ICES CM 2006/I 12

Timely Evaluation of Stock Status Based on Scientific Surveys, an update

Michael Pennington and Odd Nakken

Abstract

The usual method for assessing a fish stock for which there exist scientific surveys and commercial catch statistics is to use the survey series to 'tune' a VPA- type model. Such assessments are often subject to rather large revisions as more catch data for cohorts remaining in the fishery become available. It is conjectured that one reason VPA abundance estimates for cohorts still in the fishery tend to be variable and often biased is that the relation between the age composition of the commercial catch and the actual population is unknown, and this relation likely varies from year to year. It is suggested that for some species a more stable method for assessing the current condition of the stock would be to reverse the roles played by surveys and catch data. That is use abundance estimates based on historical catch data (*i.e.* catch statistics for cohorts that are no longer in the fishery) to calibrate the survey series. As an example, converged VPA-type abundance estimates of Northeast Arctic cod (*Gadus morhua*) during a calibration period were used to 'tune' a yearly bottom trawl survey of this stock. For the two age groups considered in this paper, the survey-based procedure generated estimates of subsequent converged VPA estimates that were usually more precise than the annual estimates. Since survey-based estimates will not be revised and would be available as soon as the survey is completed, it is concluded that they would form a timely basis for developing and implementing a stable management strategy.

Michael Pennington: Institute of Marine Research, P.O.Box 1870 Nordnes, N-5817 Bergen, Norway [tel: +47 55 23 63 09, e-mail: michael@imr.no] Odd Nakken: Institute of Marine Research [tel: +47 55 23 8676, e-mail: odd.nakken@imr.no]

1. Introduction

For fish stocks that are monitored by scientific surveys and for which commercial catch statistics are collected, the generally accepted method for assessing these stocks is to integrate the survey estimates with commercial CPUE and catch-at-age data in a virtual population (VPA) type analysis (Fig. 1). Before a particular cohort leaves the fishery, its estimated abundance tends to vary from year to year. Not only are the annual estimates of a cohort's abundance quite variable (Nakken, 1998; Pennington and Strømme, 1998; Korsbrekke *et al.*, 2001), there is a tendency for the catch-based estimates to decrease as more catch data becomes available, which is the so called "retrospective problem" (Sinclair *et al.*, 1991; Parma, 1993; Sinclair, 1998; Mohn, 1999).

One reason that VPA estimates of current stock size may be subject to large revisions is that the relation between the commercial catch during recent years and the actual population structure is usually unknown (Fig. 1). Many factors may cause this relationship to vary from year to year. One obvious factor is a change in the spatial distribution of fishing effort over time (Salthaug and Aanes, 2003). If the commercial catch data are correct, then for a cohort no longer in the fishery the estimate of its historical abundance (*i.e.* the converged estimate) may be fairly accurate.

Abundance indices based on scientific surveys often track converged VPA estimates fairly closely, while the non-converged estimates and the survey-based indices tend to diverge (Pennington and Godø, 1995; Pennington and Strømme, 1998; Korsbrekke, *et al.*, 2001). Because recent VPA estimates will be revised in due course, while the survey estimates will stay the same, this implies that the information contained in the survey data is not being effectively used to assess the stock.

An alternative to a VPA-type assessment of the current condition of a stock would be to base the assessment on, at least in theory, known relations. A survey ideally covers the entire stock while converged VPA-type estimates, based on accurate commercial catch data, should provide fairly accurate historical estimates of a cohort's size. Therefore it may be sensible to reverse the roles currently played by surveys and commercial catch data for stocks that are extensively surveyed. That is, instead of using survey data to tune the current catch data, historical catch data may be used to calibrate the survey indices (Fig. 3).

As an example of this alternative assessment technique, converged VPA abundance estimates for Northeast Arctic cod during an initial time period are used to calibrate abundance indices generated for this stock by the winter bottom trawl surveys in the Barents Sea. The survey-based estimates are compared to subsequent converged estimates of cohort size and to the annual assessments.

2. Calibrating Survey Abundance Indices

Suppose there are two abundance estimates available for a stock; a fishery independent index of relative abundance generated by research surveys and VPA-type estimates of absolute abundance based on commercial catch data. For the converged part of the VPA estimates (N_i), which only depend on commercial data and are independent of survey indices, it is assumed that the expected value (E)

$$E[N_i] = P_i \, , \tag{1}$$

where N_i refers to a particular age or group of ages in year i and P_i is the true number in the population.

Furthermore, assume that the expected value of the survey index, I_i, is also proportional (with constant β) to P_i:

$$E[\beta I_i] = P_i \, . \tag{2}$$

Then it follows that

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

The estimates, N_i and I_i, can be expressed as

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

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

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

where $\xi_i = \varepsilon_i - \beta\delta_i$. Although (5) has 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).

If the relation between the survey index and the VPA estimates differs significantly from (5), then this implies that either assumption (2) or (3), or both, are not valid. When this is the case, other information needs to be employed to select the index that is most likely proportional to P_i.

