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Acoustic and Bottom Trawl Surveys; How Much Information Do They Provide for Assessing the Northeast Arctic Cod Stock?

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Abstract

Acoustic and bottom trawl surveys of the Northeast Arctic cod stock provide fishery independent estimates of trends in abundance and population characteristics. Given the recent uncertainties in the catch based assessment of the stock, survey based abundance estimates of ages 5+ cod, generated by calibrating the survey indices with converged estimates from a VPA, were compared with the estimates from the annual assessments. The results indicate that the survey based estimates were more accurate than the estimates from the annual assessments. Since the survey and the VPA abundance estimates for younger cod were inconsistent, the amount of information contained in the surveys was tested indirectly by determining how well estimates based on previous survey indices could predict the following year's survey value. A time series model of the ages 3+ cod and haddock survey indices predicted the subsequent value of the cod survey index fairly accurately. Furthermore, the Lofoten acoustic survey indicates a much greater decrease in spawning stock size over the last several years than do the VPA estimates. It is concluded that it is likely that these fishery independent surveys are providing a more accurate assessment of the current health of the cod stock than the assessment based on combining the survey data with commercial catch statistics.

Introduction

Acoustic surveys of the Northeast Arctic cod stock in the Barents Sea in winter began in the early 1970's, and since 1976 the surveys have been conducted using a statistically sound sampling scheme, which was based on the experience gathered during the previous surveys (Jakobsen *et al.*, 1997). In 1981 a bottom trawl survey was combined with the acoustic survey. The primary reason for initiating the swept area winter surveys in the Barents Sea was the difficulties experienced in the assessment of Northeast Arctic cod in 1979 and 1980, years in which there were large discrepancies between the signal on the status of the stock sent by the commercial catch at age data and that by the survey. Because of the troubling inconsistencies in the data, the Advisory Committee on Fishery Management (ACFM) made the following recommendation to the Arctic Fisheries Working Group (ICES, 1980):

In estimating fishing moralities and stock sizes in 1979 and 1980 more weight should be given to reliable survey results, particularly if two independent surveys are in reasonable agreement, than to fishery dependent data.

The bottom trawl (swept area) indices generated by the winter trawl survey have become the most reliable source of fishery independent information on the status of the cod stock (Jakobsen *et al.*, 1997). In the mid 1990's it was apparent that cod assessments based on survey data and those from the annual ICES assessments were again sending conflicting signals on the development of the stock (Aglen *et al.*, 1996; Pennington and Strømme, 1998). Subsequently, the 1997 and 1998 annual assessments of the cod stock produced substantially lower estimates of the stock sizes in 1995 and 1996 (ICES, 1999).

It appears that the annual cod assessments systematically underestimated fishing mortality rates which caused the stock numbers to be overestimated (Nakken 1998). Since 1982 fishing mortality rates for the cohorts ages 5-10 years (F_{5-10}) have been 55 to 110% of those based on the 'converged' VPA with an average value of about 80%. It is not known if this bias is due to errors in the input data (catch at age and survey indices), parameter estimates (natural mortality rates) or to difficulties in the assessment methodology. Whatever the case, this underestimation of fishing mortality has the unfortunate effect that stock sizes for a given year will be adjusted downward in subsequent assessments, often rendering previous management strategies ineffective.

In this paper we examine whether surveys have the potential to produce a more accurate and timely assessment of the cod stock than one that also incorporates (contemporary) commercial catch data.

A comparison of survey and VPA estimates of current stock size

For the ICES stock assessments, the winter bottom trawl (swept area) index is one of several abundance indices used to tune a virtual population analysis (VPA) type model which is based on commercial catch at age data. The relative weight or impact each index series has on the final results is assessed using tuning diagnostics, though estimates of abundance based only on each index series are not derived. In this section we use the converged VPA estimates of stock abundance (that is, historical estimates which are only a function of the commercial catch data) to calibrate the winter swept area indices and then we compare the resulting estimates of absolute abundance with those produced by the annual ICES assessments. The comparisons were made for ages 5 and 6 cod and age groups 5+, 6+ and 7+ during the period 1993-1999.

The swept area indices, I, were calibrated to yield stock numbers, N, by assuming a linear relation between N and I (Aglen and Nakken, 1997; Jakobsen *et al.*, 1997). That is

$$N = a\,I + b \qquad (1)$$

where a and b were determined by regression. Calibrations were made for cohorts ages 3, through 6 and 7+ using data from the period 1981-1992. The values of N were taken from the most recent stock assessment (ICES 1999) and are, for the calibration period, dependent only on commercial catch at age data and the assumed rates of natural mortality and thus are totally independent of the indices. The estimates of a and b are in Table 1.

In 1993 the survey area was extended (Jakobsen *et al.*, 1997) and since then the swept area indices have been based on a larger area than the indices used in the calibration procedure. Estimates for the period 1993 through 1996 of the proportion, p, of the stock (by age) in the sub-area covered by the surveys in 1981 through 1992 are in Table 2.

In order to make the post 1992 series compatible with the earlier series, the survey indices for ages 5, 6 and 7+ were adjusted for the period 1993 through 1999 using the factor $p = .84$, which is the average value of p over age and year (see Table 2). Abundance estimates of age 5, 6 and 7+ cod based on equation (1) (using estimates of a and b from Table 1 and the adjusted index, pI) are in Table 3 and Fig. 1 along with the corresponding estimates from the annual ICES assessments (ICES, 1994-1999).

