ during t = 1 year, and the ratio of catchabilities of $LG1$ and $LG0$ fish α_1/α_0, and

$\beta_{1\to2}$ is the product of the loss due to natural mortality $e^{-\mu t}$ during t = 1 year, and ratio of catchabilities of $LG2$ and $LG1$ fish α_2/α_1.

The estimates for the two composite parameters were:

$$\beta_{0\to1} = 0.7984 \quad \text{standard error} = 0.1112$$

$$\beta_{1\to2} = 0.02019 \text{ standard error} = 0.00061$$

When the 1995 data were added, a normal error structure was found to be acceptable for both equations. The analysis of deviance showed a significant recruitment signal for the combined analysis, although not for the $LG1 \to LG2$ component by itself (Table 1).

Table 1 shows the deviance of the data from the source term when it is present in the model. Thus, for $LG1$ fish, the deviance was 13 010 from the overall mean β_0. This dropped to a deviance of 1 449 when a regression against age 0 fish (β_{LG0}) was added to the model. The change in deviance was 11 561 on one degree of freedom, a significant improvement (p <0.001 calculated from a Chi square distribution). The change in deviance for the combined model (Δ deviance = 11 561 + 1.421) exceeded the degrees of freedom (df = 2)

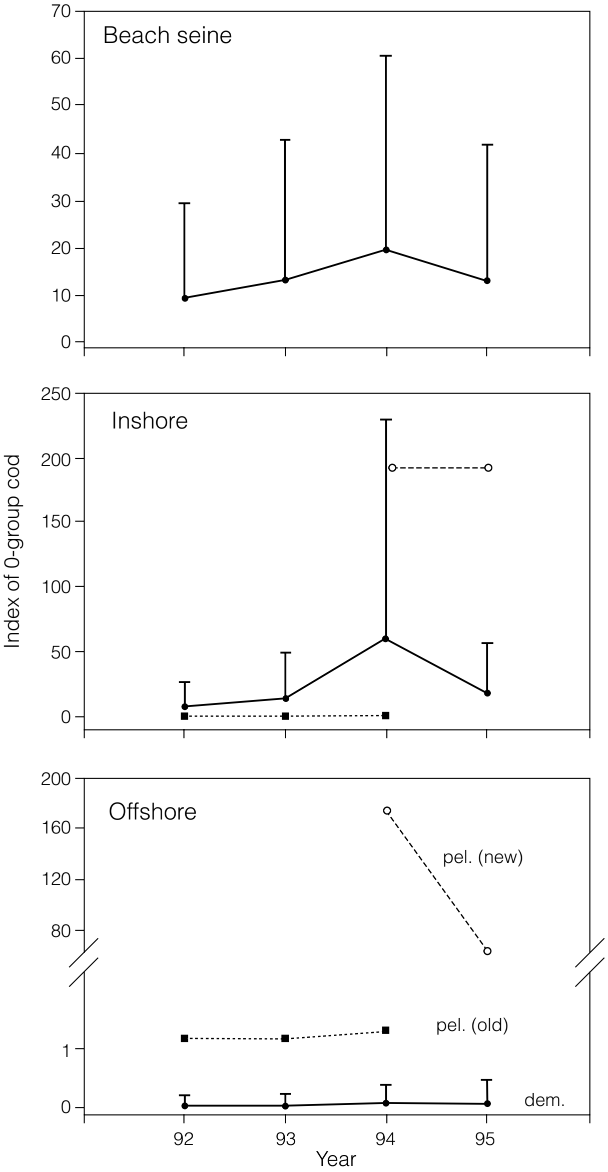

Fig. 1. Indices of 0-group cod for 1992–95 in NAFO Div. 3K and 3L. The beach seine and demersal trawl surveys are shown with 1 standard deviation above the mean.

TABLE 1. Analysis of deviance.

$LG1 = \beta_{LG0} \cdot LG0$			$LG2 = \beta_{LG1} \cdot LG1$		
Source	Deviance	df	Source	Deviance	df
β_0	13 010	7	β_0	2.655	5
$\beta_0 + \beta_{LG0}$	1 449	6	$\beta_0 + \beta_{LG0}$	1.234	4
The change	11 561	1		1.421	1

and was significant ($p < 0.001$, again as calculated from a Chi square distribution). The addition of the 1995 data did not substantially change the parameter estimates.

