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Consistency of Some Northwest Atlantic Groundfish Stock Assessments

by

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B. Abstract

The consistency of population estimates from seven northwest Atlantic groundfish stock assessments was investigated using a combined case study and simulation approach. The stocks investigated were 2J3KL cod, 3Pn4RS cod, 4TVn cod, 4VsW cod, 4TVW haddock, 4X haddock, and 5Z haddock. For each stock a series of assessments were performed using an objective and automated calibration technique (ADAPT). The assessments contained progressively shorter time series of input data and yielded several estimates of the same populations. The variability of the resulting estimates of the same population was investigated in terms of both range and trend when compared to those obtained from the assessment with the longest data series (the reference). For several stocks there was a tendency for the annual estimates to be higher than the reference estimates. Different formulations of the calibration model were attempted to eliminate this trend in selected case studies. Simulations of model error and statistical errors were also used to investigate possible causes for the observed trends. The tendancy for annual assessments to overestimate the reference estimates was reproduced in cases of catch misreporting and misspecification of natural mortality in the presence of a trend in fishing mortality.

I Introduction

Virtual population analysis (VPA) (Gulland 1965) and cohort analysis (Pope 1972) have been used extensively for estimating fish stock size for management purposes. The method basically consists of adding up the catches of a cohorts of fish while adjusting for non-fishing or natural mortality (M) during the life of the cohort (Ulltang 1977). An estimate of the number of surviving fish in the last year of the time series is required to begin the process. We have called this process sequential population analysis (SPA). These estimates can be derived by calibrating the analysis with an independent index of stock size. Calibration consists of choosing the set of survivor estimates that produce the best match between the SPA population estimates and the index. While the SPA estimates from the most recent time are highly sensitive to the assumed number of survivors, those from earlier years are not, provided that fishing mortality is high enough (Pope 1972). Thus the population estimates are said to converge to values that are insensitive to the input values. After doing assessments for several years it is possible to compare the most recent estimates of the populations in years gone by to those that were obtained annually in previous assessments. This is what we have called retrospective analysis.

A working group was formed in 1986 by the Canadian Atlantic Fisheries Scientific Advisory Comittee (CAFSAC) to investigate the consistency of the northwest Atlantic finfish stock assessments which used SPA. It was noted that, for several stocks, the yearly assessments generated population estimates more optimistic than those from the reference year (i.e. the most recent assessment) (Gascon 1988, Annon. 1987). The pattern was age structured with the deviations from the current assessment increasing with age. However, the assessments of the day employed a wide variety of *ad hoc* calibration techniques, too many to allow the systematic examination of the assessment deviations in relation to assessment method.

Thus a more objective calibration framework was developed and this has become the main analytical tool of recent Atlantic Canadian stock assessments. We like to call it the adaptive framework, or ADAPT for short (Gavaris 1988 a). With ADAPT one treats the independent index as observed values and SPA is used as a model produce predicted values. Functional relationships between the observations and the model results are defined, usually in the form of linear relationships on an age-by-age basis. The calibration process consists of defining an objective function, usually in terms of minimizing residuals between observed and predicted values, and then using non-linear techniques to choose the set of input parameters for SPA and the regression coefficients that satisfy the objective function. The residuals may be treated in different ways to account for scale, relative error of the observation, and their distribution. Two common treatments are a log transformation and standardization by the inverse standard error of the observation. The method addresses many of the technical problems noted in other *ad hoc* calibration procedures previously used (e.g. the basis for choosing the best estimate, determination of functional relationships, appropriate treatment of errors).

CAFSAC then directed its Statistics, Sampling, and Surveys Subcommittee to evaluate the use of retrospective analysis as a tool for measuring the accuracy of past stock size estimates. A workshop was held in Halifax, N.S. in February 1989. Two main issues were considered, how reliable are the reference (those obtained from the most recent SPA for the complete time series) and the assessed (all other) stock size estimates, and what is the best way to do a retrospective analysis. The discussions centered on population size estimates and did not consider catch projections. This was done in order to focus attention on the SPA. Population estimates are important to the accuracy of catch projections, but other factors such as target fishing mortality, weights at age, and partial recruitment in the projection years are also important.

II Previous Use of Retrospective Analysis. D. Gascon

SPA is a composite of at least three independent models: 1)A model relating population numbers, fishing mortality (F), and catch (the Baranov catch equation). This model includes a major assumption about natural mortality (M), which is a rather untractable parameter. 2) A model about age specific susceptibility (or relative catchabilities) to the fishery: the partial recruitment. 3) A model relating other independent indicies of stock size to those obtained from model 1.

The problem with model 1, is that one has n observations to estimate n+1 independent parameters (the $n+1^{th}$ parameter being F or population numbers in the last year: therefore, model 3 is used to estimate the absolute value of F or population numbers in the last year, whereas model 2 is used to partition F amongst ages. The latter model may not be required if age specific indicies are available, although it is usually included in one form or another to estimate terminal fishing mortalities of historical cohorts.

In spite of its widespread use, SPA has received little attention of either theorists of field biologists, with perhaps the exception of the so-called tuning techniques (see review in Anon. 1988a), whose aim is to relate the three models. The use of "Retrospective Analysis" in assessing the performance of SPA is examined in this section of the report.

Gascon (1988) has examined the ratios between average F estimated in the final year of SPA with the F's in the converged part of the most recent SPA, for several gadoid stocks assessed at CAFSAC, NAFO, and ICES. It was found that the range was quite large (x0.4 and x2.0 of converged F), but also that there was a definite bias toward underestimating F (6 overestimates vs 44 underestimates after 3 years) and therefore overestimating population size.

Rivard (1981) did a similar analysis but on a shorter data set. No bias was visible from his data; however, since he was working on a much shorter time series (in the unconverged part of the SPA), bias may not have yet become apparent. Rivard and Foy (1987) undertook the most comprehensive study of errors in catch projections in which they attempted to partition errors amongst the various source of input. In all cases, initial stock size in the projections was the most important source of error, followed by partial recruitment and target fishing mortality, and by weights at age in projected years. Variation in stock size was estimated by means of retrospective analysis: they found an average absolute difference of 42.7% in the stock sizes estimated for 1980 and of 49.8% for 1982 versus the reference estimates (as of 1985 assessments). There again, there is an evident bias toward overstimating stock sizes (26 overestimates vs 9 underestimates), and amongst the underestimates, 4 occured for stocks which have a poor or inappropriate database (i.e. 3NO cod, 4RST redfish). Population estimates for herring stocks are extremely imprecise (98% absolute error) and unbiased (4 under/3 over). For gadoids and pleuronectids, bias toward overestimating is systematic (19 over/3 under).

Similar analyses have appeared in Anon. (1984), describing the errors in assessments of the ICES and have been produced systematically in some assessments (Anon 1985, 1988b), but owing to the difficulty of their interpretation, these analyses have tended to disappear recently.

Pope and Gray (1983) examined the precision of catch projection of North Sea groundfish stocks using Monte Carlo simulations. The relative importance of the sources of variation (i.e. fishing effort, recruitment, and catch at age) varied from stock to stock. Coefficients of variation were smaller when F in the projection year was set equal to F in the previous year (ie. the *status-quo*), than when F is set to a specific target, since in the first case, errors in F tend to cancel out. Brander (1987) compared nominal catches to *status-quo* projections made by various ICES working groups. He found a 14% error for one year projections and a 21% error for two year projections with no bias. However, nominal catches may be taken at different F's than the one used in projections, adding another source of variability. These studies may be of limited relevance in the context of Atlantic Canadian stock assessments where *status-quo* TAC's are not used. Rather, projections are made at a specific target fishing mortality ($F_{0.1}$) and thus the precision and accuracy of population estimates is of greater importance.

In SPA, there are three majors assumptions postulated or required: 1) That catch estimates are unbiased. 2) That catches and population numbers are related according to model 1. 3) That natural mortality is known (and error free). We briefly examine some studies that attempt to assess the impacts of biases in these assumptions.

<u>Catch at age.</u>

Catch at age is usually the only measured parameter that intervenes in the SPA *sensus stricto*, and the variation (in the population or due to sampling) can be dealt with by standard statistical techniques. Pope (1972) and Sampson (1987) have derived variance formulas for population numbers given the variances in catch and F.

In addition, systematic errors can be introduced by misreporting, discarding, or unrepresentative sampling. Mesnil (1980) was unable to assess the effect of such biases, but he emitted serious doubt about the usefulness of the technique under such circumstances. Sampson (1988) has shown that convergence (i.e. stability in the initial estimate of cohort size) was not maintained when errors in catch at age were added simultaneously to errors in other parameters.

<u>Model errors.</u>

Ulltang (1977) extended the catch equation to incorporate migration, but migration rates are nearly impossible to measure in a systematic manner; therefore they are not considered in most assessments. Sims (1982) has examined analytically and by simulations the assumption of the model that mortality occurs as an exponential function. He found moderately large departures (in the order of 20%) in the worst case scenarios (fishing restricted in the first or last month of the year), under very high M and F's. The bias was usually much lower under more usual circumstances.