For more variable surveys, using time series techniques will generate a survey index that more closely tracks the converged VPA estimates (Pennington, 1985; Fogarty *et al.*, 1986; Pennington and Godø, 1995). Using a smoothed survey index in (5) will in general cause the error term to be autocorrelated and this should be taken into account in the fitting procedure (Brockwell and Davis, 1996).

3. An Illustrative Example: Northeast Arctic Cod (*Gadus morhua*)

The fishery for Northeast Arctic cod is the largest cod fishery in the world. During its peak in the 1950's, the yearly catches averaged 800 000 t (Nakken, 1994). More recently, the catches have ranged from more than 700 000 t in 1997 down to 400 000 t in 2000. Fluctuating stock size is the main reason that commercial catches have varied over time, and failure to timely detect changing trends in abundance has been a problem for managing this stock. The next section is an overview of past assessments and in the subsequent sections it is shown that scientific surveys can provided a robust and timely assessment of the condition of the Northeast Arctic cod stock.

3.1 A brief overview of the assessments

The annual assessments of the Northeast Arctic cod stock by ICES usually underestimated fishing mortality rates and, therefore, overestimated stock numbers (Nakken, 1998; Korsbrekke *et al.*, 2001). The general tendency was that fishing mortality rates for a given year were revised upward and thus stock numbers were reduced as more catch-at-age data became available, which is an example of the common retrospective problem. An examination of the ICES assessments during the period from 1982 through 1995 indicated that the annual estimates of fishing mortality rates ranged from 55 to 110% of the converged value and were, on average, 80% of the final converged ("true") value. Furthermore, it took four to five years before the estimates converged (Nakken, 1999).

It is not known if this bias was caused by the input data (commercial catch and survey data) or by inadequacies in the assessment methodology aplied (XSA, Extended Survivor Analysis). Whatever the case, the fairly consistent overestimation of stock size had the unfortunate effect that management measures to reduce fishing mortality often were ineffective.

3.2 Calibrated survey estimates of stock size

Since 1981, the Institute of Marine Research has conducted an extensive bottom-trawl survey (approximately 250 stations annually) in the Barents Sea from mid-February to mid-March (for more details, see Aglen *et al.*, 2003). The area covered by the winter survey was expanded in 1993, and the survey abundance indices (Table 1) prior to 1993 have been adjusted accordingly (Korsbrekke *et al.*, 2001). We included only cod age 4 and older in the analysis because few cod of the younger age groups are caught in this fishery. Because of sampling variability and aging errors, both the survey indices and the VPA estimates at age are rather imprecise (Pennington *et al.*, 2002; Aanes and Pennington, 2003). To lessen the effect of aging errors, our primary focus is on two age groupings: ages 4, 5 and 6, which for the most part represent pre-spawners; and ages 7+, which represent mainly spawners. The annual VPA abundance estimates for the two age groups during the period 1995 through 2006 are in Table 2.

For the calibration period (1981 through 1995) the VPA abundance estimates for ages 4 through 6 and 7+ were not proportional to the survey indices, but were linearly related (*i.e.* $N_i = \hat{\alpha} + \hat{\beta} I_i + \xi_i$) with a significantly positive intercept (Fig. 3). Since the estimated standard error of I_t was small compared with the range of the index, it is unlikely that a bias in the slope estimate caused the intercept to be positive (Draper and Smith, 1981). It follows that either the converged VPA estimates or the survey indices (or both) were not proportional to the true population.

Because our objective was to use the surveys to predict the final, converged VPA estimates, we first included an intercept when calibrating the surveys and then, assuming that the survey abundance index was proportional to the actual population (*i.e.* the intercept equaled 0), we generated estimates of the proportionality constant in (5).

The calibrated survey estimates for 1995 through 2006 for the two age groupings, generated by the regressions shown in Fig. 3, are in Table 3, column 4. Fig. 4 and 5 are plots of the calibrated survey estimates for the two age groups and the latest ICES (2006) abundance estimates, along with the annual ICES estimates during this period.

Even though including an intercept in the calibration procedure resulted in rather accurate predictions of the converged VPA estimates in both cases, there is no reason to assume that the VPA estimates were unbiased. The implication of a positive intercept is that it tends to 'maintain' stock numbers as the survey index decreases. In particular, when abundance is low the stock may be declining (or increasing) at a much faster rate than indicated by the survey-based estimates.

Aging errors tend to cause the sizes of small cohorts to be greatly overestimated and large cohorts to be slightly underestimated. To reduce this source of bias, the survey was calibrated with zero intercept (eq. 5) based only on those years for which the survey index was greater than its average over the calibration period (Nakken and Pennington, 2001). These calibration lines are shown in Fig. 3 and the associated survey-based abundance estimates are in Table 3, columns 5 and 9.

3.3 Discussion

The calibrated survey estimates of the abundance of ages 4 through 6 cod closely tracked the 2006 ICES estimates during the years 1995 through 1998, a period in which the ICES estimates have converged, whereas for recent years the calibrated estimates were below the 2006 ICES estimates (Fig. 4). It should be noted that prior to 1998, the tendency was for the annual ICES estimates to decline over time as more catch data became available, while in the last few years the annual ICES abundance estimates have increased.

