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On the relation between 'true' numbers of Northeast Arctic cod and VPA- or survey-based abundance estimates

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Abstract

When assessing Northeast Arctic cod it is assumed that the estimates of numbers at age generated by a converged VPA type analysis are equal, on average, to the true numbers at age. Based on fishery independent survey data, we show that it is likely that the converged VPA estimates are biased, especially so for small cohorts. The probable cause of this bias is either inaccurate catch data including erroneous age readings and/or using the wrong functional form in the VPA tuning procedure. We provide evidence that it is appropriate to assume that the expected survey-based estimates are proportional to actual abundance. Therefore, we suggest that proportionality should be assumed for all ages when calculating survey catchability (*i.e.* in the VPA tuning procedure) or using the survey to estimate abundance directly. Since the converged VPA estimates of small cohorts seem to have a relatively high bias compared with those for large cohorts, only the converged VPA estimates for large cohorts should be used in the tuning process. This will not eliminate the bias in the VPA estimates caused by the tuning procedure, but it should reduce it.

Key words: Northeast Arctic cod, trawl survey, virtual population analysis.

Introduction

There are two independent estimates of the abundance or relative abundance of Northeast Arctic cod; one based on commercial catch data and the other, a fishery independent abundance index generated by research surveys. For the converged VPA estimates, which only depend on the commercial data, it is assumed that

$$\text{Hypothesis:} \quad E[N_i] = P_i, \tag{1}$$

where N_i is the estimated stock number at age in year i from the VPA and P_i is the true number in the population.

For a survey series, it is generally assumed that the expected value of the survey index, I_i, is proportional to numbers at age. That is

$$\text{Hypothesis:} \quad E[\beta I_i] = P_i. \tag{2}$$

If hypotheses (1) and (2) are both valid then

$$E[N_i] = \beta E[I_i] \tag{3}$$

The estimates, N_i and I_i, can be expressed as

$$N_i = E[N_i] + \varepsilon_i \qquad \text{and} \qquad I_i = E[I_i] + \delta_i, \tag{4}$$

respectively, where ε_i and δ_i are random errors. Then it follows from equations (1) through (4) that

$$N_i = \beta I_i + \xi_i, \tag{5}$$

where $\xi_i = \varepsilon_i - \beta\delta_i$. Though equation (5) is in the form of a standard regression equation, it differs since I_i and ξ_i are generally not independent, and, therefore, the standard regression estimator of β is usually biased (for more details, see Draper and Smith, 1981). If the variance over time of the expected survey index, $E[I_i]$, is large with respect to the variance of δ_i, then the bias of the standard regression estimator of β will be small and can be safely ignored (Draper and Smith, 1981).

Since the VPA estimates are presently the basis for management decisions and the survey series is used to 'tune' the current VPA assessment, it is necessary to determine whether hypotheses (1) and (2) are acceptable. A way to test these assumptions is to add an intercept to equation (5) and fit the equation to the VPA and survey estimates. In particular, if the intercept is significantly different from zero, then this implies that one or both of the hypotheses (1 and 2) are not acceptable.

The relation between N_i and I_i for Northeast Arctic cod

Unfortunately, it appears that for Northeast Arctic cod, either the survey indices or the VPA estimates are not proportional to true numbers at age. This is because the converged VPA (XSA) estimates of number at age are not proportional to their respective swept-area abundance indices generated by the Norwegian bottom trawl surveys, but there seems to be a linear relation. That is

$$N_i = \beta I_i + \alpha, \tag{6}$$

where the estimated intercept, $\hat{\alpha}$, is positive and significantly different from zero for ages 4 through 6 and 7+, with estimated slope, $\hat{\beta}$, that increases with age (Aglen and Nakken 1997, Jakobsen *et. al* 1997, Korsbrekke *et. al.* 1999 and 2001). Fig. 1 shows the observations and the fitted regressions for the period 1981 through 1995.

Korsbrekke *et al*. (1999; 2001) used equation (6) to predict stock numbers for the most recent years (VPA not converged) and showed that the estimates compared much better with the most recent assessment than with the annual assessments. They were, however, concerned with the implications of a relatively large positive value of the intercept, α , in equation (6). The intercept will tend to 'maintain' stock numbers as index values are decreasing and hence estimates of changes in stock size based on equation (6) will be biased, especially so when abundance is low, that is the stock may decline at a faster rate than indicated by the survey-based estimates.