It appears that in the years 1993 through 1998 the swept area generated stock numbers deviate marginally from the estimates produced by the most recent ICES (1998) assessment (see Table 3 and Figure 1). Assuming that the latest assessment has produced more accurate estimates of stock size throughout the 1990s than those generated by earlier assessments, then it follows that that the survey has provided reliable and timely estimates of stock size.

Survey based estimates of the abundance of 3 and 4 year old cod were not compared with the converged VPA estimates for two reasons. First, the coverage of these age groups by the bottom trawl survey, horizontally as well as vertically, is poorer than for the older ages, particularly so prior to 1993. Their range east and northward is variable during the survey period and is related to sea temperature and to cod abundance (Ottersen *et al.*, 1998). Young cod tend to have a more pelagic distribution pattern than older cod and the survey trawl has a lower effective catching height than that for larger and older fish (Aglen, 1996). All these factors may cause the survey indices for young cod to be more variable than those for older and larger cod. Furthermore, the converged VPA abundance estimates for the younger ages are thought to be less reliable than those for the older fish because of variable discard rates and cannibalism (ICES, 1989 and 1999). The second reason for focusing on the older age groups is that 5 year and older cod make up the bulk of the catch (at least it ought to be so!) and it was considered most important to investigate to what extent the swept area indices provide information on the harvested part of the stock.

A prediction model of the winter survey abundance index

In the previous section it was shown that the winter survey appears to produce more accurate estimates of the current abundance of ages 5+ cod than those generated by the annual ICES assessments. It was also mentioned that either the VPA estimates or the survey index of the abundance of younger cod may be inaccurate. Since the two indicators of abundance seem to be inconsistent (Pennington and Strømme, 1998), it would be inappropriate to use one to calibrate the other. Thus in this section, a time series model is used to describe the dynamics of the survey index for ages 3+ cod. The primary reason to model the series is to determine how well the model predicts next year's index based on the previous values of the series. Since 'noise' is unpredictable, relatively accurate predictions are taken as an indication that the survey series may in fact be tracking actual trends in cod abundance.

In Figure 2 is a plot of the winter survey index of the abundance of ages 3+ cod. The autoregressive model (Box and Jenkins, 1976)

$$y_t = 1.18y_{t-1} - .67y_{t-2} + 2.77 + c_t \qquad (2)$$

fit the series adequately, where y_t is the log of the survey index (adjusted for 1993 forward as in the last section), the c_ts are independent and identically distributed and $\hat{\sigma}_c^2 = .17$. Model (2) exhibits pseudo periodic behavior (Box and Jenkins, 1977) in that it appears to oscillate with a period of approximately 8 years. This pseudo periodicity can be seen in Figure 3 which is a realization of model (2) from a simulation.

In Figure 4 are plots (linear scale) of the ages 3+ index for cod and the forecast generated by model (2) in year t-1 of the value of the index in year t (*i.e.* the one-step-ahead forecasts). The estimated variance of the forecast errors ($\hat{\sigma}_c^2$) equals (log scale) .17. The forecasts tracked the cod series but diverged considerably in 1986 and 1987 and to a lesser extent in the mid-nineties.

One way to improve the forecasts is to incorporate more information in the model. It was found (Pennington and Strømme, 1998) that the winter survey index for ages 3+ haddock (Figure 5) can be described by an autoregressive model similar to the one for cod. The model for haddock is given by

$$x_t = 1.20x_{t-1} - .63x_{t-2} + 2.10 + a_t \qquad (3)$$

where x_t denotes the abundance index for ages 3+ haddock (log scale) and $\hat{\sigma}_a^2 = .70$. The pseudo period of the haddock model is approximately 9 years.

The estimated cross-correlations between the (estimated) residuals, $\hat{c}_t$ and $\hat{a}_t$, from models (2) and (3)were calculated to determine if there was any relation, after taking into account the information contained in past trends of the series, between the two indices (Figure 6). There was little or no correlation at any lag except at lag 1 ($r_1 = .8$). That is the haddock series contains information in year t-1 on the future value of the cod survey index in year t, which can be used to improve the forecast of the cod index.

The model for the ages 3+ cod survey index based on the cod and haddock indices (log scale) is

$$y_t = 1.18y_{t-1} - .67y_{t-2} + 2.77 + c_t' + .41a_{t-1} \qquad (4)$$

where $\hat{\sigma}_{c'}^2 = .05$. Plots (linear scale) of the forecasts, including the forecast of the value of the survey index in the year 2000, based on model (4) along with the original index, are shown in Figure 7. The addition of the haddock series reduced the forecast error from .17 (model (2)) to .05 for model (4).

The one-step-ahead forecasts of y_t based on model (4) and denoted by $\hat{y}_{t-1}(1)$, were generated by setting c_t' equal to zero, its expected value in year t-1 (i.e. $\underset{t-1}{E}[c_t'] = 0$) and replacing a_{t-1} with its estimated value. The estimate, $\hat{a}_{t-1}$, of a_{t-1} can be written as

$$x_{t-1} - \hat{x}_{t-2}(1) = \hat{a}_{t-1} \qquad (5)$$

From equations (4) and (5) it follows that the forecast in year t-1of the cod index in year t is raised if the haddock index was greater in year t-1than predicted in year t-2 (*i.e.*, $\hat{a}_{t-1} > 0$) and lowered if the haddock index was smaller than predicted ($\hat{a}_{t-1} < 0$).