For ages 7+, which form the bulk of the spawning stock, the survey-based abundance estimates and the 2006 VPA estimates are fairly similar (Fig. 5). An advantage of the survey-based estimates in both cases is that they accurately predicted the converged 2006 VPA estimates for the period 1995 – 1998 years before the these estimates had converged to their present levels (Fig. 4 and 5). In particular, while the 1996 through 1998 ICES assessments were significantly overestimating spawning stock size, the survey-based estimates were apparently providing accurate and timely estimates of the true size of the spawning stock (Fig. 5).

There were two major sources of uncertainty in the catch data used in the assessments that may have caused the VPA estimates of absolute abundance to be biased. In most years the officially reported landings were used in the assessments. However, in the periods 1990-1994 and 2002-2003 ICES added to the reported landings significant amounts of estimated unreported catches. For example, the reported landings were raised by more than 30% in 1992 and increased approximately 20% in 2003. The other source of bias was that discards at sea were not taken into account in the assessments. Dingsør (2001) estimated that the number of 4 year olds would increase by up to 8% during the calibration period if discards were included.

It is not yet clear whether or not to include an intercept when calibrating the winter survey. Though aging errors may be a problem, there is no other apparent reason for the surveys to be biased. Helle *et al.* (2000) found that the estimates of the relative abundance of Northeast Arctic cod as three-year-olds generated by the winter survey were proportional to survey-based estimates of the cohort's abundance at earlier life stages. In contrast, the VPA estimates of the abundance of age 3 cod were not proportional to survey indices at any stage, and in particular, all intercepts were significantly positive. The consistency of the survey indices is an indication that the converged VPA estimates may not be proportional to 'true' stock numbers.

4. Conclusions

There are at least two likely reasons that simply calibrating a survey series using historical catch data may generate more robust abundance estimates than a VPA-type analysis. The first is that the calibration procedure is based on an established relation between the total catch of each cohort that has gone through the fishery and on a scientific survey monitoring the same cohorts while still in the fishery. Secondly, the calibration procedure is based on a much simpler model than a VPA-type analysis. It has been observed in many fields that predictions based on complicated structural models are often less accurate than those based on simpler models (see, *e.g.*, Nerlove *et al.*, 1979; Wheelwright and Makridakis, 1985; Newbold *et al.*, 1993; Stergiou *et al.*, 1993). Jenkins (1976, page 132) gives a nice summary of some of the problems associated with predictions based on complicated models.

Because of inaccurate or incomplete commercial catch data, converged VPA-type estimates of abundance may be biased. Therefore, it is important to choose a calibration period for which the catch data are judged to be fairly accurate, or use ancillary information on known or likely sources of errors to adjust the historical catch data. It should be noted that after the calibration period, it is not necessary to estimate the age composition of the commercial catch.

For stocks that are adaptively managed, another advantage of using survey-based estimates is that they would be available as soon as the survey is finished. It often takes considerable time to collect and collate commercial fishery data, and, therefore, VPA-type estimates are usually not available until several months after the survey is completed. As demonstrated by the Northeast Arctic cod example, an appealing feature of survey-based abundance estimates is that they are not subject to frequent revisions as are the VPA-type estimates. It is difficult to see how stable and effective management strategies can be agreed on and implemented if the assessment of the condition of the stock varies significantly from year to year (Fig. 4 and 5, Table 2).

References

Aanes, S., Pennington, M., 2003. On estimating the age composition of the commercial catch of Northeast Arctic cod from a sample of clusters. ICES Journal of Marine Science. 60:297-303.

Aglen, A., Alvsvåg, J. Halland, T.I., Høines, Å., Nakken, O., Russkikh, A., Smirnov, O., 2003. Investigations on demersal fish in the Barents Sea winter. 2003. IMR/PINRO Joint Report Series, No.1/2003.

Brockwell, P.J., Davis, R.A., 1996. Introduction to time series and forecasting. Springer-Verlag, New York, 420pp.

Dingsør, G.E., 2001. Sstimation of discards in the commercial trawl fishery for Northeast Arctic cod (*Gadus morhua* L.) and some effects on assessment. Cand. Scient., University of Bergen.

Draper, N.R., Smith, H. 1981. Applied Regression Analysis. 2nd ed. John Wiley and Sons, New York, 709 pp.

Fogarty, M.J., Idoine, J.S., Almeida, F.P., Pennington, M., 1986. Modeling trends in abundance based on research vessel surveys. International Council for the Exploration of the Sea (ICES) C. M. 1986/G:92.

Helle, K., Bogstad, B., Marshall, C., Michalsen, K., Ottersen, G., Pennington, M. 2000. An evaluation of recruitment indices for Arcto-Norwegian cod (*Gadus morhua* L.). Fisheries Research, 48:55-67.

ICES, 1995-2006. Reports of the Arctic Fisheries Working Group.

Jenkins, J.M., 1976. Practical experiences with modeling and forecasting time series. In: Anderson, O.D. (Ed.), Forecasting. North-Holland, New York, pp. 43-166.

Korsbrekke, K., Mehl, S., Nakken, O., Pennington, M., 2001. A survey-based assessment of the Northeast Arctic cod stock. ICES Journal of Marine Science, 58:763-769.