<u>Natural mortality.</u>

Natural mortality for groundfish is likely to be dynamic, depending on fish age, the abundance of predators, prey, and other factors. However, M is usually not estimated on a routine basis in SPA. Attempts have been made to estimate M due to predation in the North Sea (Anon. 1989) but this was based on several years of extensive stomach contents analysis and on the existance of fisheries which sample both predator and prey populations at juvenile and adult life history stages. This latter condition is not present in Atlantic Canadian fisheries. Nevertheless, the North Sea model has indicated substantial variation in predation mortality and has yielded some interesting conclusions. Specifically, it was suggested that increased mesh size in cod fisheries from 80mm to 120mm would actually decrease yield in other fisheries by increasing the predation of juveniles by cod and whiting (Anon. 1989). In other cases a "reasonable" value for M is assumed (0.2 or 0.3). Consequently, it is an additional assumption in the model, rather than a real parameter, and it is better treated as such.

Agger *et al.* (1973), Ulltang (1977), Mesnil (1980), Sims (1984), Sampson (1988), Hilden (1988) have discussed various aspect of the effects of M on SPA. All concur to say that higher M lead to higher estimates of initial population numbers, and that errors in M could yield substantial errors in the estimate of population numbers. Sims (1984) found that on 10 and 20 year spans, errors of M (mean =0.18) of +56%, +11%, -11% and -56% yielded errors in population numbers of +91%, +13%, -11% -42% and +261%, +26%, -20% and -62% respectively. Vetter (1988) has thoroughly reviewed the methods of estimating M and the effects of the assumptions about it on fishery models. He concluded that the effects of errors in M were complex, and dependent on the errors in other parameters: in general, the effects were generally a function of the relative values of F and M. He provided strong evidence that M varied both from age to age, and from year to year.

If a bias in M exists, the effects will not be uniform throughout the VPA. The most recent years are all composed of incomplete cohorts, which will suffer smaller cumulative effects of the errors in M, than the more ancient, complete cohorts.

So far, no one has attempted a full analysis of the effects of M on the assessment process (Vetter, 1988), from the SPA to the tuning, projections and yield per recruit. A higher M would result in higher estimate of historical population size, thus changing the slopes of the tuning relationships, yielding a lower (at least relative to the past) current estimates of population size, lower projected catches, but a higher F_{max} (Vetter, 1988). These effects may or may not cancel out, and it is difficult to say for the time being.

III Report of Group 1.

This working group carried out case studies on seven stocks; 2J3KL cod (Baird and Bishop 1988), 3Pn4RS cod (Fréchet 1988), 4TVn cod (Chouinard and Sinclair 1988), 4VsW cod (Fanning et al. 1988), 4TVW haddock (Zwanenburg and Fanning 1988), 4X haddock (O'Boyle et al. 1988), and 5Z haddock (Gavaris 1988 b). The retrospective analysis for each stock commenced by first re-doing the 1988 assessment. This analysis served as the reference to which all subsequent runs were compared. Next, the assessments were conducted with progressively shorter catch and abundance index data sets. The population estimates from each assessment were compared to the reference estimates. Based on previous observations that systematic deviations from the reference estimates varied with age, comparisons were again done by age groups. The years used and the age groupings in the analyses are given in Table 1. All population estimates are given in Annex II.

An index of deviation (D_{ijta}) was calculated as the ratio between the population estimates (N_{ijta}) for age group i, stock j, population year t, and assessment year a, and the corresponding reference estimate ($N_{ijt.ref}$). The distribution of these ratios were examined among stocks and age groups. The index was calculated as

$$D_{ijta}=\frac{N_{ijta}}{N_{ijt.ref}}$$

Plots of population size by age class from the retrospective assessments indicate that of the seven stocks examined, 4RS3Pn cod and 5Z haddock had consistent patterns of estimates from one year to the next for all age groups, that is to say that by dropping one year of data there was not a tendency for the subsequent estimates of the same population to increase (Figure 1). The pattern for 4TVn cod was also consistent for the partially recruited ages. For 2J3KL cod, 4VsW cod, and 4TVW haddock there was a distinct tendency for the estimates in the assessment year to be higher than those in the following years. This was also the case for 4TVn cod and 4X haddock in the older 2 age groups.

Box and whisker plots (Tukey 1977) of D_{ijta} in Figure 2 give the distribution of these ratios for all stocks by age group. For 2J3KL cod and 3Pn4RS cod the deviations for all age groups are the smallest and the ratios are close to 1. The largest deviations were found for 4VW haddock and 5Z haddock. When compared among age groups (Figure 3), it is apparent that over 75% of the population estimates are greater than the reference estimates. The deviations were slightly higher for the recruitment estimates than for the other two ages. If the ratios are plotted against the lag between the assessment year and the popuation year, one can see the effect of convergence of the SPA's (Figure 4). After a lag of three years 50% of the population estimates for partially and fully recruited ages are within +- 10% of the reference estimates. However, for estimates of recruitment, the same degree of convergence was not evident until a lag of five to six years. For the population estimates from the last year of the assessment series (ie. lag=0) the range of ratios was 0.3 to 3.9 and the middle 50% of the ratios were between 1.0-1.8. This indicates considerable variation in population estimates as more data were added to the assessments.

We considered whether the source of abundance index data, either from a research survey or commercial catch rates, could be related to the pattern of population estimates. The assessment of 2J3KL cod uses both indices in its calibration. Two series of assessments were conducted using survey and commercial catch rates separately in the calibration. The results are presented in terms of fully recruited fishing mortality (Table 2). The calibrations with survey indices alone gave consistently higher fishing mortalities, and thus lower population estimates, than calibration with the commercial index although the two converged to virtually the same reference estimate by 1983. The commercial catch rate series generated assessed fishing mortalities 40-70% lower than the reference. The research survey index generated F's 30-40% larger than the current estimates in the 1983-85 period, but similar estimates in the last 2 years. A significant change in the pattern occured in 1986, the year of what now appears to be an anomalously high survey estimate (Baird and Bishop 1989).

How general this was for other stocks could not be determined due to time constraints. However, a similar comparisons could be made for other stocks where both research survey and CPUE time series are available.

IV Report of Group 2.

This group developed alternative formulations within ADAPT in an attempt to eliminate systematic deviations in the restrospective analyses. The alternative formulations which were considered are those related to 1) structural changes in the underlying population dynamic model, 2) the formulation of the objective function for the minimization, or 3) the choice of the index (or combination of indices) for the calibration. The list of alternative formulations that were investigated is as follows:

- allowing temporal changes in catchabilities for the commercial fleet;
- allowing exploitation patterns to be dome-shaped rather than assuming full recruitment for older ages;
- allowing natural mortality (M) to be estimated within the framework (i.e. M as a parameter) or assuming that M is something else than 0.2;
- using alternative indices of abundance or a different combination of them (relative weighting)
- using alternative formulations of the objective function (e.g. logarithmic transformations, weighting by inverse of standard error for indices, etc.);
- using age disaggregated indices from the commercial fleet rather than a single global index.

It was not possible to extensively explore the area of "alternative indices" within the time available. Similarly, the question of stock definition and its implication for the various formulations was not addressed. The questions of relative weighting of multiple indices and of using multiple indices in a single formulation or in separate formulations of the adaptive framework (combine estimates within or combine them after) were not considered extensively.

Cod in the southern Gulf of St. Lawrence (4TVn) and haddock on the eastern Scotian Shelf (4TVW) were used as case studies. The purpose of the exercise was to compare the retrospective analysis obtained by Group 1 with the retrospective view obtained from the "new" formulation. The aim was to find a formulation that provided the "most consistent" analysis. Consistency, while a desirable property, must not be confounded with the "truth" and there is no guarantee that the "most consistent formulation" corresponds to the "truth".

Cod in 4TVn

The results for this stock ar summarized in two figures, the ratios of assessed and reference estimates (Figure 5) and a comparison of absolute population estimates from the different options (Figure 6).

Research index at age using log transformations. In this formulation, only the research index at age was considered for the calibration. Rather than weighting the residuals by the inverse of standard error as was done in the original analysis, a logarithmic transformation was applied to the residuals. The results are comparable to those of the original analysis both in terms of deviations and absolute estimates. This is not surprising since the original formulation (Chouinard and Sinclair (1988)) gave very little weight (1/9) to the commercial catch rates. The estimates for partially recruited ages were generally less consistent and more dispersed using the RV data alone. The interannual changes in estimates of recruitment were less using the RV data alone.

Age-disaggregated commercial catch rates. In this formulation, only commercial catch rates at age (from otter trawlers) were used for the calibration. This formulation lead to a systematic underestimation of recruitment and partially recruited ages relative to the reference (Figure 5). However, for the fully recruited ages, the stock size estimated each year was closer to the reference than those based on the surveys. Consequently, the commercial catch rates might be better for estimating the fully recruited ages but the research survey information provides a more satisfactory index for estimating recruitment and partially recruited ages.

Time-varying catchability for the commercial fleet. In this formulation, the following modifications were used:

-logarithmic transformation was applied to the residuals;
-commercial catch rates were disaggregated by age (this implies a relative weighting of 1:1 for the commercial index and the research index);
-the catchability coefficients (q) for the commercial fleet were arbitrarily assumed to be time dependent, increasing at 5% per year.

The population estimates for fully recruited ages are systematically higher than the reference with this formulation but to a lesser extent than the results obtained using a formulation based on surveys only. The opposite was true for the partially recruited and recruitment estimates. This is similar to the pattern obtained when only the CPUE index was used. This option produced the lowest absolute population estimates.