Model (4) tracks the cod index fairly accurately, though from 1993 onwards the forecast errors appear to increase. This increase in variance may have been caused by the adjustment of the index when the survey area was expanded in 1993 and the interpolation of the index in 1997 and 1998, the years in which the Russian zone was not covered.

Comparison of acoustic and VPA estimates of spawning stock size

The acoustic survey of the spawning grounds off the Lofoten islands covers the most important spawning area for the Northeast Arctic cod stock. Only a modest fraction of the spawners are believed to spawn south or north of the survey region (Godø and Sunnanå, 1984). The survey is conducted annually from the middle of March, the beginning of the spawning season, and ends in early April, which covers the period of peak spawning. A description of survey procedures and the calculation of the abundance index for spawning biomass can be found in Korsbrekke (1997).

Converged VPA estimates, S, of spawning stock biomass for the years 1985 through 1995 (ICES, 1999) were used to calibrate the survey index of spawner biomass, I_{sp}. In Figure 8 is a plot of S versus I_{sp} for the calibration period. Also depicted are the values for 1996 through 1999. The estimated calibration equation is (see Figure 8) :

$$S = .90 I_{sp} + 156 \qquad (6)$$

where the standard errors of the slope and the intercept are .12 and 50, respectively, and $r^2 = .86$.

Acoustic survey estimates of spawning biomass generated by the calibration equation (6) for the period 1985 through 1999 are shown in Figure 9 together with the VPA estimates of spawning stock biomass. The trends in biomass depicted by the two indices in the years 1996 through 1999 are strikingly different. An increase in spawning outside the survey region may have caused the two series to diverge. But there appears to have not been a relative increase in catch on spawning grounds outside the survey area, which indicates that the proportion of cod spawning in the Lofoten survey area has been fairly stable during the survey period.

Discussion and Conclusions

Estimates of the current abundance of ages 5+ cod generated by calibrating the survey indices with converged estimates from the VPA appear to be more precise estimates of the converged VPA values than those produced by the annual assessments. For ages 3+ cod, the survey indices for cod and haddock seem to contain considerable information on the future value of the cod index, which indicates that the survey may in fact be tracking actual trends in abundance. If the survey based estimates are more accurate, then they would have the additional advantage in that they are available six months earlier than those from the annual assessment.

Nakken (1998) showed that the annual ICES assessments have tended to underestimate the fishing mortality rate and thus overestimate stock numbers during the period 1982-1994. It appears (see Table 3 and Fig. 1) that stock numbers have also been overestimated in recent years (ICES 1999). The causes of this 'overestimation' in 1996 and for age 6+ cod in 1995 by the annual ICES assessments are not fully understood but may be due to several factors. The assumption in the tuning process that the survey indices are **proportional** to catch at age based stock numbers, *i.e.* that b in equations (1) equals zero, does not hold for most age groups (Aglen and Nakken, 1997; Jakobsen *et al.*, 1997; Helle *et al.*, 1999). For the swept area survey index, the intercept b is positive and significantly different from zero for all age groups below age 8 years. Hence, catchability estimates based on assuming proportionality between I and N may in such cases introduce a gross overestimation of stock numbers for high index values (Jakobsen *et al.*, 1997). Ignoring that the survey area was extended in 1993 will compound the problem. In addition, there has been a general improvement of survey methodology and instrumentation resulting in improved survey efficiency that is difficult to take into account (Jakobsen et al., 1997).

The method used to estimate stock numbers based on survey indices is simple and transparent as compared with the procedure used in the ICES assessments. The results obtained are totally independent of catch at age data for recent years, which might be an advantage for stocks with rapid changes in fishing patterns or those for which the uncertainties associated with the actual catch at age are unknown (no monitoring of discards and no error measurements associated with the catch at age data). Calibration techniques can also be used to estimate the variance of survey and VPA abundance estimates (Pennington and Godø, 1995).

The survey based estimate of the number of ages 5+ cod for 1999 is 28% lower than that predicted by the most recent VPA assessment (ICES, 1998), and the survey estimate of the trend in the size of the spawning stock shows a much larger decrease than does the current estimates from the VPA. Given the tendency in the past for the VPA to overestimate stock sizes, it is likely that the VPA values may at present be too high.

The problem with comparing assessment methods is that we never know the 'correct' answer. However, given the failures of the catch based assessments of Northeast Arctic cod in the past, survey based assessments of the cod stock should be considered independently of the catch based assessments. Following the precautionary approach to fishery management, it would be prudent to accept the more conservative assessment until it can be shown that the more optimistic assessment is the more accurate one.