Mohn, R., 1999. The Retrospective problem in sequential population analysis: an Investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56 :473-488.

Nakken, O. 1994. Causes of trends and fluctuations in the Arcto-Norwegian cod stock. ICES Marine Science Symposia, 198: 212-228.

Nakken, O., 1999. Retrospective review of management advice and TAC's for some stocks. In: Jakobsen, T. (Ed.) 2002.Management strategies for the fish stocks in the Barents Sea. Proceedings of the 8th Norwegian-Russian Symposium.

Nakken, O., 1998. Past, present and future exploitation and management of marine resources in the Barents Sea and adjacent areas. Fisheries Research. 37:23-35.

Nakken, O., Pennington, M., 2001. On the relation between 'true' numbers of Northeast Arctic cod and VPA- or survey-based abundance estimates. ICES CM 2001/Q:15.

Nerlove, M., Grether, D.M., Carvalho, J.H., 1979. Analysis of Economic Time Series. Academic Press, New York, NY, 468 pp.

Newbold, P., Agiakloglou, C., Miller, J., 1993. Long-term inference based on short-term forecasting models. In: T. Subba Rao (Ed.), Developments in Time Series Analysis. Chapman and Hall, London, pp. 9-25.

Parma, A.M., 1993. Retrospective catch-at-age analysis of Pacific halibut: implications on assessments of harvesting policies. G. Kruse, D.M. In: Eggers, R.J. Marasco, C. Pautzke and T.J. Quinn II (Eds.). Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations, Alaska Sea Grant College Program Report No. 93-02, Fairbanks, University of Alaska.

Pennington, M. 1985. Estimating the relative abundance of fish from a series of trawl surveys. Biometrics 41:197-202.

Pennington, M., L.-M. Burmeister and V. Hjellvik. 2002. Assessing the precision of frequency distributions estimated from trawl-survey samples. Fishery Bulletin. 100:74-81.

Pennington, M., Godø, O. R. 1995. Measuring the effect of changes in catchability on the variance of marine survey abundance indices. Fisheries Research 23:301-310.

Pennington, M., Strømme, T. 1998. Surveys as a research tool for managing dynamic stocks. Fisheries Research 37:97-106.

Salthaug, A., Aanes, S. 2003. Catchability and the spatial distribution of fishing vessels. Canadian Journal of Fisheries and Aquatic Sciences 60: 259-268.

Sinclair, A., Gascon, D., O'Boyle, R., Rivard, D., Gavaris, S., 1991. Consistency of some northwest Atlantic groundfish stock assessments. Northwest Atlantic fisheries Organization Scientific Council Studies 16: 59-77.

Sinclair, A.F., 1998. Estimating trends in fishing mortality at age and length directly from research survey and commercial catch data. Canadian Journal of Fisheries and Aquatic Sciences 55:1248-1263.

Stergiou, K.I., Christou, E.D., Petrakis, G., 1997. Modelling and forecasting monthly fisheries catches: comparison of regression, univariate and multivariate time series methods. Fish. Res., 29:55-95.

Wheelwright, S.C., Makridakis, S., 1985. Forecasting Methods for Management (4th ed.). John Wiley and Sons, New York, NY, 404 pp.

Table 1**.** The winter survey indices of abundance for Northeast Arctic cod adjusted for the expansion of the survey area in 1993.

	Age			
Year	4	5	6	7+
1981	29.1	47.6	45.7	7.3
1982	34.6	28.1	18.5	21.0
1983	65.4	51.6	20.2	12.0
1984	35.4	25.5	14.0	5.5
1985	157.5	23.7	9.1	4.4
1986	179.9	76.4	9.9	2.8
1987	488.9	64.7	18.7	3.0
1988	100.6	206.3	24.4	4.9
1989	94.8	45.0	107.4	13.0
1990	43.6	41.2	24.5	34.8
1991	42.1	30.5	25.6	30.3
1992	72.1	21.2	15.3	17.7
1993	140.1	72.5	15.8	14.7
1994	310.2	147.4	50.6	14.6
1995	241.4	255.9	76.7	22.9
1996	115.4	137.2	106.1	27.7
1997	64.0	70.4	52.7	35.4
1998	181.3	36.5	25.9	27.9
1999	173.2	58.1	13.4	13.1
2000	132.1	108.3	26.9	7.9
2001	182.8	83.4	38.2	10.6
2002	135.0	109.6	42.5	18.0
2003	129.7	91.1	67.3	24.4
2004	172.5	56.9	44.7	37.0
2005	62.1	98.1	24.7	21.5
2006	111.5	28.7	43.7	17.1

Table 2. Annual VPA estimates of the abundance of the total number (in millions) of Northeast Artic cod ages 4 through 6 (a) and ages 7+ (b). The data are from the annual reports of the Arctic Fisheries Working Group, ICES, 1995 – 2006.