Assessing the hypotheses

An intercept in equation (6) different from zero implies that the VPA estimates, or the abundance index, or both, are not proportional to actual abundance. Do we have any information as to which of these possibilities is more likely for this stock?

Evidence from survey results

Helle *et al.* (2000) found that the survey estimates of the relative abundance of Northeast Arctic cod as three year olds were proportional to survey estimates of the cohort's abundance at earlier life stages, while the VPA estimates of three-year-olds were not proportional to survey indices for the younger stages, and in particular, the intercepts were significantly positive. The consistency of the survey indices is an indication that it may be the converged VPA estimates that are not proportional to 'true' stock numbers, that is reject Hypothesis (1).

Evidence from age readings

It is well known that (random) errors in age reading tend to reduce differences in year class abundance between neighboring year-classes (Hilborn and Walters 1992). In our case the question is: Can age reading errors affect commercial catch at age data (VPA) and survey abundance indices differently and in such a way that the intercept in equation (6) becomes positive?

Norway and Russia account for 80-90 percent of the total annual catch of Northeast Arctic cod; 40-45 percent from each of the two countries. The Norwegian catch is converted to numbers-at-age based on age readings made at the IMR, and the Russian catch numbers are based on age readings at PINRO. Catches by other countries are in some cases provided as catch numbers at age to the Arctic Fisheries Working Group, if not, Norwegian or Russian age samples are used to calculate catch numbers at age.

Thus the total annual catch in numbers at age used in the VPA depends on age readings carried out at several (mainly two) laboratories and by many readers, while the survey abundance indices at age are based on the work of 1-3 readers at a single laboratory. Yaragina *et al*. (1998) showed that the discrepancies in age readings between PINRO and IMR varied between 17 and 34 percent during the years 1992-1996. Most often PINRO aged fish 1 year older than IMR. When age readings were conducted jointly and discussed by the staff from the two institutes (PINRO and IMR), the discrepancies were reduced to 2-10 percent (Fig. 2). From this we conclude that discrepancies in age readings between the institutes are considerably larger than within the institutes and that catch numbers at age are subject to larger 'uncertainties' caused by age reading than are survey abundance indices at age.

The obvious effect of a larger error rate for the commercial catch data is that VPA type estimates of year-class abundance are more smoothed than are the survey abundance indices. In other words; the transfer of fish (smearing) among age groups because of aging errors is larger in the catch data than in the survey data. For example, assuming error rates of 30 and 5 percent for the commercial and survey catch data, respectively, and that the age is one year "wrong" at random, then this would result in the age distributions shown below:

Age	2	3	4	5	6
True distribution	20	10	100	10	20
Catch estimates	16+	25	73	25	16+
Survey estimates	19+	13	96	13	19+

As the '+' sign indicates, the numbers of estimated 2 and 6 year olds will of course depend on the 'true numbers' of 1 and 7 years, which in this example are ignored. Though simple, this example illustrates the effect that aging errors can have on estimates of the age distribution, especially for small year classes.

Another source of bias for the VPA catch-at-age estimates is that it is difficult to obtain a sample from the commercial catch that is representative of the entire catch. In contrast, survey sampling can be carefully designed and implemented to minimize bias and maximize precision.

Bias and the VPA tuning procedure

To estimate the current stock numbers using the VPA procedure, it is necessary to 'tune' the VPA. That is use survey indices of abundance to estimate the number of fish in a cohort that is still in the population. The XSA assessment program has two options for relating stock numbers at age, N_i, and survey abundance indices, I_i. They are:

I. Proportionality: $N_i = \beta I_i$, *i.e.* survey catchability is independent of abundance.

II. Power curve: $N_i = \alpha \cdot I_i^{\beta}$, *i.e.* survey catchability is a function of abundance.

One or both of the equations is used to tune the XSA. In the most recent assessments of Northeast Arctic cod (ICES, 2000 and 2001), Option I (the proportionality assumption) has been applied to ages > 5 years while Option II (the power curve) has been used for ages $\leq$ 5 years

The appropriateness of Option I depends on the validity of Hypotheses (1) and (2), which, as shown above, is unlikely to be true for Northeast Arctic cod. If Option II is applied, then this implies that survey catchability increases rapidly at low population levels. It appears that the major motivation for using Option II is that it 'fits' the observed estimates. A likely explanation for the power curve fitting these estimates is that the VPA estimates of the abundance of relatively small cohorts are significantly biased upwards. It is an open question whether using an inappropriate tuning procedure caused the apparent biases in the VPA estimates or if it is caused by the biases and uncertainties inherent in estimates of the amount and age distribution of commercial catches (Korsbrekke *et al.*, 2001).