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Table 1. Calibration of the swept area indices. Estimated coefficients from a linear regressions, $N = a I + b$, of 'converged' VPA-stock numbers at age, N, on swept area estimates, I, for the period 1981-1992. VPA-stock numbers are taken from the 1998 Report of the Arctic Fisheries Working Group (ICES, CM, 1999)

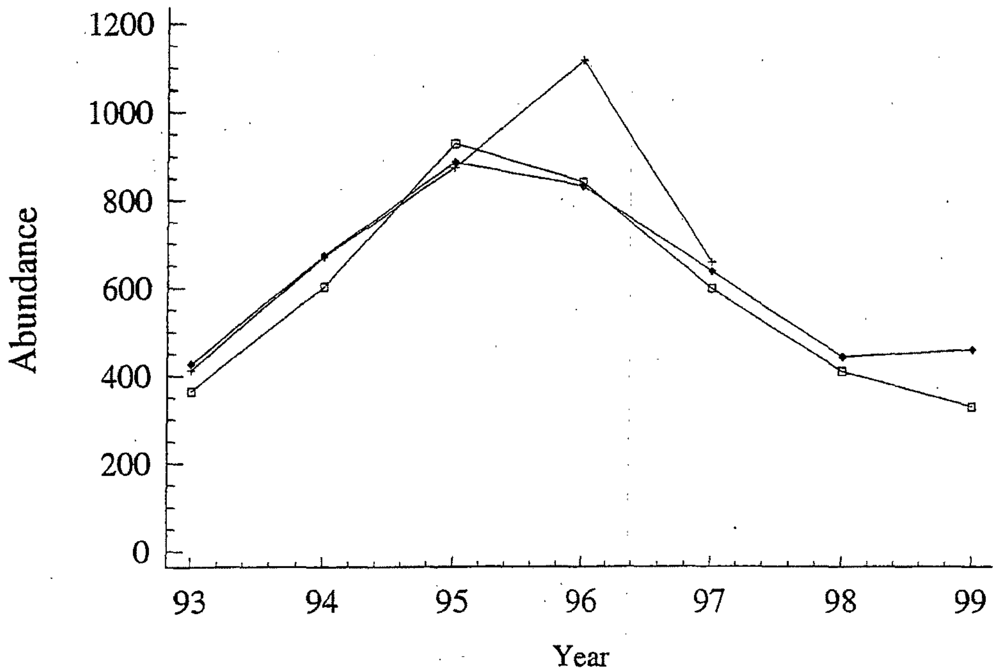
	Age				
	3	4	5	6	7+
$\hat{a}$	1.22	1.74	2.39	3.27	6.96
SE($\hat{a}$)	0.29	0.19	0.26	0.49	0.80
$\hat{b}$	200	100	52.4	29.7	14.2
SE($\hat{b}$)	65	24	17.1	11.8	10.0
r^2	0.63	0.89	0.89	0.86	0.88

Table 2. The adjustment factor, p, is the proportion of swept area indices, I, within the area covered prior to 1993 (1981-1992) as observed during the years 1993-1996.

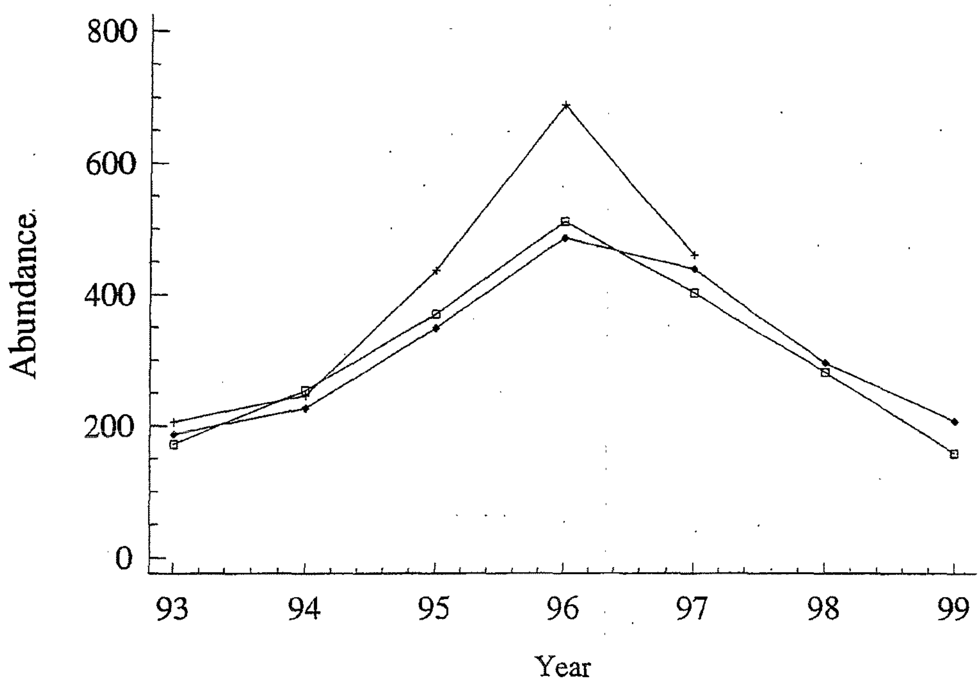
	Age				
	3	4	5	6	7+
1993	0.63	0.76	0.88	0.79	0.90
1994	0.65	0.75	0.80	0.84	0.89
1995	0.77	0.83	0.86	0.85	0.79
1996	0.67	0.85	0.86	0.81	0.86
Mean	0.68	0.80	0.85	0.82	0.86

Table 3. Comparison of estimated stock numbers 1993-1999. SWEPT AREA is calculated by using the equation, $N = a \cdot p \cdot I + b$, where values of a and b are taken from Table 1, p from Table 2 and I is the swept area index. The Ass(98) estimates are from the Arctic Fisheries Working Group 1998 Report, and the Ass(Ann) estimates are from the annual assessments (ICES, 1994-1999).