(a) Ages 4 through 6 Abundance

Year	Assessment Year 95	96	97	98	99	00	01	02	03	04	05	06
1995	1069	1646	1418	1363	1257	1240	1254	1233	1233	1236	1236	1236
1996		1219	1038	1011	927	905	914	899	899	899	899	899
1997			610	637	607	583	581	574	574	577	579	578
1998				669	611	648	634	620	632	635	639	637
1999					768	792	758	748	776	786	782	780
2000						831	801	776	850	870	840	828
2001							884	858	964	1015	937	916
2002								834	973	1006	951	913
2003									902	879	837	794
2004										835	852	840
2005											689	701
2006												690

(b) Ages 7+

Year	95	96	97	98	99	00	01	02	03	04	05	06
1995	140	108	94	89	86	85	86	85	85	85	85	85
1996		223	176	157	141	141	141	136	137	138	137	141
1997			268	240	186	179	181	178	177	177	177	178
1998				190	138	130	131	126	125	125	125	126
1999					87	77	76	72	72	72	73	73
2000						50	45	45	46	47	48	48
2001							56	58	63	66	68	67
2002								93	107	111	110	109
2003									154	145	129	123
2004										217	170	156
2005											176	149
2006												110

Table 3. Calibrated survey abundance estimates (with and without an intercept) of the number (in millions) of Northeast Arctic cod in the two age groupings and for comparison, the 2006VPA estimates and the annual VPA estimates of abundance. The data are from the annual reports of the Arctic Fisheries Working Group, ICES, 1995 – 2006

	Estimated total number of ages 4 - 6				Estimated total number of ages 7+			
Year	ICES 2006	ICES Annual	Calibrated Survey (intercept)	Calibrated Survey (no intercept)	ICES 2006	ICES Annual	Calibrated survey (intercept)	Calibrated survey (no intercept)
1995	1236	1069	1269	1249	85	140	127	128
1996	899	1219	910	827	141	223	150	157
1997	578	610	574	430	178	268	182	196
1998	637	669	634	500	126	190	150	157
1999	780	768	630	495	73	86	87	78
2000	828	831	703	564	48	50	60	45
2001	916	884	779	672	67	55	83	73
2002	913	834	739	624	109	93	105	101
2003	794	902	754	644	123	154	134	137
2004	840	835	703	585	156	217	191	207
2005	701	689	557	407	149	176	121	120
2006	690	690	550	403	110	110	101	96