Forcing exploitation patterns to be dome-shaped. Input parameters for VPA are usually given as fishing mortalities (F) for all ages in the last year and for the oldest ages for all other years. It has been our experiance that there are insufficient data to estimate all these parameters. Instead, the oldest age F's are estimated by assuming a relationship between F at younger ages in the same year and that at the oldest age. In the original formulation for this stock, F at the oldest age was assumed to be equal to the mean (weighted by popularion numbers) fully recruited F (ages 9 and 10), a so called flat-topped recruitment pattern. An alternative formulation was used where the pattern was assumed to be dome-shaped, that is where the oldest age F was set at 25% the fully recruited F. Only the research vessel index was used for calibration. This formulation produced a much more consistent retrospective pattern for the oldest age group and a slight improvement for the recruitment estimates. This option produced the highest absolute population estimates.

Defining M as a parameter. When M was introduced as an additional parameter, it was estimated to be 0.37. However, all values of the correlation matrix of the parameters became relatively large which would indicate that while there is some information in the data to estimate M, there is insufficient information to estimate simultaneously M and F (through the survivors and the calibration coefficients).

Haddock in 4TVW

Forcing exploitation patterns to be dome-shaped. Fishing mortality on the oldest age group was set at 50% of the fully recruited fishing mortality in each year. This formulation did not improve the retrospective analysis for any age group (Figure 7).

Defining M as a parameter. When M was introduced as an additional parameter it was estimated to be 0.27. The standard error was relatively small, i.e. 0.09, but all values of the correlation matrix of the parameters were relatively large. Again, as was the case for 4TVn cod, there is insufficient information to estimate simultaneously M and the other parameters.

Assuming M=0.4. There was no consistency of the restrospective analysis when M was assumed to be 0.4. The analysis could not be completed for 1986 and 1987.

Assuming M is age-specific. In this formulation, M was assumed to take the following arbitrary values for each age:

AGE	1	2	3	4	5	6	7	8	9	10	11
M	.9	.54	.36	.18	.18	.18	.18	.18	.18	.27	.324

With this pattern, no improvement in the consistency of the retrospective analysis could be detected (Figure 7).

General Comments

Adding parameters in an attempt to develop new/alternative formulations often led to an overspecification of the model. This was apparent by examination of the correlations among parameter estimates, a useful diagnostic tool available in ADAPT. Under these conditions, there is insufficient contrast in the data to allow estimation of all parameters simultaneously. This observation is consistent with the general experiance in stock assessments, for example the inability to estimate F on the oldest age groups.

For one of the two stocks for which dome shaped partial recruitment was assumed, the retrospective analysis provided a more consistent picture than the formulation which assumes full recruitment for the oldest age. However, by assuming a dome, the results imply an abundance of older fish in the population that are not found either by the research surveys or the commercial fishery. In addition, when a dome shaped pattern is assumed there is not complete convergence of estimates of abundance of the oldest age groups.

The question of relative weighting of multiple indices in a single formulation and of using multiple indices in separate formulations of the adaptive framework (combine estimates within or combine them after) were only addressed in two new formulations for the 4TVn cod stock. The commercial catch rates provided a more consistent estimation for the fully recruited ages but the research survey information proved more consistent for estimating recruitment and partially recruited ages. This should be explored further.

V Report of Group 3.

The general approach of this group was to use simulated data to investigate the effects of model misspecification on population estimates, both reference and in the assessment year. Input data for an assessment were generated with the set of parameters: initial numbers at age, recruitment, fully recruited F, partial recruitment, and natural mortality at age. Population numbers (N) at age i and year t were then projected using the standard equation:

$$N_{i+1,t+1}=N_{i,t}e^{-(M_{i,t}+F_{i,t})}$$

Catch at age i and in year t was also generated using the Baranov catch equation:

$$C_{i,t}=\frac{F_{i,t}N_{i,t}(1-e^{-(M_{i,t}+F_{i,t})})}{M_{i,t}+F_{i,t}}$$

The simulated population numbers were used as the index of abundance for calibration. For the analyses, either the input data (catch at age or index of abundance) or the parameters used in the SPA (M, partial recruitment) were adjusted to mimic systematic errors in the analytical models. The specific deviations investigated were;

- Differences between assumed and actual natural mortality.
- Changes in the catchability of the survey.
- Errors in partial recruitment assumptions (domed or flat topped).
- Misreporting of catches.

Populations with two age spans were used, ages 1-5+ and 1-10+. Catches and population numbers for older ages were combined. The formulations of ADAPT had the following in common.

Parameters Estimated

-Survivors in the last year, either 1-4 or 1-8 depending on the age span of the simulated population.
-Slopes (k's) for the calibration relationships (to beginning of the year). The relationships used the population estimates from SPA to predict the index, in the form;

$$f_{i,t}=k_iN_{i,t}$$

Structure Imposed

- For the short age span, F at age 5+ in the final year was set equal to age 4. This was consistent with the partial recruitment used to generate the numbers. F on the oldest age was set equal to age 4.
- For the long age span F at age 9+ in the final year was set equal to the mean of ages 5-7, as was F on the oldest age.
- M assumed to be .2 in all cases.
- Error in catch at age was assumed to be negligible and thus the abundance index was treated as the dependent variable in the calibration regressions. (see report of group 4 for details)

Differences between assumed and actual M at age.

Four scenarios of deviations of M were investigated: true M declining, true M U-shaped, true M lower than assumed, and true M higher than assumed. In all cases M was assumed to be 0.2. The actual values used are given in Table 3.

The effects of these deviations between the true and assumed M on the resulting population estimates are demonstrated by the estimated slopes of the calibration relationships (Table 4). Since the true population abundance was used as the calibration index for each age, the true calibration slopes were 1.0. Higher estimated slopes indicate an underestimate of the true population (on average) while slopes less than 1.0 indicate an overestimate of the true population.

In the case with declining M, the older age groups were correctly estimated (slope ≈ 1.0) (Table 4) since the assumed and true M's matched. The SPA underestimated the true abundance for younger ages because the true M was higher than the assumed value. The population estimates were lower than the true values when the true M was higher than the assumed value (M=0.3 and U-shaped), while the opposite was true when the true M was lower than that assumed (M=0.1). The residuals in the calibration were negligable (less than 0.5%) meaning that the differences between the estimated population sizes and the index were almost totally explained by the calibration regressions. This is probably because the deviations between true and assumed M as well as the fully recruited fishing mortality were constant for all years. Consequently, there was no divergence between the reference and assessed estimates and there was no retrospective pattern.

This was verifed by using different M's while generating the simulated data. In a 10 year simulation with M=0.2 for 5 years and M=0.4 for 5 years the calibration produced residuals, and these were autocorrelated with time.

We also investigated whether a trend in F accompanied by a misspecification of M could generate a retrospective pattern similar to that observed by group 1. Population and catch numbers were generated using M=0.1 and M=0.3 and either continuously increasing or decreasing F for a 20 year period. Fishing mortality trends were from 0.05 to 1.00 in steps of 0.05. The data were analysed assuming an M of 0.20. Examination of the deviations between the reference and assessed population estimates indicated retrospective paterns (Figure 8). When M was underestimated and F decreased there was a tendency for the assessed values to exceed the reference values. The same was true when M was overestimated and F increased. It was reported by Lapointe, et al. (1989) that such a situation created spurious trends in recruitment estimates. Many groundfish stocks in the northwest Atlantic have experianced lower fishing mortalities since the extension of fisheries jurisdiction in 1977.

Changes in Catchability of the Index

As mentioned above, the simulated true population numbers were used as the calibration index. Thus, the true values were used in a manner analogus to having an abundance survey with a catchability of one. A change in catchability was simulated by changing the index either by year or by age before carring out the calibrations. When the calibration index was doubled after 5 years this generated a discontinuous pattern in the residuals of the calibration regressions with respect to time. If the calibration index was adjusted in an age dependent manner the calibration regressions were perfect (no residuals) and the calibration slopes accurately estimated the simulated catchabilities.

Partial Recruitment

In this case the true population was generated with a dome shaped PR and analysed with a flat-topped PR (Table 5). The results indicated no deviation between the reference and assessed estimates. However, the population estimates were consistently lower than the true values. The resulting estimates of F indicated an increasing trend with age (Table 5). In a standard assessment, such a trend might be interpreted as a continually increasing partial recruitment to the fishery rather than the real dome shaped pattern. The estimated k's also increased with age (Table 5). The largest errors were for the oldest ages and there was a convergence of the estimated and true population values toward younger ages. However, such a pattern of k in a standard assessment might be interpreted as an increasing trend in catchability to the survey. Only if a dome shaped PR was assumed or if F was high (close to 1.0) did a dome appear in the F matrix. The lack of residuals in the fits made diagnosis of the misspecification of PR very difficult. Based on these observations, the interpretation of a dome-shaped pattern in an F matrix is unclear.

The same catch at age matrix was analysed with SVPA (Pope and Shepherd 1982) and the dome shaped PR was detected.

Misreporting

In this case a simulation of annual assessments was used on a population with a 5 year age-span over a 30 year period. Two cases were examined; in one misreporting began after 10 years, in the second misreporting occured throughout the period. The first simulation began with 10 years of perfect data. Beginning in year 11 only half of the actual catch at age was used, thus simulating a situation where only half of the catch was reported. An assessment was done each year and catches for the next year were projected at F=0.2. The fishery then caught twice the TAC, and the catch at age necessary to achieve this was estimated. But for the next year's assessment only half the catch numbers were used since only half the catch was reported.