		Age (years)				
		5	6	7+	6+	5+
1993	SWEPT AREA	192	69	103	172	364
	Ass (98)	239	87	100	187	426
	Ass(Ann)	206	56	150	206	412
1994	SWEPT AREA	348	160	94	254	602
	Ass (98)	446	138	89	227	673
	Ass(Ann)	424	129	117	246	670
1995	SWEPT AREA	558	226	144	370	928
	Ass (98)	537	261	88	349	886
	Ass(Ann)	438	296	140	436	874
1996	SWEPT AREA	329	329	182	511	840
	Ass (98)	345	330	156	486	831
	Ass(Ann)	427	465	223	688	1115
1997	SWEPT AREA	195	176	226	402	597
	Ass (98)	198	198	240	438	636
	Ass(Ann)	198	191	268	459	657
1998	SWEPT AREA	126	102	180	282	408
	Ass(98)	145	106	190	296	441
1999	SWEPT AREA	170	67	91	158	328
	Ass (98) pred				207	458



(a)



(b)

Figure 1. Estimates of the number of ages 5+ cod (a) and 6+ cod (b) from the annual assessments (plus signs), the 1998 assessment (solid diamonds) and the winter bottom trawl survey (open squares) for the years 1993 through 1999.

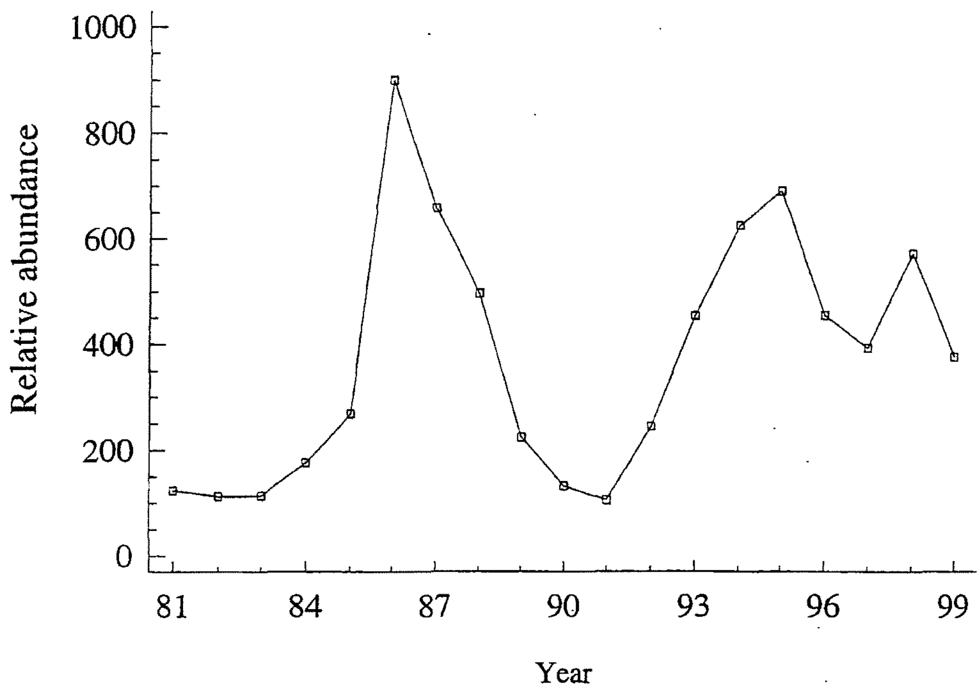


Figure 2. The winter bottom trawl abundance index for the number of age 3+ cod.