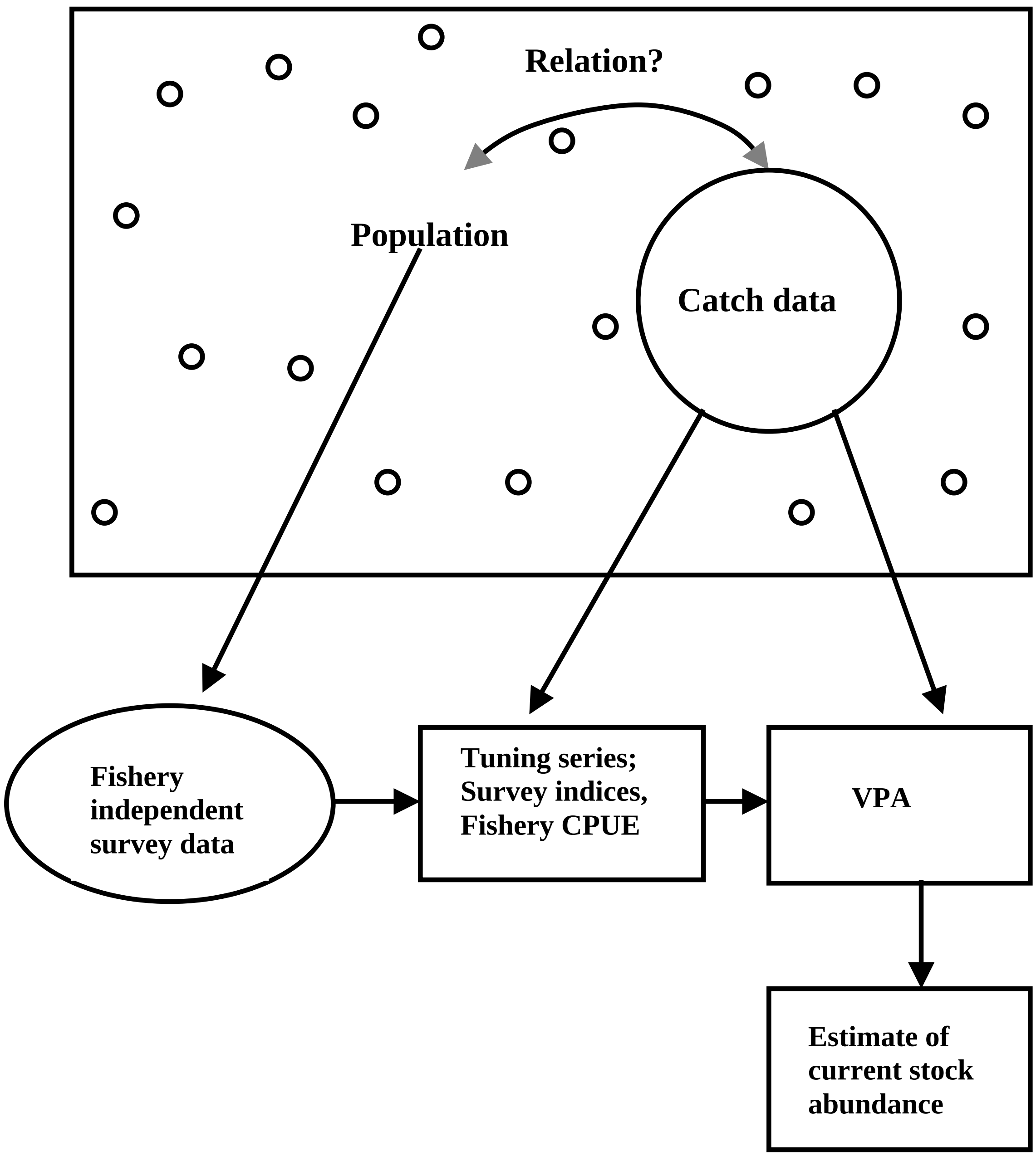

Fig. 1. Diagram of the data flow for the standard VPA-type assessment of a stock for which both fishery independent survey data and commercial catch data are available.

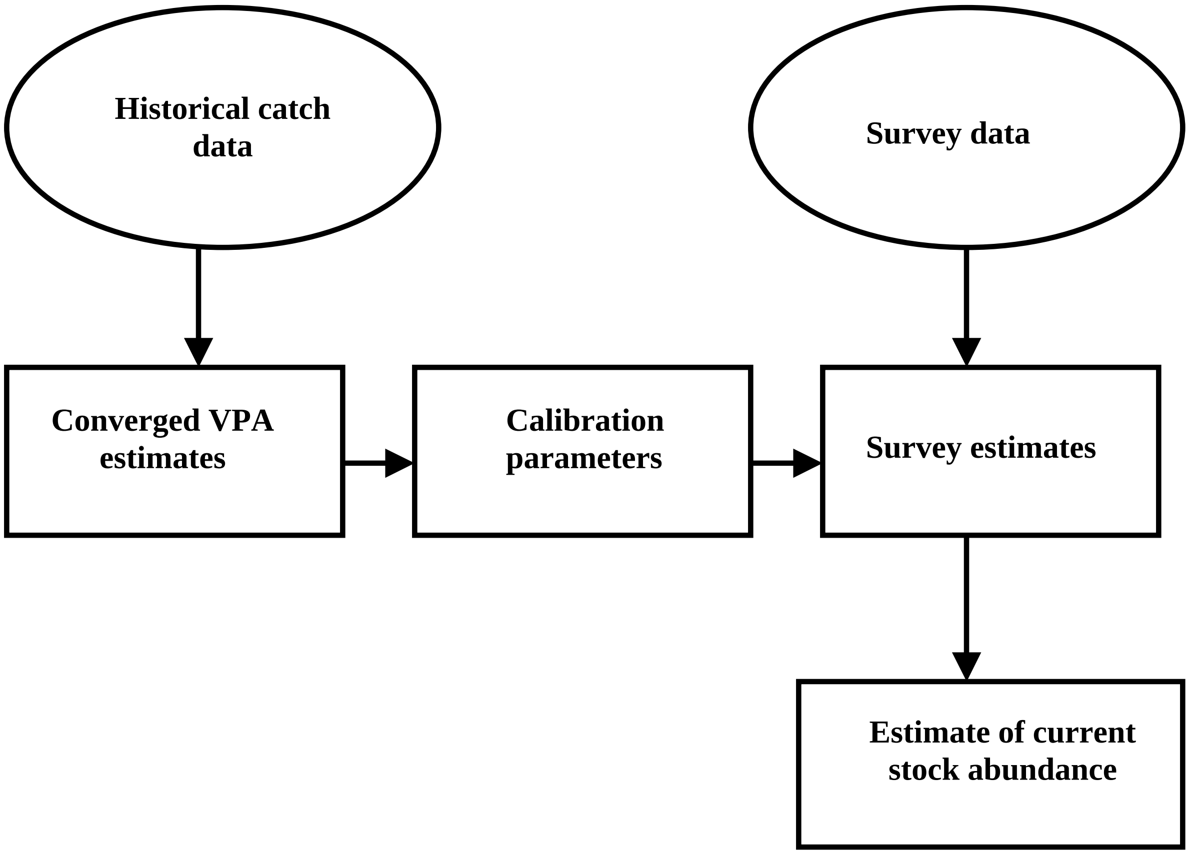

Fig. 2. Diagram of the assessment procedure when historical catch data are used to calibrate the survey data.