The annual assessments of population size were consistently higher than the reference estimates when misreporting began at year 11 (Figure 9). The assessed values were higher than the true values in the years immediately following the beginning of misreporting and the assessed estimates were always closer to the truth. However, the assessments consistently indicated increasing trends in population size contrary to the actual trends. This pattern in the retrospective analysis was similar to that observed for several cases studied by Group 1.

When misreporting always occured the reference and assessed estimates were equal but half the real values. Thus the retrospective pattern described above was due to a change in simulated reporting practices.

VI Report of Working Group 4.

There are two fundamentally different types of data available for the estimation of stock size, commercial catch at age and information from abundance indicies. It is currently popular to use the catch at age with cohort analysis to estimate the population. An alternative approach is to use the abundance index scaled by age specific catchabilities to estimate the population. The choice of approach may be based on the relative uncertainty in the two types of data. This working group used simulated data to investigate the effects of error misspecification on the resulting population estimates.

Three formulations of ADAPT were considered to take into account the relative importance of the uncertainty in these data.

Model I	no-catch-error; assumes that the error in the catch at age can be ignored
Model II	no-index-error; assumes that the error in the abundance index can be ignored
Model III	full-error; account for the error in both types of data in *ad-hoc* sequential manner.

Model I is similar to the standard assessment approach. The cohort equations (Pope 1972) were used to generate the population matrix. ADAPT was used to estimate the survivors in the final year and the calibration constants between the population estimates and the abundance index. The calibration criterion used was to minimize the residuals between the observed abundance indicies and those predicted from the population estimates. The survivors for the oldest age were calculated by assuming that the F on that age was equal to the F on fully recruited ages. This assumption was consistent with the way the simulated data were produced.

Model II calculated the population as the product of the abundance indicies and age specific calibration constants. The catch at age was then predicted given the estimated population by estimating the total annual mortality (Z) for each cohort, substracting the natural mortality to obtain annual fishing mortality, and using this to estimate annual catch at age using the Baranov equation. ADAPT was used to estimate the calibration constants using the criterion of minimizing the residuals between the observed and predicted catch at age.

Model III used both methods to sequentially estimate the population and produced two estimates of the population.

A single population matrix was generated and the resulting true catch at age and abundance index were calculated for the given exploitation pattern and the index catchability. The catch at age and index were decomposed into proportions and total numbers before lognormal error similar to that calculated for these stocks was added. Ten data sets were then generted for each of the the three data classes described below. Each data class was analysed with each model.

Data Class I	True catch at age, abundance index with error
Data Class II	True abundance index, catch at age with error
Data Class III	Both data types with error

The results are summarized below. Model I performed well even when the data violated model assumptions, i.e. there was error in the catch at age. There was also a slight tendancy to underestimate the population size in the most recent years when there was error in the catch at age. Model II performed poorly. When the model assumptions were met, i.e. no error in the index, the estimates were unbiased but highly variable. When there was error in the index, the estimates from this model were severely biased. Model III incorporated the populations from models I and II. The poor performance of model II was reflected in the results of model III. Consequently, model III did not perform as well as model I.

Model	Data Class I	Data Class II	Data Class III
I	good	acceptable	acceptable
II	biased severely	unbiased but highly variable	biased severely
III	poor	acceptable	poor

It appears that random errors in catch at age of a magnitude similar to what has been calculated for several finfish stocks can safely be ignored. That is, the performance of Model I was not severely degraded when there were errors in the catch at age. All models performed relatively well when there was no error in the index. Random error in the catch at age is easily handled if the abundance index is precise and accurate. However, attempts to estimate the survivors for the oldest age with Model I were unsuccessful with the level of error used in these simulations.

The CVs of the survivor estimates from Model I and 10 replications of Data Class III ranged from 34% to 55% (Table 6). A comparison of these to the model estimates showed that the model underestimated standard error by approximately 30%. This could be due to the model misspecification, i.e. the model estimates assume that there is no error in the catch at age. Further simulations matching Model I and Data Class I would provide a clearer answer.

It is noteworthy that Model I, the standard model now used, performed well if errors are random.

VII. Summary and Conclusions

The workshop concentrated on the use of retrospective analyses for examining the consistency and accuracy of population estimates. While Rivard and Foy (1987) estimated that population estimates accounted for 2/3 of the error in catch projections used for TAC advice, this is only part of the input data. Partial recruitment, weight at age, and recruitment in the projection year are also important. One must be careful to interpret the results presented here only for estimates of population size. It is expected that errors made in assumptions of M and PR for estimates of stock size may cancel when catch projections are made. The effects of errors in these assumptions although important, were not examined at this meeting and further investigation may be warrented.

Most of the groundwork for this meeting was laid by the CAFSAC Working Group on the Accuracy of Analytical Assessments (1986). Since then significant progress has been made in several areas as recommended in that unpublished report. This includes;

- the development of more objective assessment approaches
- simulation studies of the effects of input on the converged part of SPA
- quantification of the sources of variability in SPA

Indeed the conclusion of Group 1 are consistent with the earlier observations that there is a tendency to overestimate the converged population estimates for the stocks investigated. We were unable to determine a common factor responsible for this pattern. Some improvement in the retrospective analysis was attained for 4TVn cod if a dome shaped PR was used for assigning F to the oldest ages. However, this was not the case for 4TVW haddock. A misspecification of M in concert with a trend in F produced the desired pattern. It is generally accepted that northwest Atlantic groundfish stocks have undergone a reduction in F since the extension of fisheries jurisdiction in 1977. Simulations of catch misreporting also geenerated the desired pattern of estimates if the reporting practices changed from full to partial reporting. However, these findings need further study before conclusions may be drawn regarding probable causes in the case studies.

Given the present state of assessment methodology, it was generally concluded that the precision of stock size estimates in the final year will only be as good as the precision of the abundance index. For current abundance surveys age-by-age estimates have coefficients of variation of 30% or more. Coefficients of variation for aggregated age groups are less. While estimates of commercial catch rates have lower CV's, there is considerable uncertainty about changes in catchability and for several stocks such indices are currently not available. In addition, Group 4 found, following simulations of realistic errors in basic input data, that CV's of 35% or more on population estimates should be expected. Thus, the development of more reliable abundance indicies is called for if fisheries management plans require more precise population estimates.

The question of accuracy is another matter altogether. We must make assumptions about several important parameters. Natural mortality is commonly assumed to be fixed through time and at age. However, there is a dearth of information regarding the dynamics of M. Data are usually inadequate to estimate the fishing mortality (or survivors) of the oldest age classes. However, faulty assumptions regarding the F on older fish can significantly bias estimates of population size and F in the past (Table 3). Other assessment methods such as SVPA (Pope and Shepherd 1982) may be useful for estimating the PR of older fish. Nominal catch data are often taken at face value when in fact there are no programs in place to measure its accuracy on a routine basis and there are substantial allegations that the reported values are far from the truth, particularly for the Scotian Shelf, Georges Bank area. The simulation studies presented here have indicated that population estimates may be biased in complex ways by faulty assumptions of these parameters. Furthermore, it was seen that in some cases the yearly assessed population sizes may be closer to the truth than the reference estimates from the most recent assessment. The use of diagnostic plots (residuals) may be useful in detecting deviations between assumed parameters and reality, however further simulation studies are needed. Thus it is clear that estimates of population size from the converged part of the SPA do not necessarily represent the true population size for those years.

This meeting was asked to address three questions:

1. Are retrospective analyses worth doing?

It was agreed that analyses of the type carried out here are useful for two purposes. First they indicate the variability, both in terms of range and direction, of population estimates depending on the number of years of data used. They are also useful for examining different assessment formulations which may improve the consistency of estimates. Once an improvement is attained the implications of the new formulation in terms of population dynamics and biology of the resource should be investigated.

2. How should they be done?

The general approach taken here was to repeat the assessments using a common formulation and sequentially dropping years of data. Then the variability of estimates of the same population were examined in relation to the time span of the analysis. Other factors not considered were trends in calibration coefficients and the interpretation of residuals. While not available for this meeting, the development of objective measures of variability, including direction, of the estimates is warrented.

3. Can we use retrospective analyses to improve assessments?

To the extent that retrospective analyses generate questions and promote investigations, one may say that they may improve assessments. They do indicate the sources of variability in population estimates. However, this exercise alone will not necessarily give more reliable estimates of true population size.

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Table 1: Data characteristice of groundfish stocks used in retrospective analyses. For the abundance index used, RV indicates the results of research vessel surveys while CPUE refers to commercial catch per unit effort.

Stock	Abundance Index Used	Time Span		Age Groups in Comparisons		
		SPA	Retro.	Recruits	Partially Recruited	Fully Recruited
Cod						
2J3KL	RV/CPUE	1978-88	1983-86	4	5-8	9-13
3Pn4RS	CPUE	1974-87	1980-85	4	5-9	10-15
4TVn	RV/CPUE	1971-87	1978-85	3-4	5-9	10-15
4VsW	RV	1971-87	1979-85	3	4-6	7-15
Haddock						
4TVW	RV	1970-87	1980-85	1-3	4-6	7-11
4X	RV	1970-87	1980-85	1-3	4-6	7-11
5Z	RV	1963-87	1982-85	1	2-3	4-8

Table 2: Comparison of terminal F's (age 13) obtained for the 2J3KL cod stock when either research vessel or commercial CPUE indicies were used to calibrate the SPA.