Discussion and conclusions

Godø (1995) provides an argument for the existence of density dependent trawl survey catchability for Northeast Artic cod and, therefore, a justification for using Option II in the tuning procedure. Based on the social behavior of cod, he suggests that cod are more 'catchable' when they are schooling than when scattered, and thus survey catchability will increase as cod density increases. He then assumes that the converged VPA estimates are unbiased (that is Hypothesis 1 is valid) and uses a power curve to describe the apparent increasing survey catchability with increasing density. Furthermore, Godø *et al.* (1999) show, based on field experiments, that the catchability of cod appears to decrease at low densities for 30 – 49 cm cod (ages 3 and 4), while catchability did not seem to decrease with density for cod greater than 50 cm (ages 5 and older).

If decreasing catchability with density is the reason for the positive intercepts, then we would expect that the intercepts for the regressions of converged VPA estimates on acoustic indices of abundance would be much smaller than those observed when the independent variable is the swept area index. This is because the acoustic indices are based on acoustic density measurements and catch compositions, which are, for the most part, independent of catch quantity. Comparisons show that the intercepts are not significantly different for the two indices, swept area and acoustics (Aglen and Nakken, 1997, Helle *et al*., 2000).

Based on the consistency of survey abundance indices for a cohort of Northeast Arctic cod at various life stages (Helle *et al*., 2000) and the discrepancies in age readings (Yaragina *et al.*, 1998), we conclude that the swept-area indices are likely proportional to true stock numbers (Hypothesis 2 is not rejected) and that the converged VPA estimates are biased (*i.e.* reject Hypothesis 1). In particular, VPA abundance estimates of small cohorts are significantly biased upwards.

If an assessment of Northeast Arctic cod is based on a VPA type analysis, then we suggest that

$$N_i = \beta I_i \tag{7}$$

should be used in the VPA tuning procedure. Because the VPA estimates of the abundance of small cohorts appear to be highly biased, while the bias for large cohorts may be relatively small, we propose that only the points (N_i, I_i) for which the survey index, I_i, is greater than the average value of the survey index should be used to determine β. The effect of such a procedure is to reduce substantially an estimate when abundance is low and to increase moderately an estimate when abundance is high (see Fig. 1 and Table 1).

Assessments of current stock size based on recent commercial catch statistics are often rather inaccurate (Pennington and Strømme, 1998; Korsbrekke *et al.*, 2001), and it is not clear that adjusting the ’tuning’ procedure as above will result in more reliable VPA type estimates. Korsbrekke *et al.* (2001) show that calibrating surveys with converged VPA estimates using equation (6) generate more accurate estimates of Northeast Arctic cod abundance than did the annual VPA assessments, when both are compared with the most recent VPA estimates. Given that it is likely that the converged VPA estimates are biased, especially for small cohorts, we suggest that a survey-based assessment of the Northeast

Arctic cod stock should be based on the assumption, until proven otherwise, that the indices are proportional to true abundance (*i.e.*, eq. 7 is valid). The survey-based abundance estimates in Table 1 show that assuming proportionality significantly reduces the estimates when abundance is low. For now, the proportionality constant (β) can be estimated as above, while future research should focus on developing techniques for more accurately determining β .