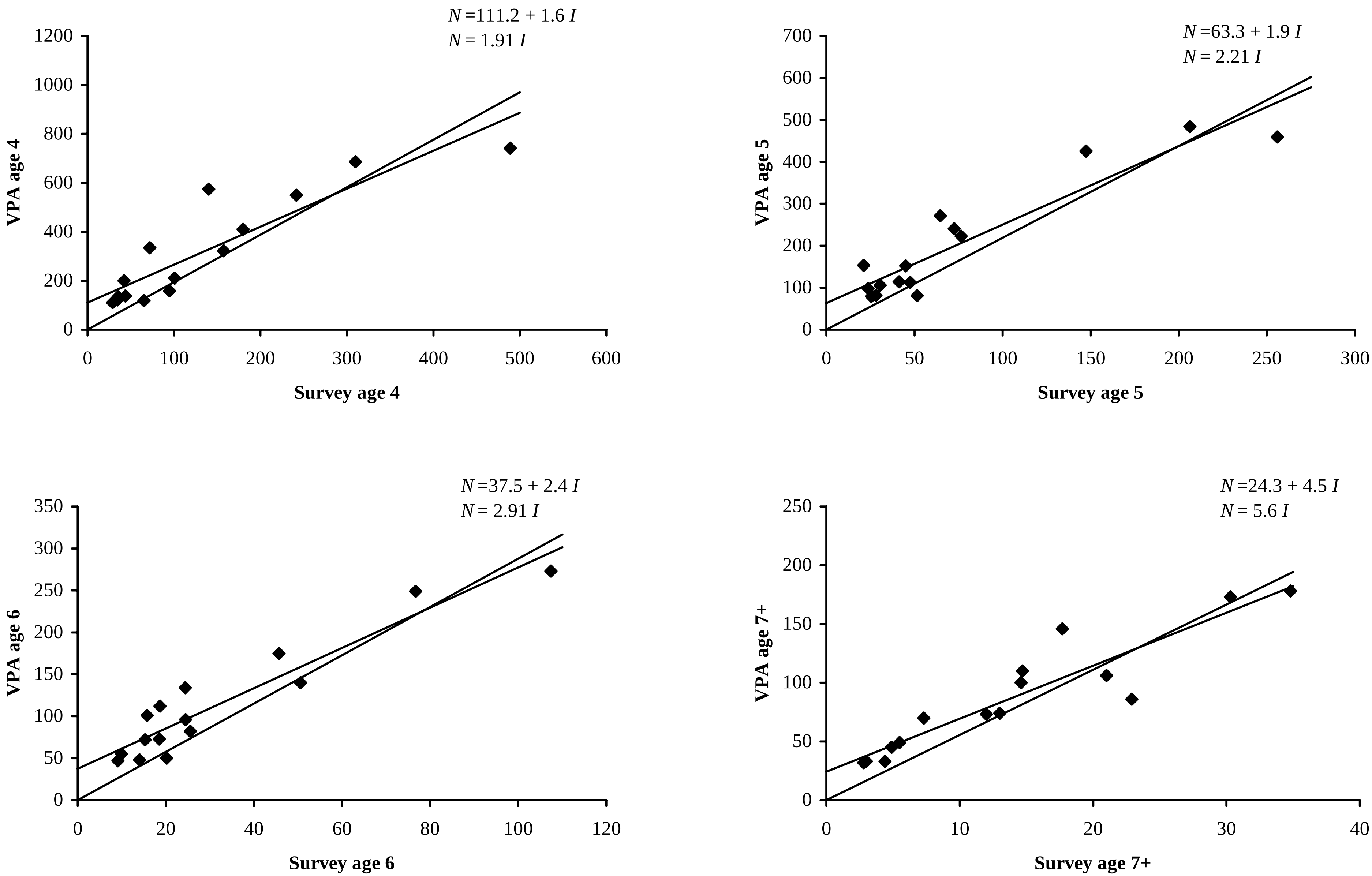

Fig. 3. VPA estimates of the abundance of Northeast Arctic cod versus the winter survey index of abundance for the period 1981 through 1995. The regression line with an intercept is based on all the data and the line through the origin is based only on those years for which the survey index is greater than its mean value.