Year	Calibration with RV			Calibration with CPUE		
	Reference	Assessed	Deviation (%)	Reference	Assessed	Deviation (%)
1983	0.472	0.627	32.8	0.470	0.202	-57.0
1984	0.507	0.707	39.4	0.475	0.174	-63.3
1985	0.545	0.758	39.1	0.552	0.147	-73.4
1986	0.484	0.480	-0.80	0.422	0.165	-60.9
1987	0.552	0.516	-6.50	0.361	0.223	-38.2
1988	0.566			0.305		

Table 3: Natural mortalities at age used to generate simulated data used by working group 3.

Age	True Natural Mortality			
	Decline	U-Shaped	M = 0.1	M = 0.2
1	1.00	0.50	0.10	0.30
2	0.80	0.40	0.10	0.30
3	0.60	0.30	0.10	0.30
4	0.40	0.20	0.10	0.30
5	0.20	0.10	0.10	0.30
6	0.20	0.10	0.10	0.30
7	0.20	0.20	0.10	0.30
8	0.20	0.30	0.10	0.30
9	0.20	0.40	0.10	0.30
10	0.20	0.50	0.10	0.30

Table 4: Slopes of calibration relationships as determined for population simulations of 20 years where various errors in M occured. M was always assumed to be 0.2 while the true M is indicated in the table.

Age	Slopes of Calibration relationships			
	M Decline	M U-Shaped	M = 0.1	M = 0.3
1	6.61	1.87	0.38	1.95
2	3.08	1.39	0.42	1.78
3	1.74	1.15	0.45	1.64
4	1.20	1.05	0.49	1.53
5	1.00	1.05	0.50	1.49
6	1.00	1.19	0.50	1.49
7	1.00	1.40	0.50	1.50
8	1.00	1.53	0.50	1.50

Table 5: Fishing mortality and calibration constants (k) estimated using catch at age generated with a dome shaped partial recruitment but assuming a flat-topped partial recuitement.

Age	Fishing Mortality		Calibration Slope (k)	
	Estimated	True	Estimated	True
1	0.01	0.04	1.48	1.00
2	0.03	0.08	1.49	1.00
3	0.09	0.12	1.51	1.00
4	0.23	0.16	1.56	1.00
5	0.37	0.20	1.70	1.00
6	0.46	0.20	2.02	1.00
7	0.49	0.16	2.61	1.00
8	0.53	0.12	3.63	1.00
9	0.54	0.08		
10	0.42	0.04		

Table 6. Comparison of coefficient of variation for the replications and model estimates.

Age	Coefficient of Variation	
	Replication Estimates	Model Estimates
1	0.55	0.45
2	0.39	0.33
3	0.39	0.28
4	0.40	0.28
5	0.34	0.26
6	0.51	0.32
7	0.48	0.33
8	0.42	0.35

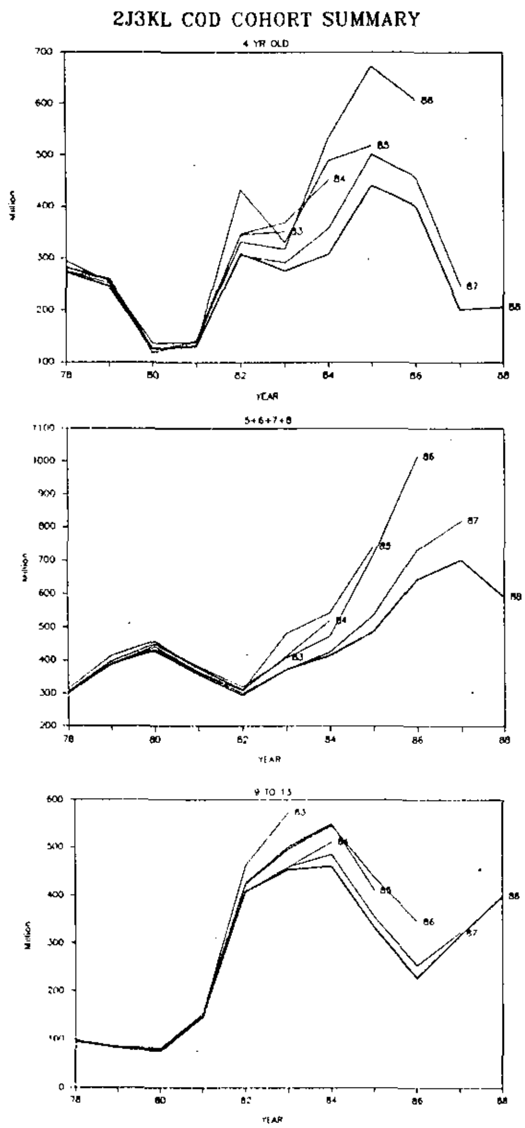
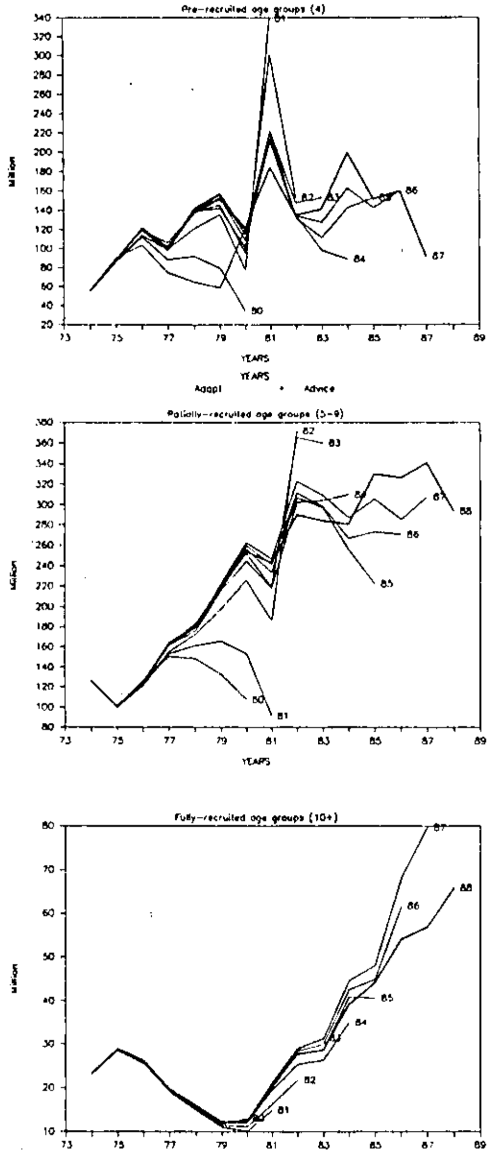


Figure 1: Comparison of population estimates by age groups for several northwest Atlantic groundfish stocks resulting from the use of data sets of various time periods.

RETROSPECTIVE ANALYSIS: 3Pn4RS Cod



RETROSPECTIVE ANALYSIS - 4TVn COD

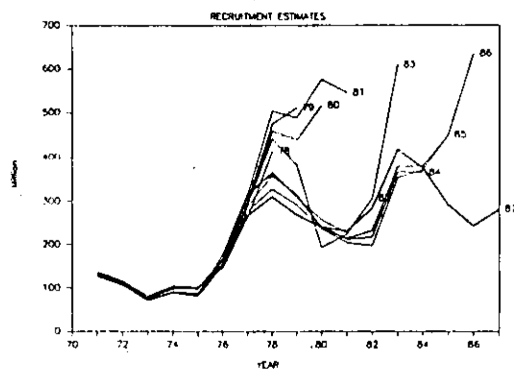
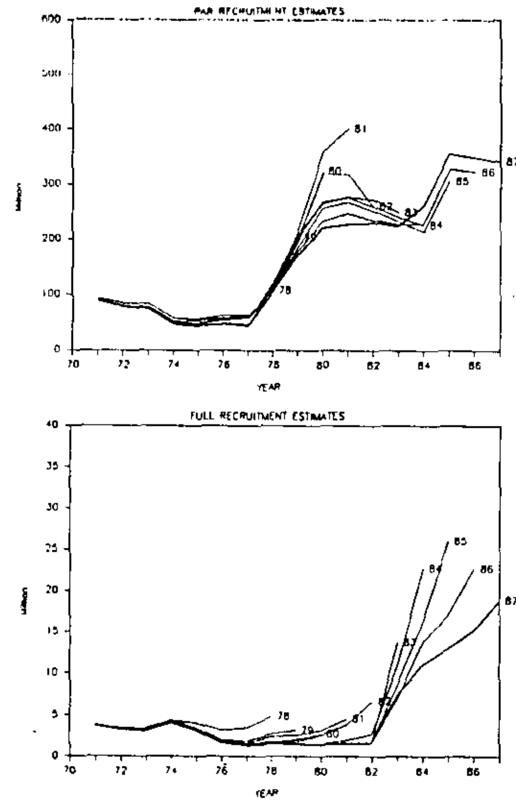