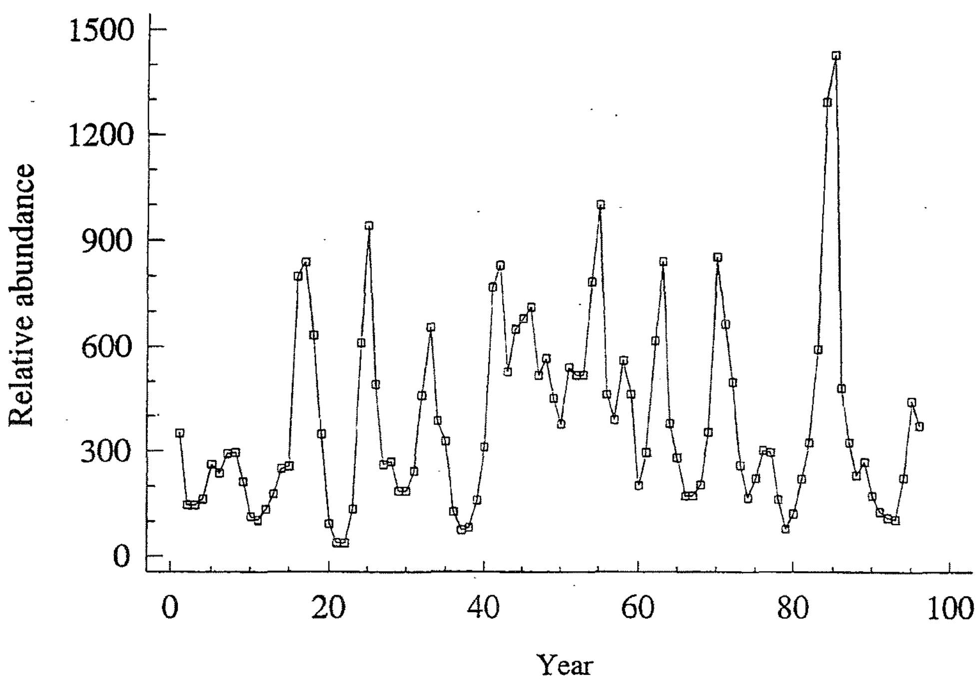


Figure 3. A simulation of the time series model ($y_t = 1.18y_{t-1} - .67y_{t-2} + 2.77 + c_t$) for ages 3+ cod.

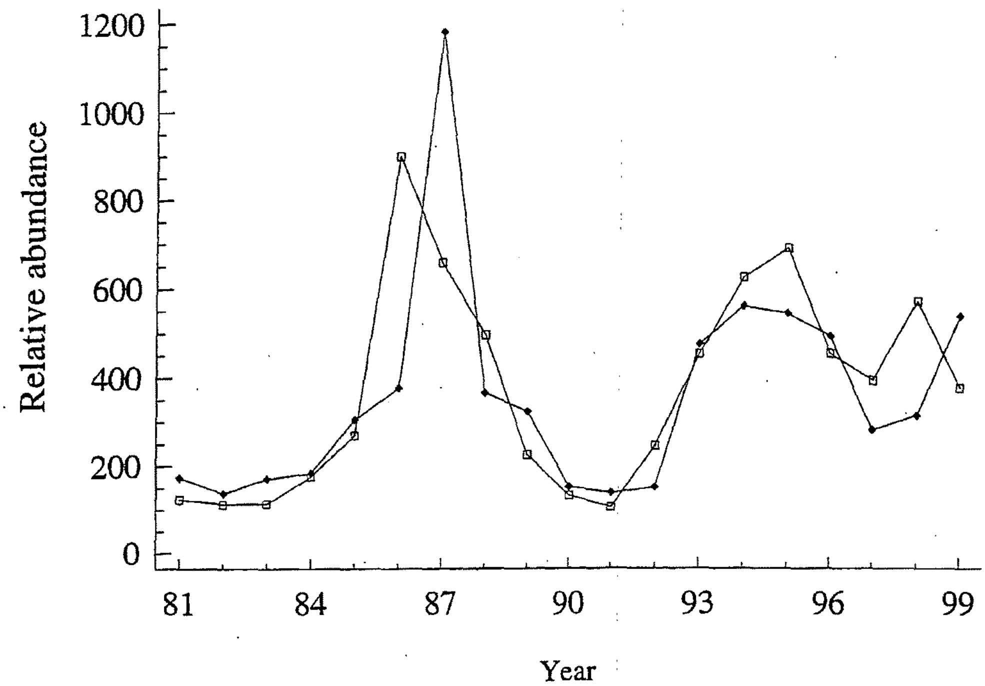


Figure 4. The survey index for ages 3+ cod (open squares) and the one-step-ahead forecasts (solid diamonds) generated by model (2).

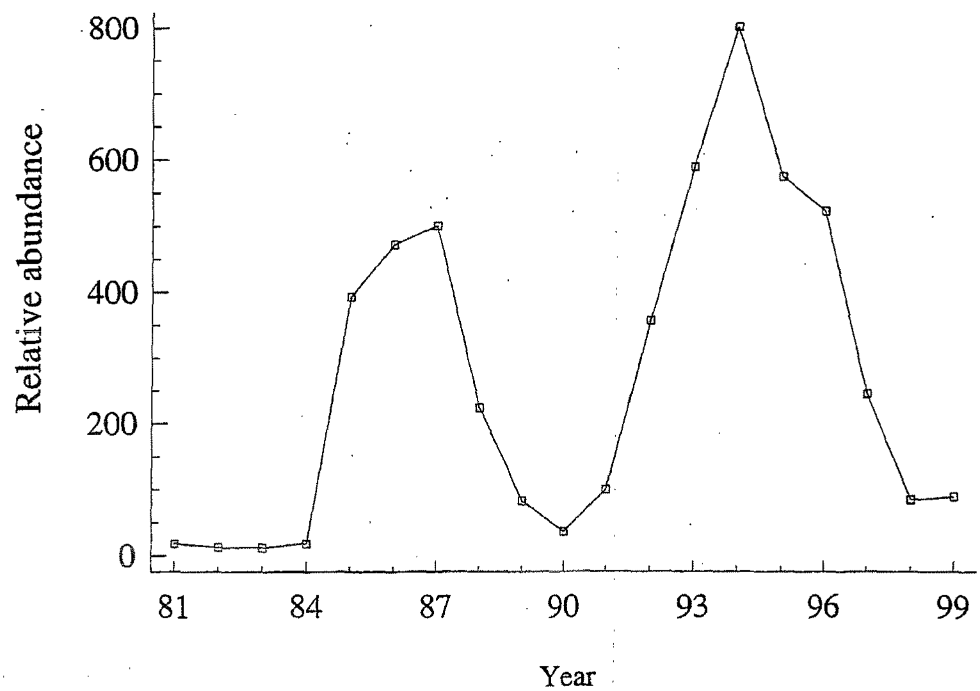


Figure 5. The winter bottom trawl abundance index for the number of age 3+ haddock.