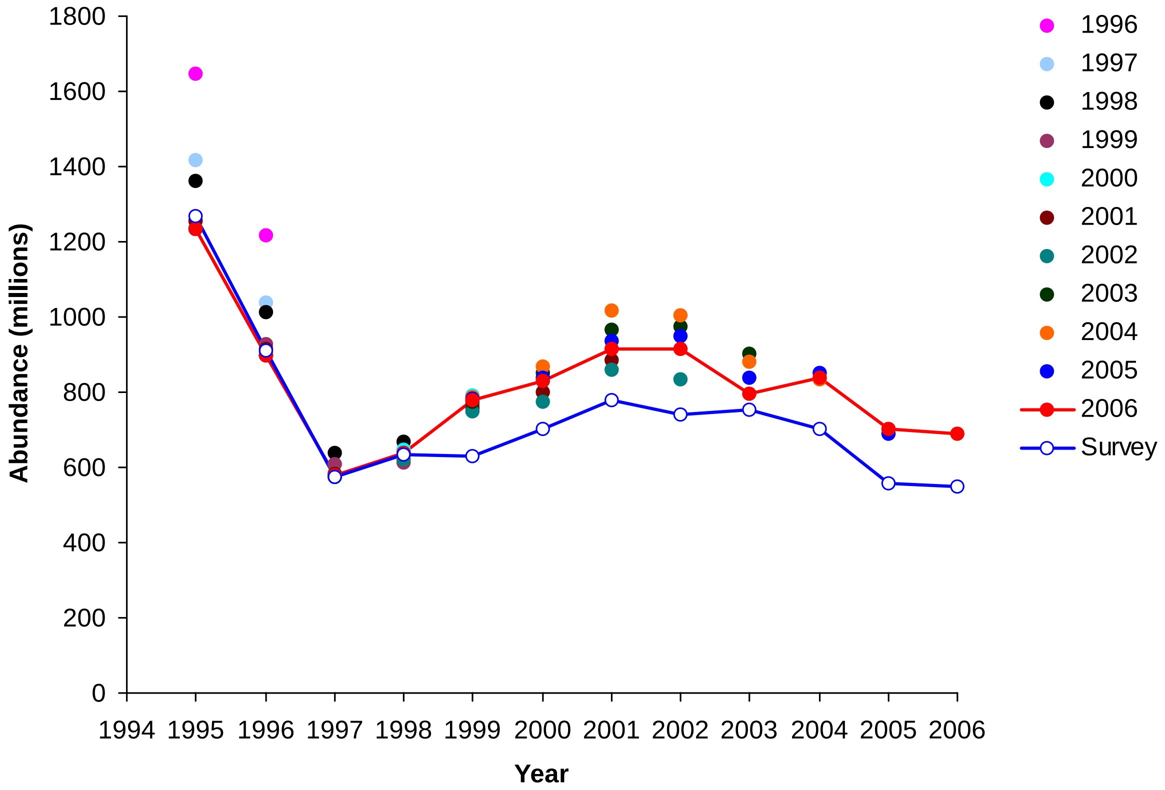

Fig. 4. Calibrated (with intercept) survey estimates (connected open circles), ICES 2006 estimates (connected solid circles) and the 1995- 2005 ICES annual assessments (unconnected solid circles) of the total number of Northeast Arctic cod ages 4 through 6.

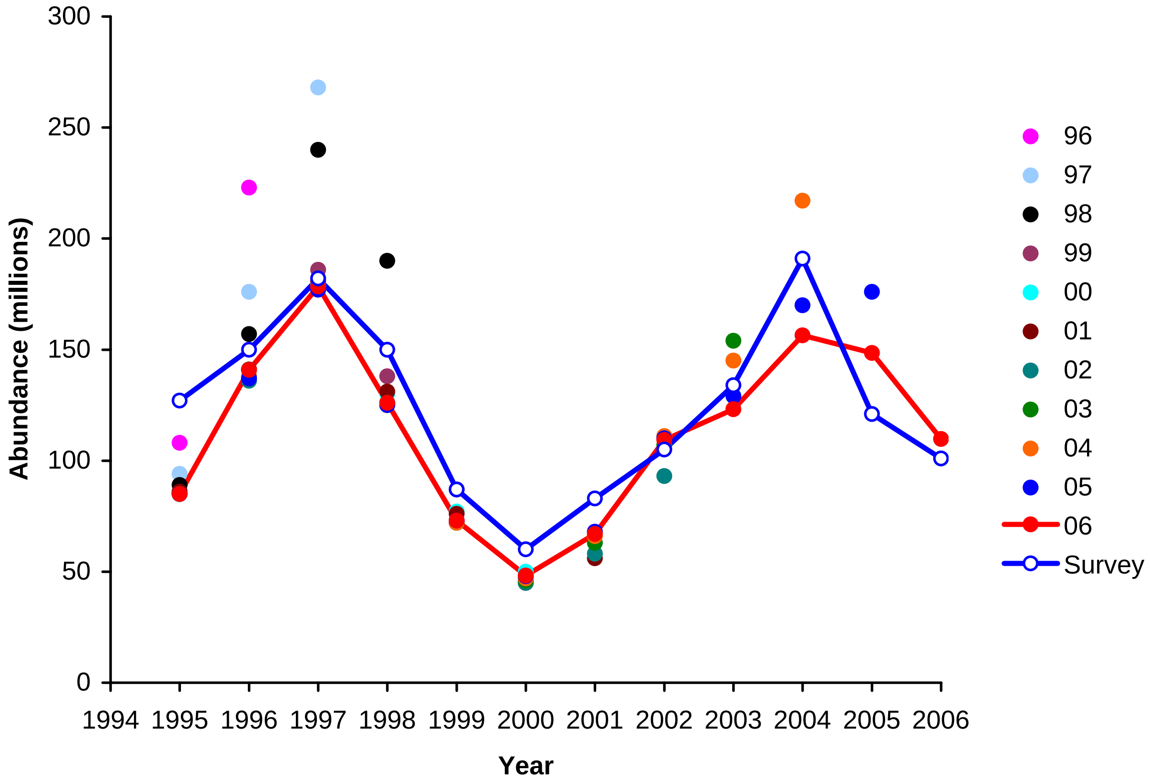

Fig. 5. Calibrated (with intercept) survey estimates (connected open circles), ICES 2006 estimates (connected solid circles) and the 1995- 2005 ICES annual assessments (unconnected solid circles) of the total number of Northeast Arctic cod ages 7 and older.