Figure 1: con't



Retrospective analysis - 4VSW COD

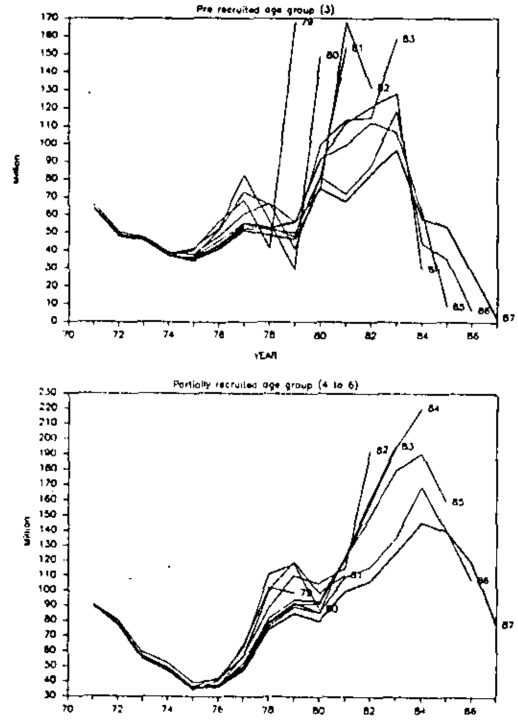
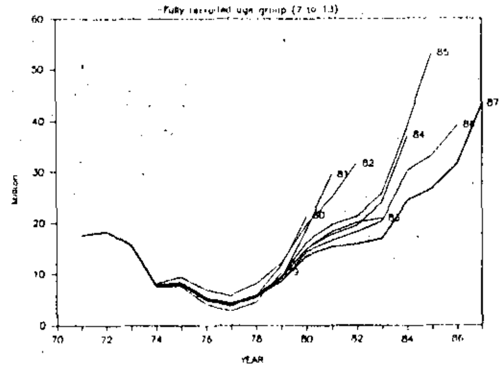


Figure 1: con't



RETOSPECTIVE ANALYSIS: 4TVW HADDOCK

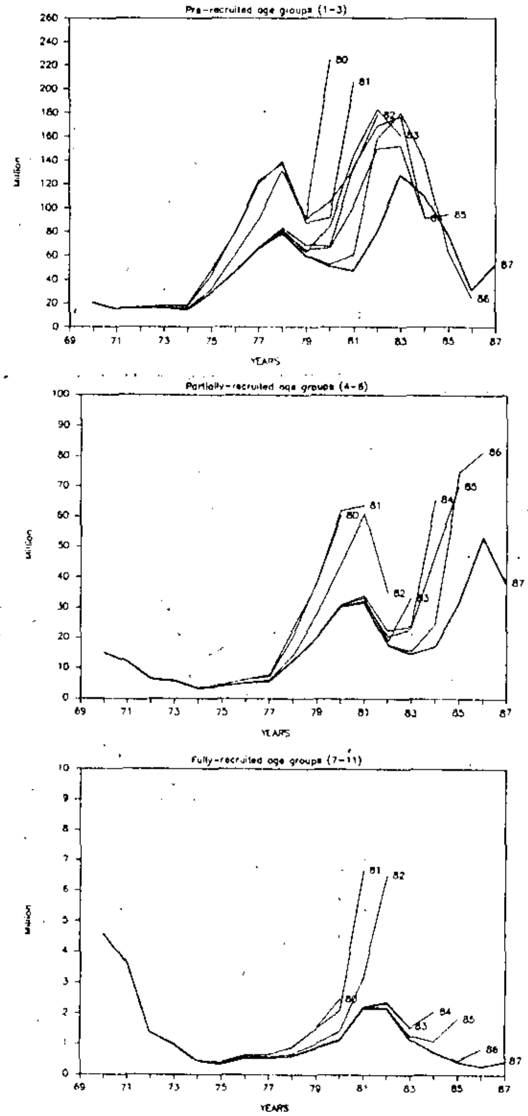
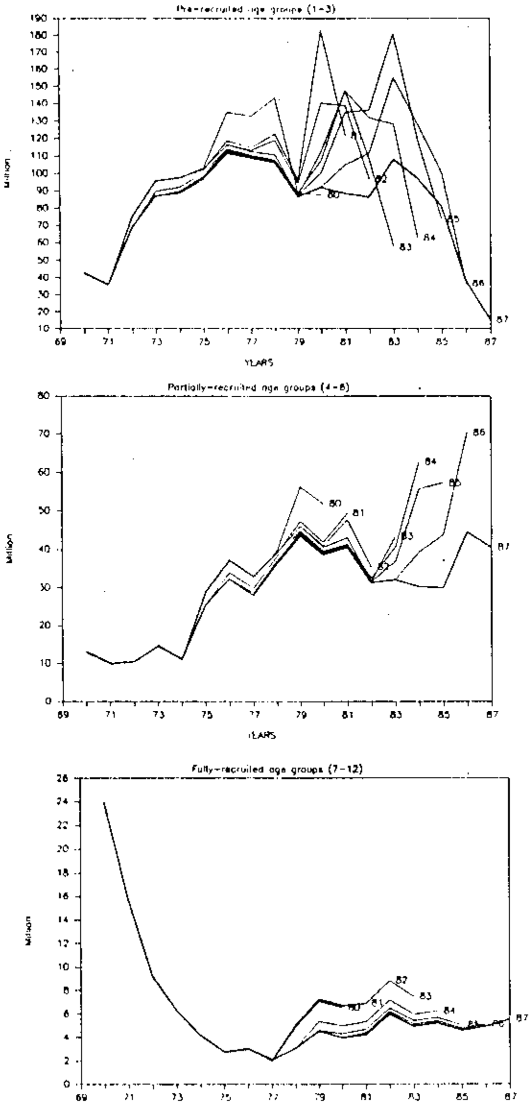


Figure 1: con't

RETROSPECTIVE ANALYSIS: 4X HADDOCK



Retrospective analysis 5Z Haddock

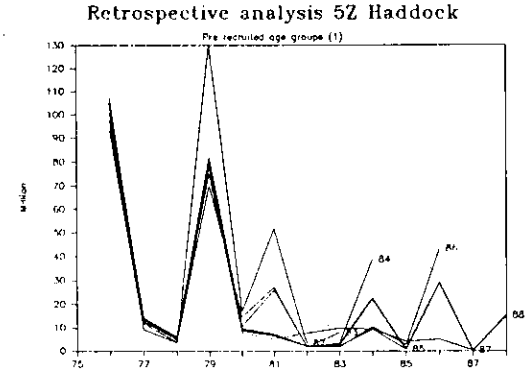


Figure 1: con't

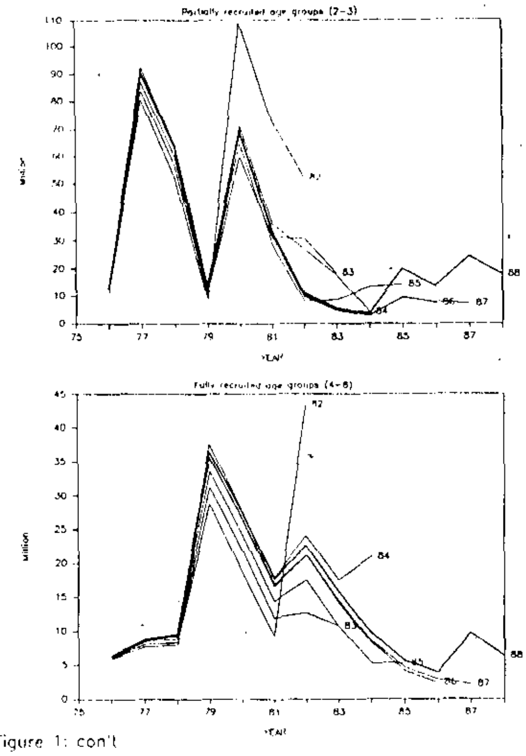


Figure 1: con't

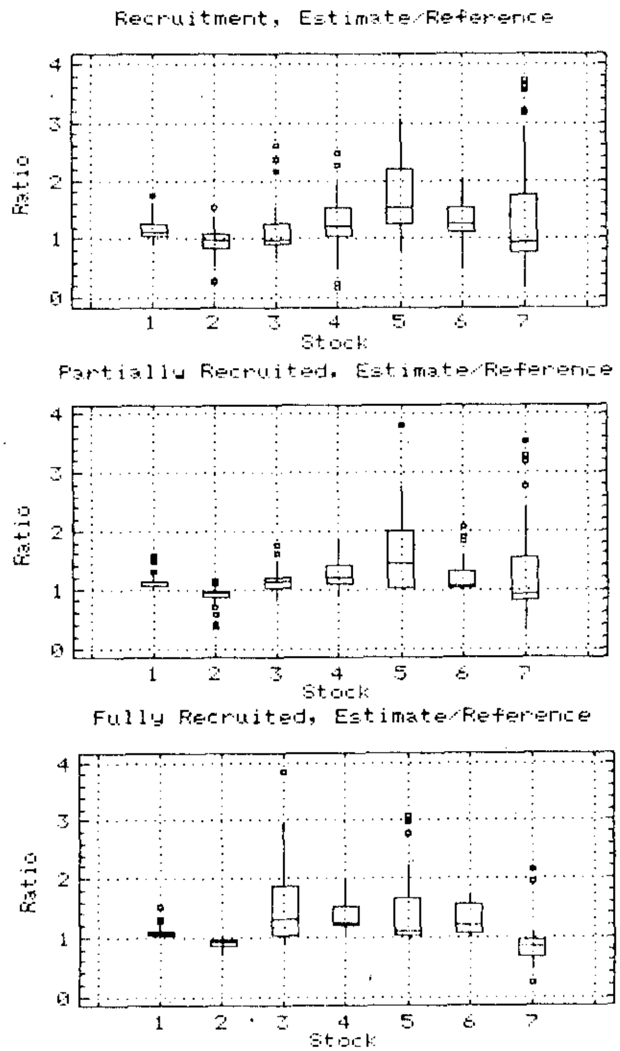


Figure 2: Box and whisker plots of the distribution of the ratios between assessed and reference population estimates for seven northwest Atlantic groundfish stocks. The stocks are 1- 2J3KL cod, 2- 3Pn4RS cod, 3- 4TVn cod, 4- 4VsW cod, 5- 4TVW haddock, 6- 4X haddock, 7- 5Z haddock.