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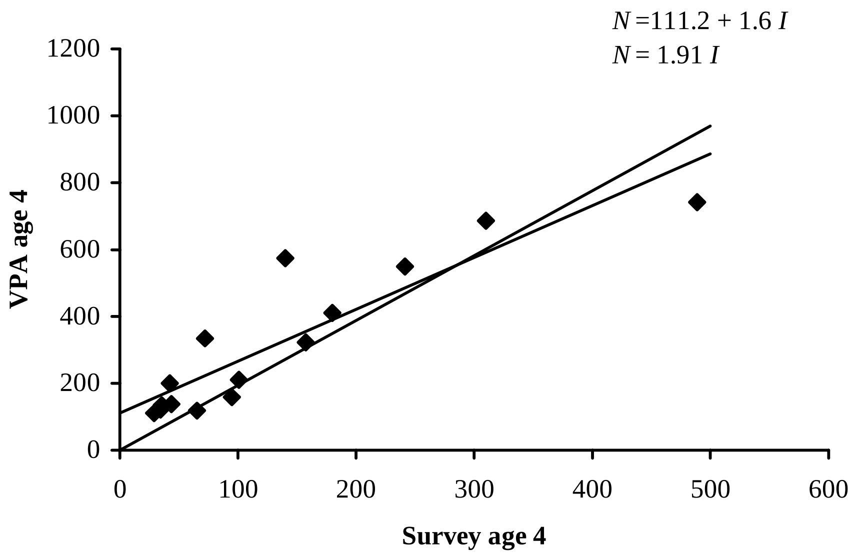
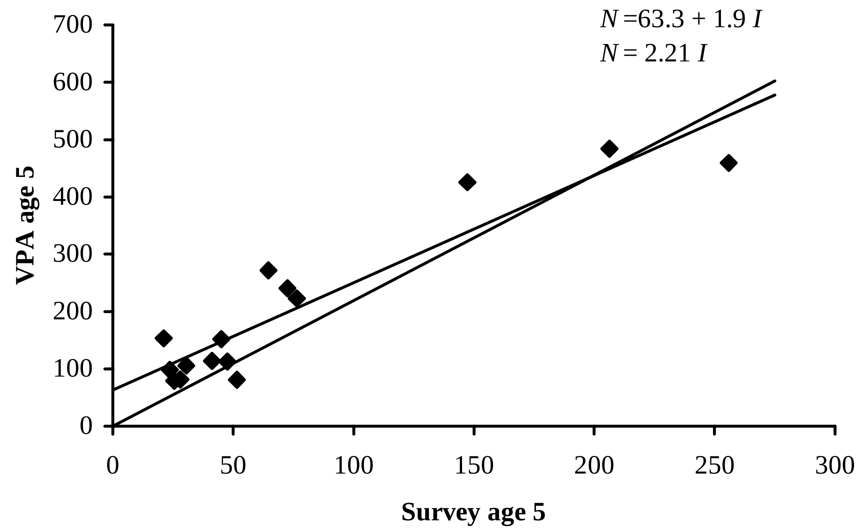
Table 1. Estimated abundance of Northeast Arctic cod based on the Barents Sea winter survey abundance indices and pre-1996 VPA estimates. The estimates were generated using the equations shown in Figure 1. For each age, the first column contains the estimates when the intercept is non-zero and the in second column, estimates when the intercept is set equal to zero and the slope is estimated as described in the text.

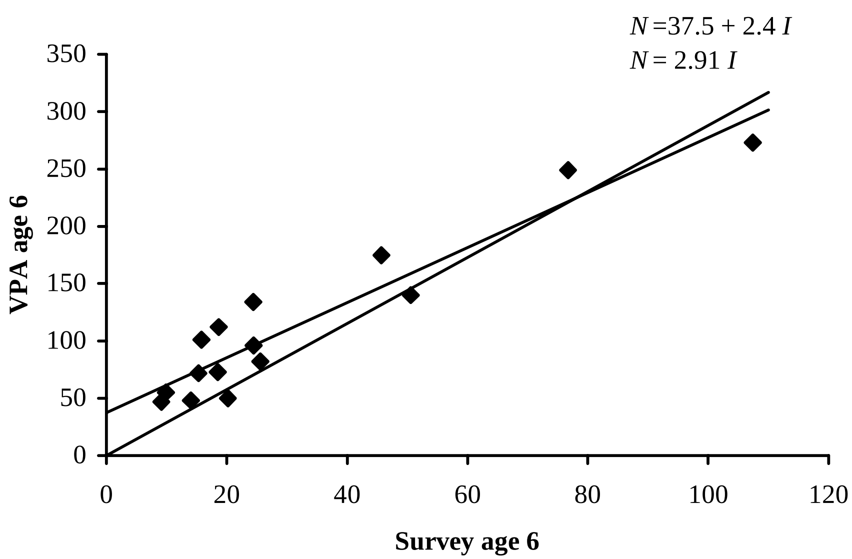
	Age (years)										
	4		5		6		7+		5+		5+
Year	α	$\alpha = 0$	α	$\alpha = 0$	α	$\alpha = 0$	α	$\alpha = 0$	α	$\alpha = 0$	col.10/col.11
1996	295	219	323	301	292	307	150	157	765	765	1.00
1997	213	122	196	154	165	154	182	196	543	504	1.08
1998	401	344	133	81	100	75	150	157	383	313	1.22
1999	388	329	173	128	69	38	87	78	329	244	1.35
2000	332	251	268	238	103	78	60	45	431	361	1.19
2001	418	365	215	176	146	131	83	73	444	380	1.17