$\beta_{0 \to 1} = 0.7785$ standard error = 0.08395

$\beta_{1 \to 2} = 0.01909$ standard error = 0.0058385

Can the cohort projection model be extended to the other surveys?

This was tested by an analysis of covariance of the data in Fig. 1 (age 0), Fig. 2 (age 1) and Fig. 3 (age 2). The analysis of deviance showed that the slopes were heterogeneous across surveys for the transition from *LG*0 to *LG*1 (Table 2). A normal error structure was found to be acceptable for the first analysis, but not the second, where a gamma error structure was used.

Analysis of deviance showed no heterogeneity across surveys for the transition from *LG*1 to *LG*2 fish. This suggested that the ratio of catchabilities of *LG*2 to *LG*1 cod was similar in all three surveys, while the ratio of catchabilities of *LG*1 to *LG*0 cod differed among the surveys. Examination of the data indicated that the trawl gear was substantially less efficient than the bottom seine in capturing *LG*0 fish, relative to *LG*1 fish. In general the cohort projection model could be applied to all surveys for *LG*1 or larger fish and the model would have to be applied separately to each survey for the transition from *LG*0 to *LG*1.

Are year-to-year changes within a length group homogeneous across surveys?

Analyses in previous assessments showed that rankings of years within length (age) groups for one survey was similar to that of another. Homogeneity across surveys was tested by estimating the interaction term in a two-way classification of catch, by year (4) and by survey (3). The data for this were only available as means and variances for each of the $3 \times 4 = 12$ cells in the two-way table and hence the iterative fitting scheme used for generalized linear models could not be applied. Means (as in

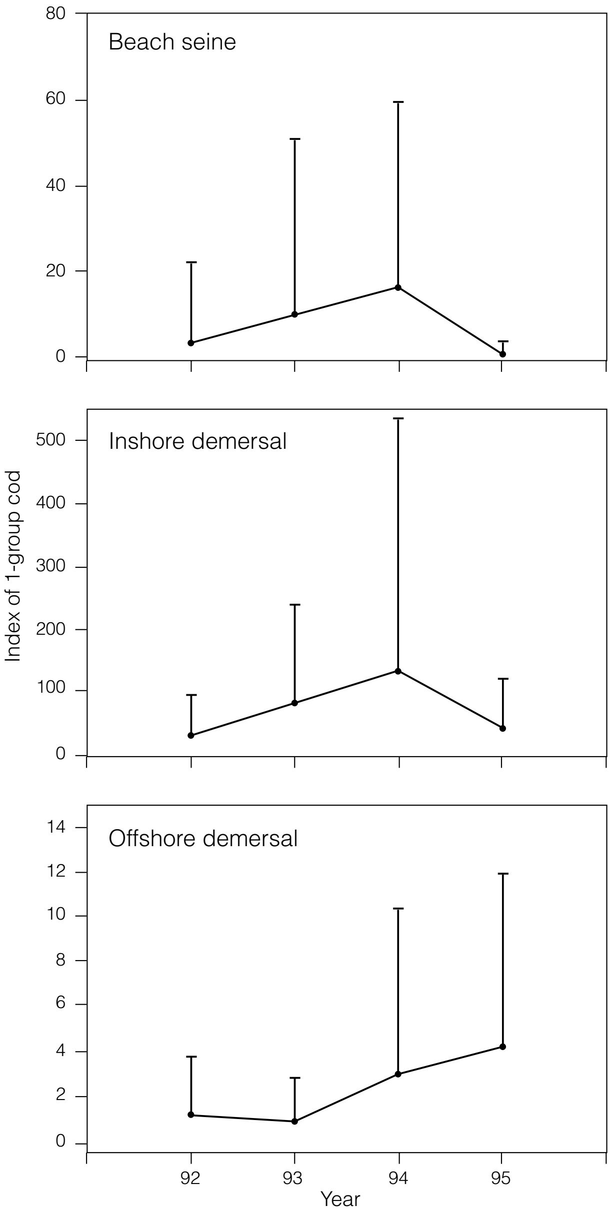

Fig. 2. Indices of 1-group cod for 1992–95 in NAFO Div. 3K and 3L. The beach seine and demersal trawl surveys are shown with 1 standard deviation above the mean.