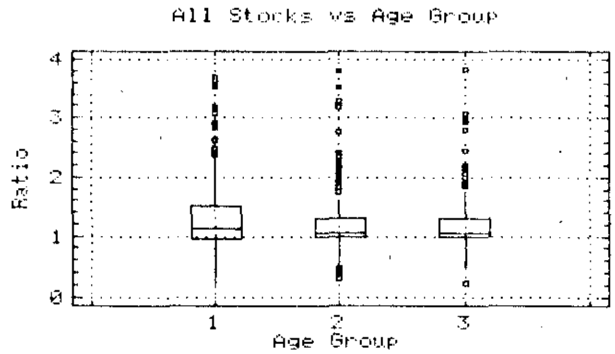


Figure 3: The distributions of ratios between assessed and reference population estimates for all seven stocks combined, but separately by age groups (1- recruitment, 2- partially recruited, 3- fully recruited).

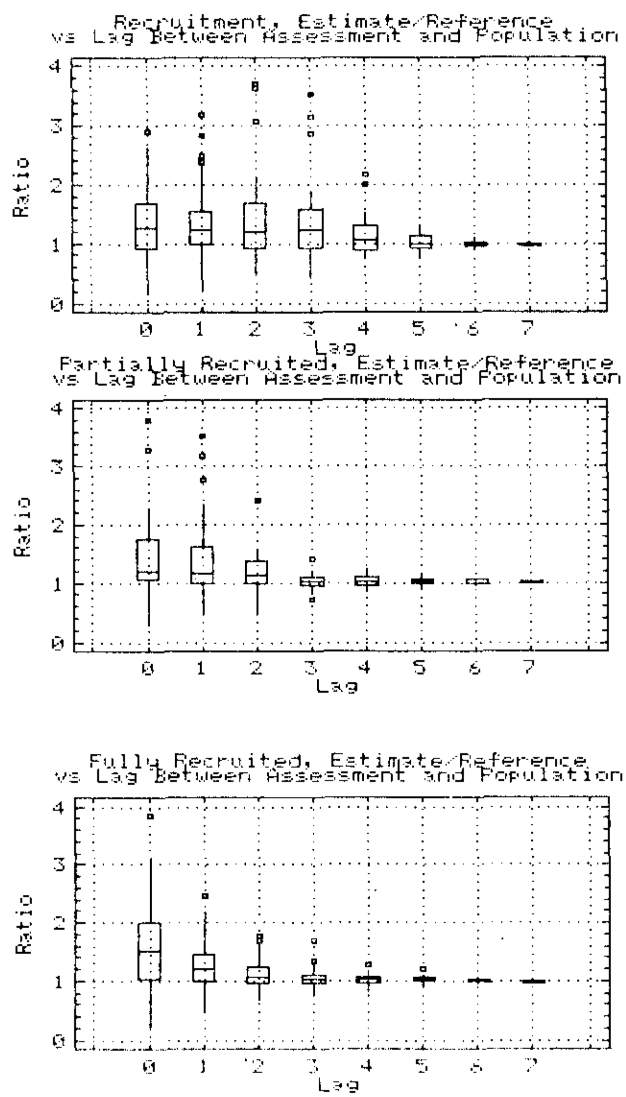


Figure 4: Distribution of ratios between reference and assessed population estimates as a function of the lag between the last year in the SPA and the population year.

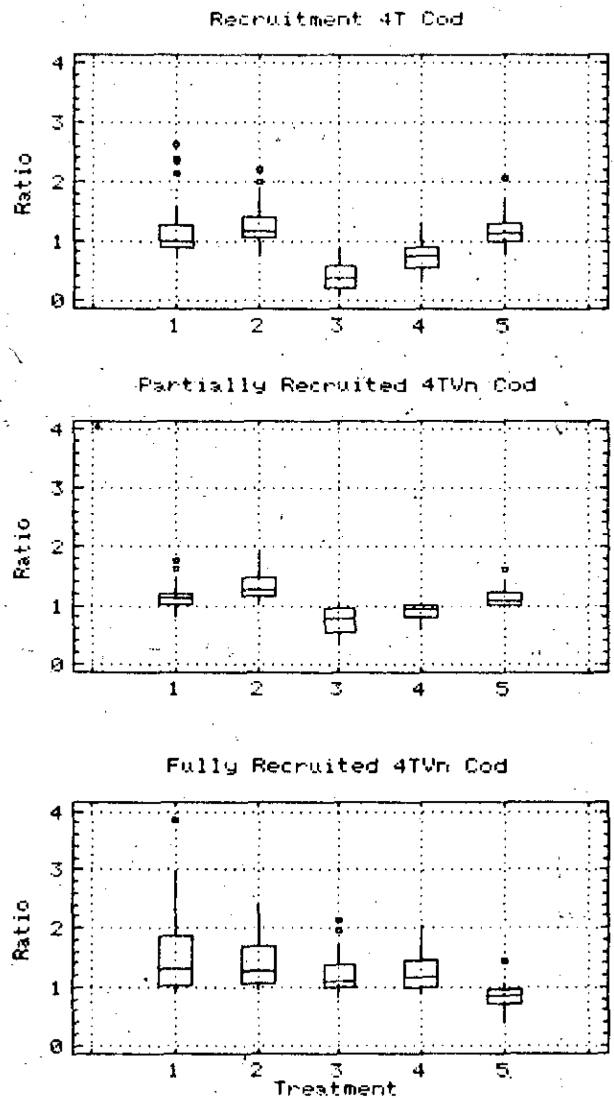


Figure 5: **Effects of changes in the ADAPT formulation on the ratios between** assessed and reference population estimates for 4TVn cod. Treatments were: 1- the standard assessment, 2- calibration with RV data only, 3- calibration with CPUE data only, 4- calibrated with RV and CPUE data and assuming a 5% annual increase in efficiency of the commercial fishery, 5- calibrated with RV data only and forcing a dome shaped partial recruitment pattern.

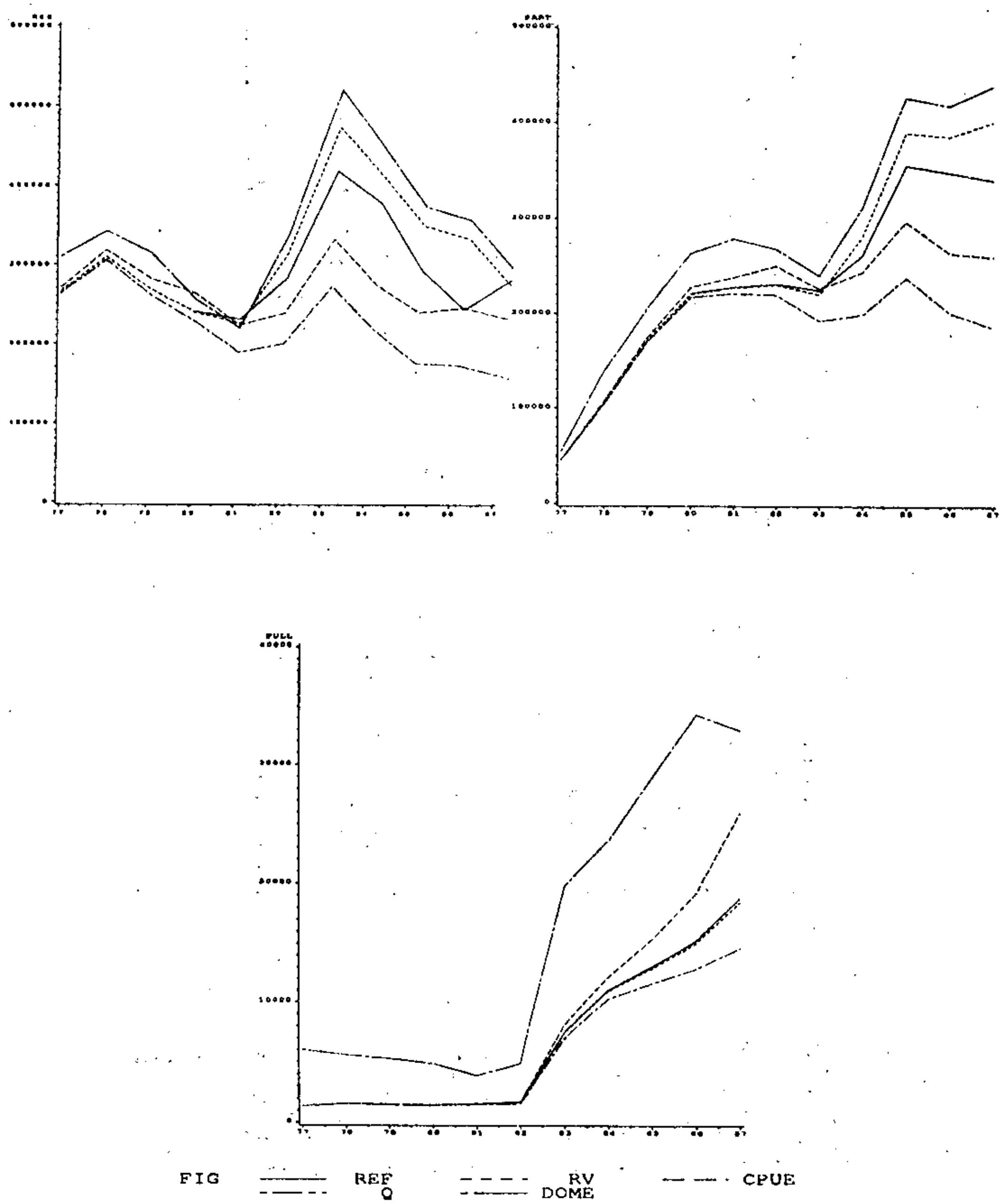


Figure 6: Effects of changes of the ADAPT formulation on the absolute population estimates of 4TVn cod.