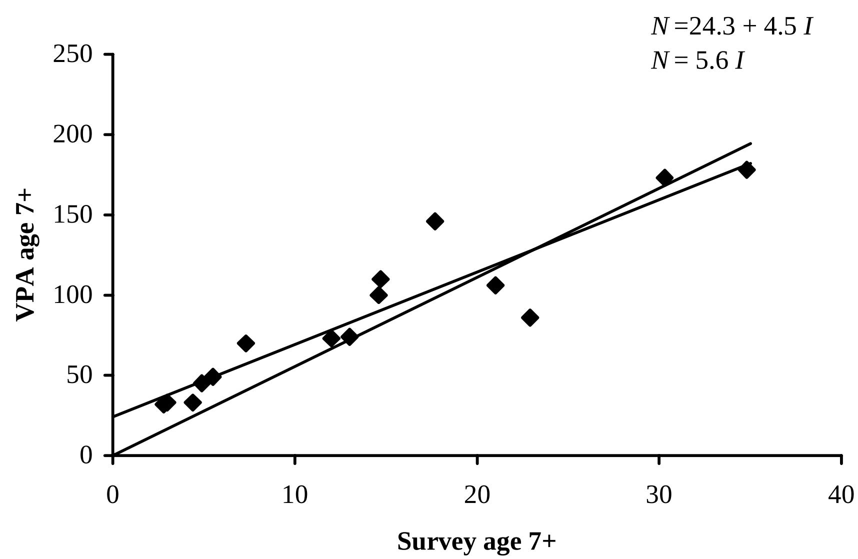
N =111.2 + 1.6 I
N = 1.91 I
VPA age 4
Survey age 4
0
200
400
600
800
1000
1200
100
300
500



N =63.3 + 1.9 I
N = 2.21 I
VPA age 5
Survey age 5
0
100
200
300
400
500
600
700
50
150
250



N =37.5 + 2.4 I
N = 2.91 I
VPA age 6
Survey age 6
0
50
100
150
200
250
300
350
20
40
60
80
120



N =24.3 + 4.5 I
N = 5.6 I
VPA age 7+
Survey age 7+
0
50
100
150
200
250
10
20
30
40

Figure 1. VPA estimates of the abundance of Northeast Arctic cod versus the winter survey index of abundance for the period 1981 through 1995. The regression line with an intercept is based on all the data and the line through the origin is based only on those years for which the survey index is greater than its mean value

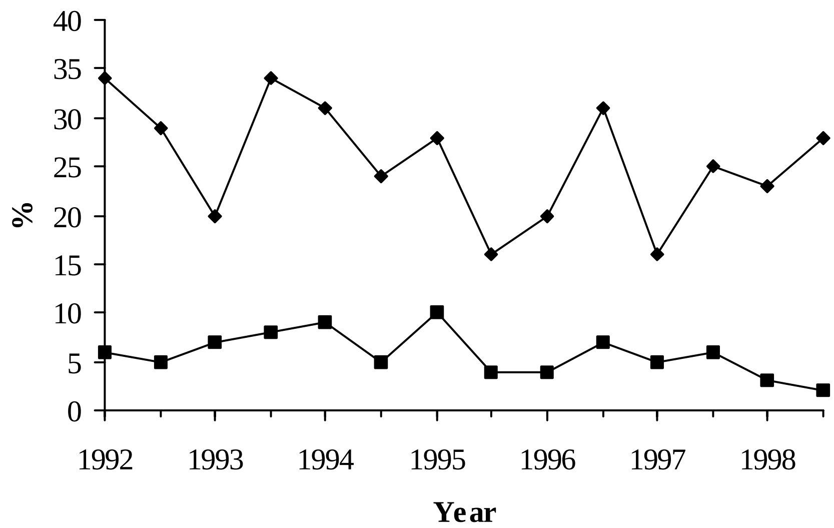


Figure 2. Percentage of otoliths for which the age estimates based on Russian and Norwegian otolith readings differed before a joint biannual analysis of the otoliths (upper curve) and afterwards (lower curve). Source: Yaragina *et al.*, 1998 (ICES, 1999).