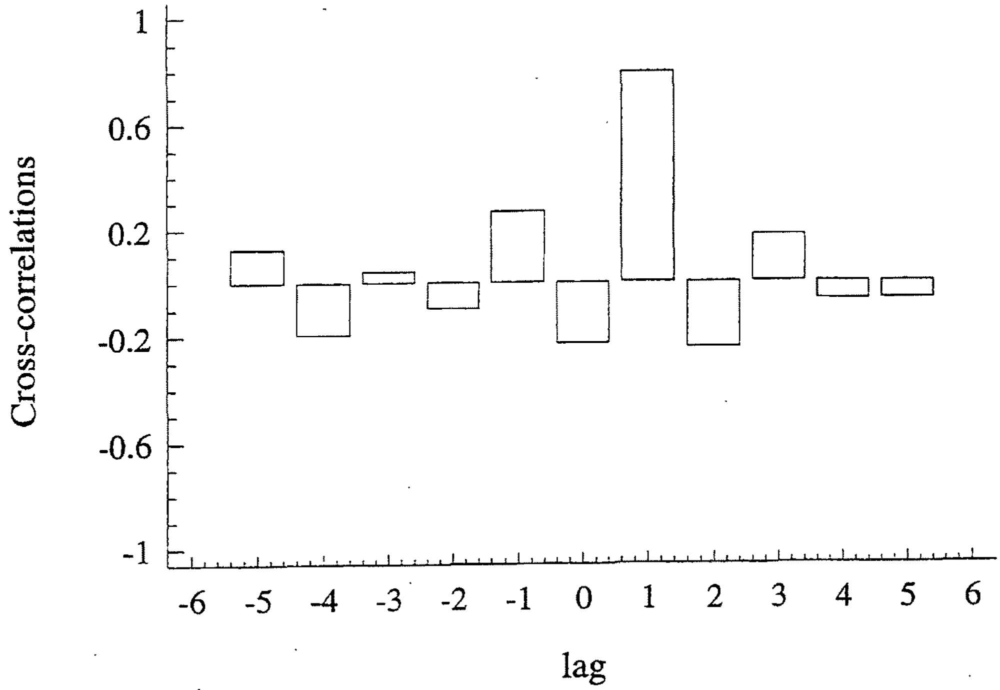


Figure 6. Estimated cross-correlations between the residuals from model (2) for ages 3+ cod and the residuals from the haddock model (3).

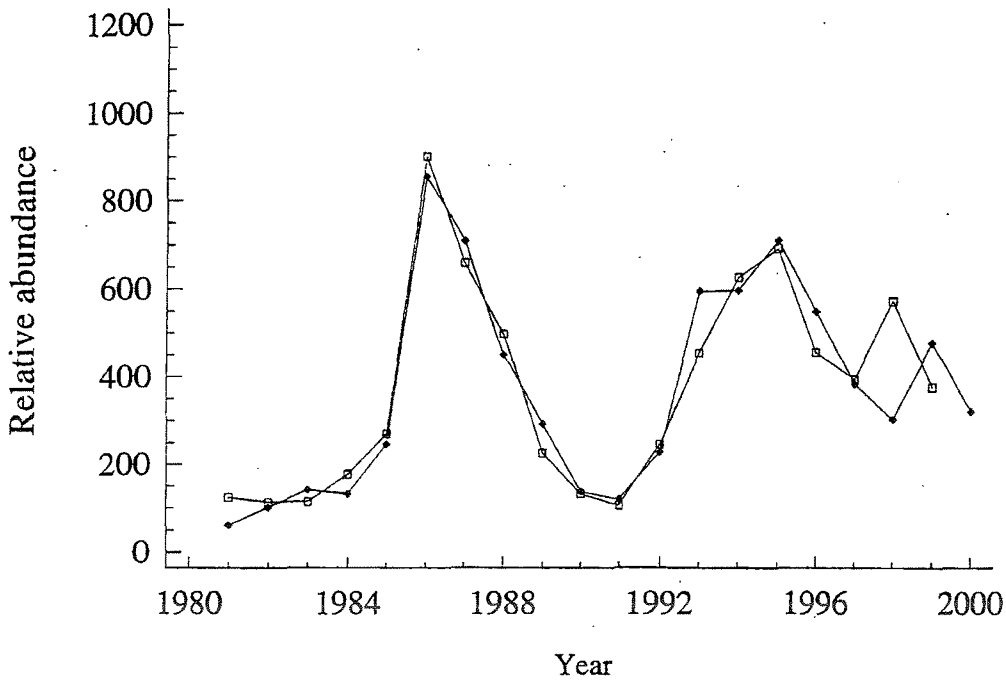


Figure 7. The survey index for ages 3+ cod (open squares) and the one-step-ahead forecasts (solid diamonds) including a forecast of the value of the survey index in the year 2000 generated by model (4).