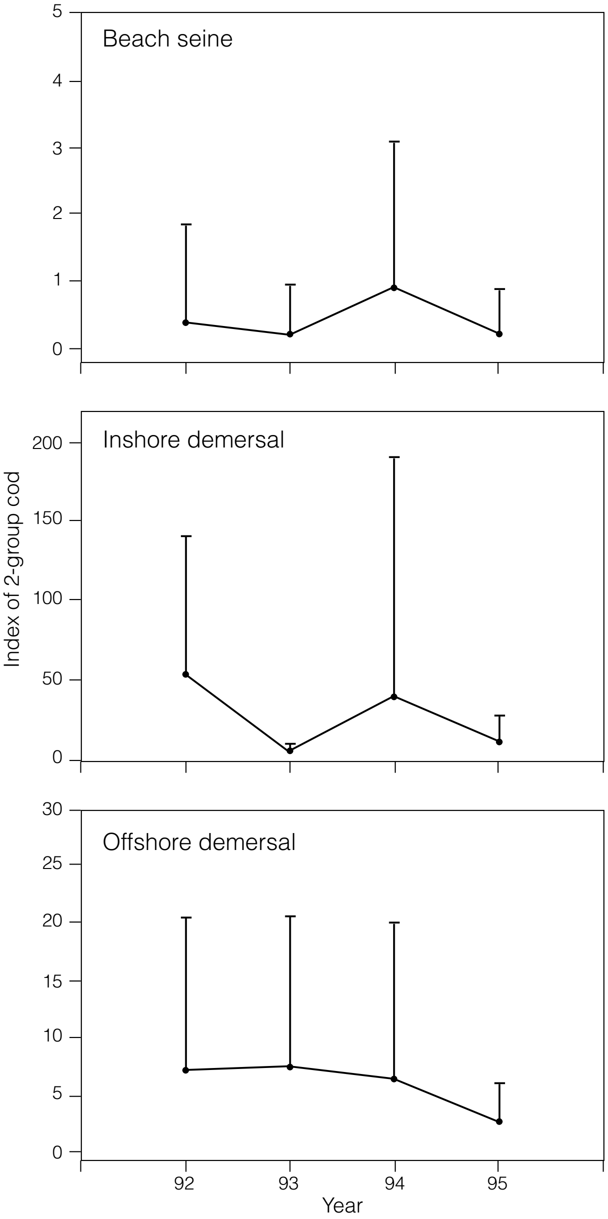

Fig. 3. Indices of 2-group cod for 1992–95 in NAFO Div. 3K and 3L. The beach seine and demersal trawl surveys are shown with 1 standard deviation above the mean.

Fig. 1, 2 and 3) and associated variances were therefore used to reconstruct ANOVA tables, under that assumption that sample sizes were large enough to assume normal distribution of errors. The means, sample sizes (within parentheses), F-ratios and associated *p*-values for each survey were as shown in Table 3.

The interaction F-ratios tended to be small, often less than unity. This homogeneity in year-to-year change across surveys meant that a single composite index could be constructed by averaging across surveys within each year.

Can a composite index be constructed?

The problem that arises in constructing a single numerical index is that of weighting the contribution of each index to the composite estimate for the year. A simple average will give undue weight to the index that has the largest mean; extreme values within a series will also have a large influence. The choice of an appropriate weighting is not straightforward, as there are several possible considerations: e.g. by area, by inverse of variance, etc. A further disadvantage of a composite number is that this leaves aside the biological differences among the surveys. One notable example is the change in distribution with age (according to Heincke's Law): small (0+) fish settle in coastal nurseries, then spread away from the coast at age 1, becoming more widely distributed in deeper water at age 2.

Because of these problems, and in light of the similarity in trends of the indices, we opted for a narrative index that reports the evolution of each year-class, as seen in the several surveys. The narrative is based on cross product ratios, defined as R1 / R2, where:

RA = Catch(cohort, Age 0) / Catch(same cohort, Age 1) for survey A

RB = Catch(cohort, Age 0) / Catch(same cohort, Age 1) for survey B.

The cross product ratio reflects the joint action of mortality, the ratio of catchabilities, and shifts in distribution. However, for many comparisons some of these factors will cancel out of the cross product ratio. For example, the effects of differential catchability (Methven, MS 1995) will cancel out of the cross product ratio for the inshore/offshore survey comparison. It then becomes possible to use this information to constrain the interpretation of the observed changes in catches from a cohort as it ages. With these constraints in mind, the following narrative of cohort evolution was constructed for the Div. 3KL area for the period from 1989 to 1995. Note that the 1989 year-class appears in the 1992 inshore and offshore demersal survey (Fig. 4).

The 1992 cohort was relatively weak during its pelagic stage, remaining weak just after settlement at the bottom. This cohort became somewhat stronger relative to other cohorts at age 1 and 2;

TABLE 2. Analysis of deviance.

$LG1 = \beta_0 + \beta_{LG0} + \beta_{svy} + \beta_{LG \times svy}$			$LG2 = \beta_0 + \beta_{LG1} + \beta_{svy} + \beta_{LG1 \times svy}$		
Source	Deviance	df	Source	Deviance	df
$LG0$ + svy + $LG0 \times svy$	7 146	10	$LG1$ + svy + $LG1 \times svy$	5.29	10
$LG0$ + svy	3 644	9	$LG1$ + svy	5.07	8
$LG0 \times svy$	3 502	1	$LG1 \times$ svy	0.12	2

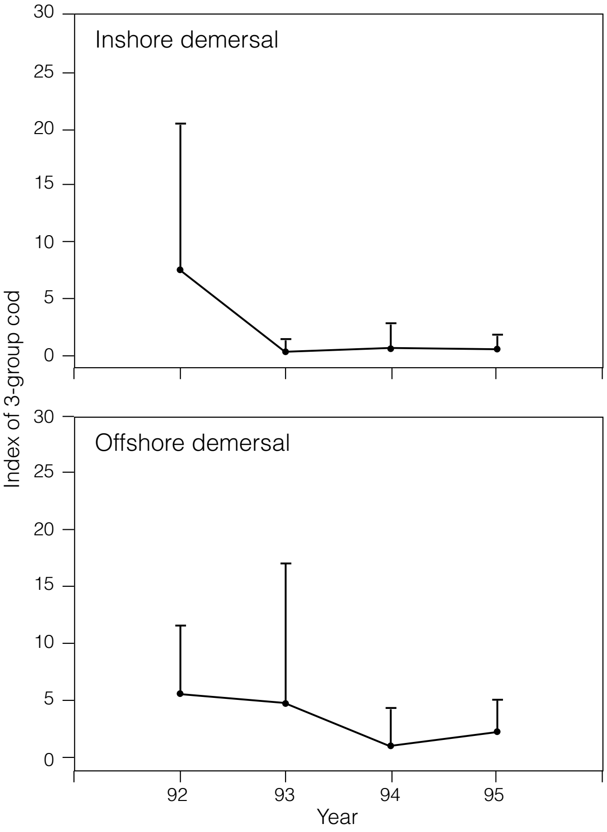

Fig. 4. Indices of 3-group cod for 1992–95 in NAFO Div. 3K and 3L from inshore and offshore demersal surveys are shown with 1 standard deviation above the mean.

this was especially true inshore. However, this cohort at age 3 still remained weak relative to the 1989 and 1991 cohorts.

The 1993 cohort began as a weak cohort in the plankton, remaining so upon settlement at the bottom. This cohort became stronger at age 1 especially inshore, but then suffered a substantial weakening in 1995, as two year old fish.

The 1994 cohort began more strongly than the two previous cohorts; it was also stronger than its predecessors upon settlement at the bottom, reaching densities in coastal nursery areas comparable to low values in the 1960s. This cohort suffered a substantial weakening in 1995, as 1 year old fish.

The 1995 cohort was comparable to the 1994 cohort in strength as pelagic larvae and just after settlement. There was some indication of distribution which was more restricted to coastal areas than the previous cohort.

Summary and Discussion

The cohort projection model developed for cod in the coastal zone could not be used to combine several surveys because the slopes(β) were found to differ among surveys. This might be due to differences in mortality among the areas surveyed (coastal, inshore and offshore). A more likely source of variation in slopes relating one year-class to another is that the ratio of catchabilities of two age-classes will not be the same for the trawl and bottom seine. Changes in collection protocol, such as change in use of net liner in the trawl, could also contribute to heterogeneity of slopes. The inconsistency of slope meant that an estimate of natural mortality, from one age-class to the next, could not be estimated directly by taking the slope common to all surveys, for the cohort projection model.