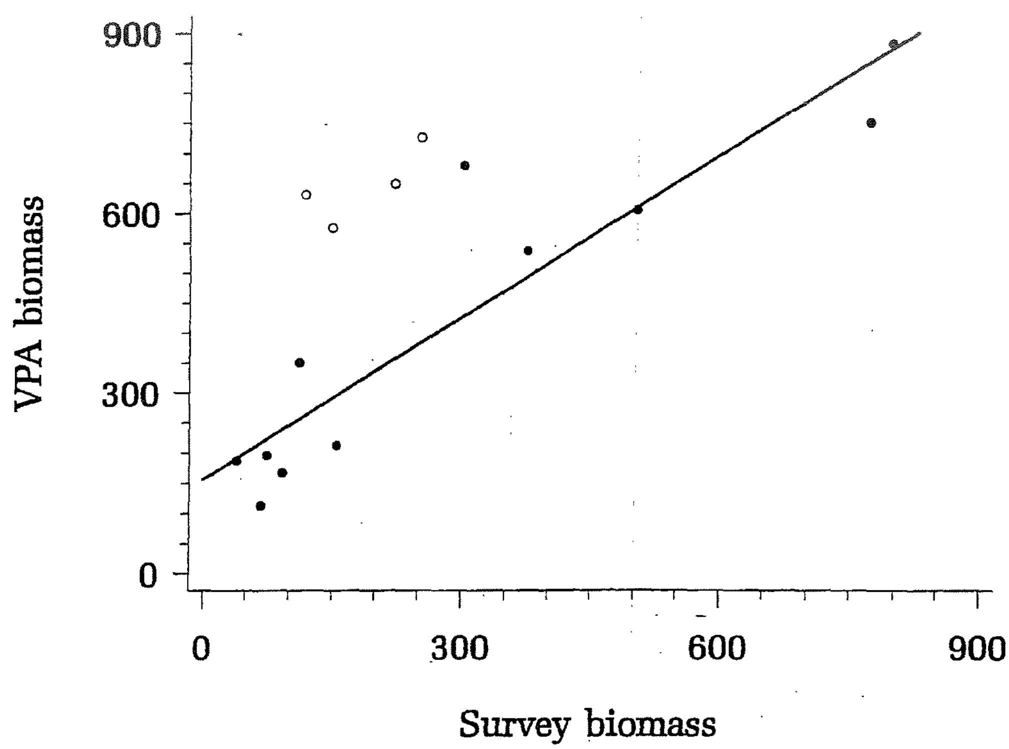


Figure 8. VPA estimates of the spawning biomass (ICES, 1999) versus the acoustic survey index of spawning biomass. The regression line is for the years (solid circles) 1985 through 1994 (the calibration period). Open circles are the years 1996-1999.

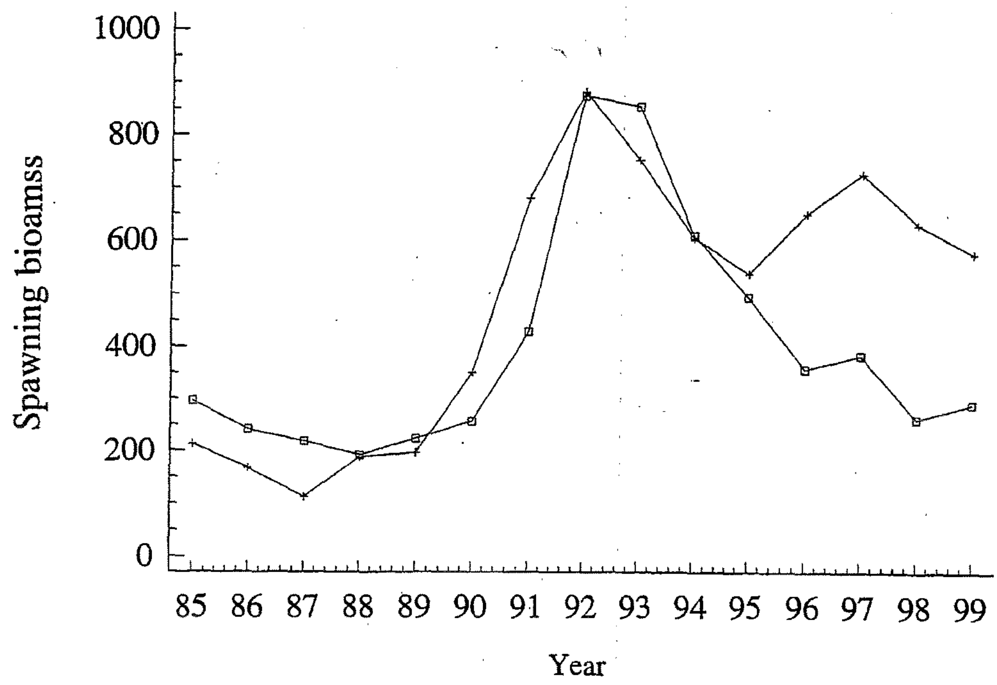


Figure 9. Estimates of cod spawning stock biomass are the calibrated Lofoten acoustic survey estimates (open squares) and VPA (ICES, 1999) estimates (solid diamonds) for the years 1985 through 1999.