When annual change was treated as a classification variable, rather than regression variable, the change in abundance of a year-class (expressed as a difference rather than ratio) was found to be homogeneous across the three demersal surveys. Interaction terms in two way classifications were found to be small in magnitude, indicating consistency of year-to-year change across the surveys. Consistent patterns of change

TABLE 3. Means (sample sizes) with F-ratios and p-values for ANOVA tests.

	Inshore	Offshore	Comparison	F	p
		*LG*0 Demersal			
1992	7.59 (27)	0.03 (37)	svy × year	1.57	0.21
1993	14.37 (27)	0.03 (36)	year	2.93	0.034
1994	59.96 (26)	0.08 (40)	svy	12.51	<0.001
1995	19.04 (25)	0.06 (39)			

	Inshore	Coastal	Comparison	F	p
		*LG*0 Demersal			
1992	7.59 (27)	9.598 (46)	svy × year	0.66	0.58
1993	14.37 (27)	13.250 (44)	year	3.6	0.014
1994	59.96 (26)	19.78 (40)	svy	2.38	0.124
1995	19.04 (25)	13.264 (36)			

	Demersal	Pelagic	Comparison	F	p
		*LG*0 Inshore			
1992	7.59 (27)	1.066 (18)	svy × year	12.01	0.14
1993	14.37 (27)	1.047 (26)	year	1.84	0.16
1994	59.96 (26)	1.506 (23)	svy	4.61	0.033

	Inshore	Offshore	Comparison	F	p
		*LG*1 Demersal			
1992	34.22 (27)	1.24 (37)	svy × year	1.03	0.46
1993	83.67 (27)	0.97 (36)	year	1.76	0.16
1994	136.0 (26)	3.05 (40)	svy	17.54	<0.001
1995	47.0 (25)	4.26 (39)			

	Inshore	Coastal	Comparison	F	p
		*LG*1 Demersal			
1992	34.22 (27)	3.95 (46)	svy × year	0.54	0.66
1993	83.67 (27)	10.22 (44)	year	2.4	0.068
1994	136.0 (26)	16.45 (40)	svy	16.19	<0.001
1995	47.36 (25)	1.19 (36)			

	Inshore	Offshore	Comparison	F	p
		*LG*2 Demersal			
1992	54.07 (27)	7.3 (37)	svy × year	1.69	0.17
1993	5.19 (27)	7.69 (36)	year	2.85	0.38
1994	39.85 (26)	6.68 (40)	svy	9.74	0.002
1995	12.88 (25)	2.93 (39)			

	Inshore	Coastal	Comparison	F	p
		*LG*2 Demersal			
1992	54.07 (27)	0.391 (46)	svy × year	1.66	0.176
1993	5.19 (27)	0.238 (44)	year	3.19	0.024
1994	39.85 (26)	0.938 (40)	svy	17.67	<0.001
1995	12.88 (25)	0.264 (36)			

within a cohort were detectable across gear (small interaction terms), even though mortality could not be estimated directly because of heterogeneous slopes in the previous analysis.

The narrative index was constructed, based on consistent patterns of change within a cohort, across gear and location. This indicated that two cohorts that began weakly (1992 and 1993) became somewhat stronger at age 1 and 2, with strong offshore shift in distribution. Two cohorts (1994 and 1995) began more strongly. Two cohorts (1993 and 1994) suffered substantial weakening in 1995 (as age 2 and age 1 fish, respectively).

This analysis of annual change in cohort strength across three surveys showed that cohort strength of cod changed substantially from year to year. One important implication of this finding is that recruitment to fishable sizes (ages 4 and older) could not be predicted from initial cohort size at age 0, even if this were known perfectly. Efforts to predict recruitment of cod to fishable sizes from physical and biological factors during the first year of life are unlikely to be successful in the presence of substantial changes in cohort strength during the first four years of life. It is not known whether the degree of change in cohort strength observed in this analysis will continue, or whether it is a temporary situation associated with the currently low spawning biomass of cod.

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