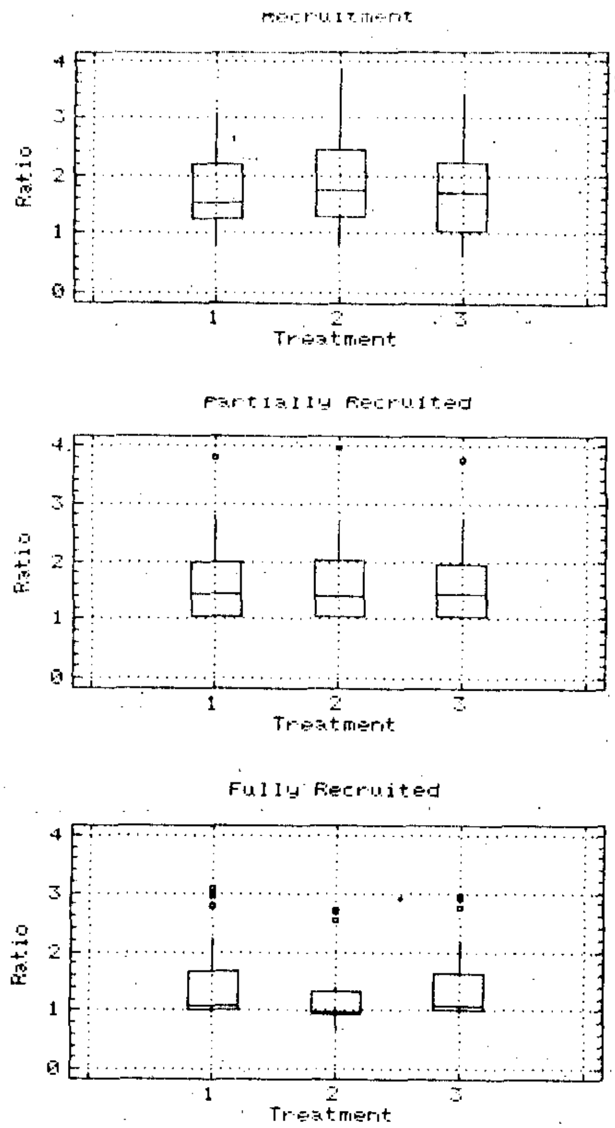


Figure 7: **Effects of changes in the ADAPT formulation on the ratios between assessed and reference population estimates for 4TVW haddock. Treatments were: 1- the standard assessment, 2- calibration with a dome shaped partial recruitment, 3- calibrated with age dependent natural mortality.**

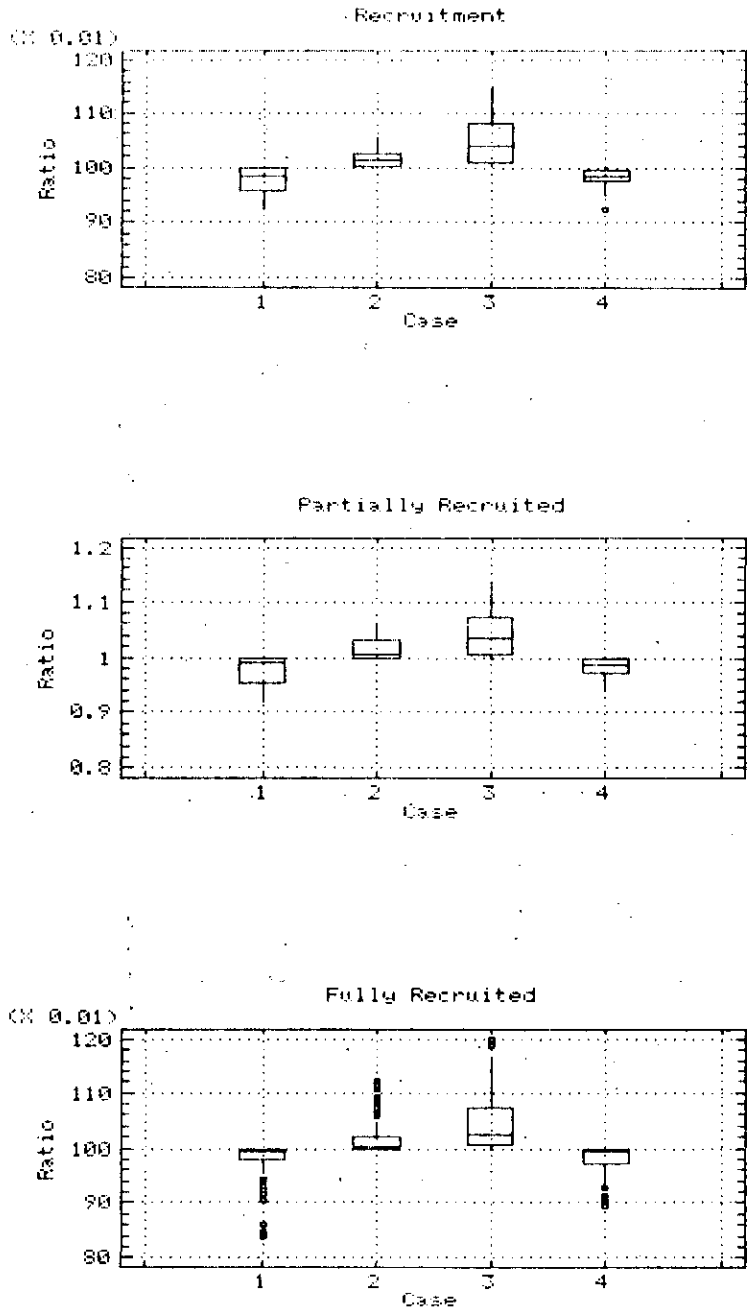


Figure 8: Distributions of ratios between assessed and reference population estimates for simulated data where M is misspecified and there is a trend in F. In all cases M=0.2 was used in SPA. In cases 1 and 2 the true M was 0.3 and in cases 3 and 4 the true M was 0.1. In cases 1 and 3 F increased while F decreased in cases 2 and 4.

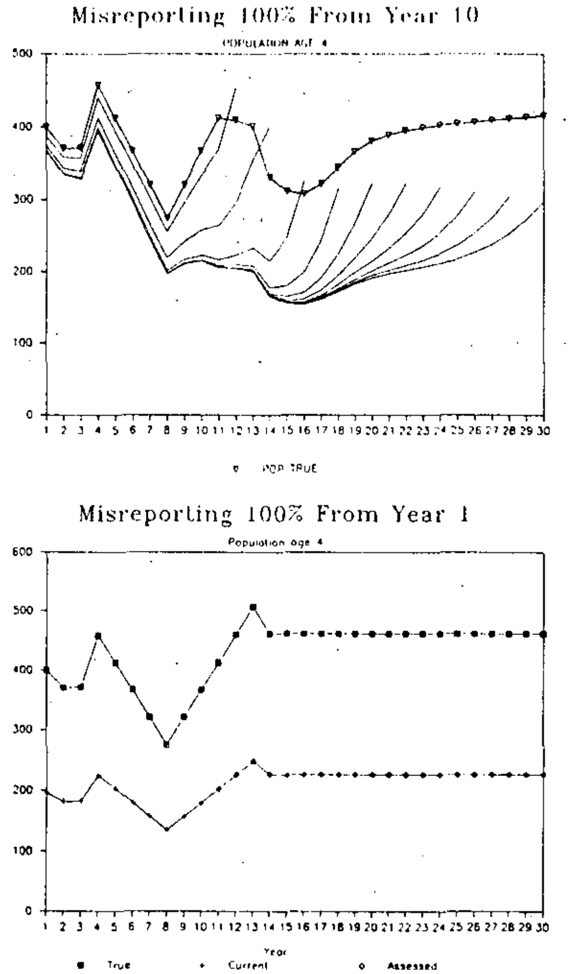


Figure 9: Population estimates for two simulated misreporting situations. In the upper graph only half the catch was reported after year 10. In the lower graph only half the catch was reported for the entire time series.

Annex 1

Participants

Name	Region
A. Sinclair (Chairman, Leader Group 3)	Gulf
I. McQuinn	Quebec
C. Annand	Scotia Fundy, Dartmouth
P. Fanning	Scotia Fundy, Dartmouth
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C. Bishop	Newfoundland
W.R. Bowering	Newfoundland
D.B. Atkinson	Newfoundland
W.B. Brodie	Newfoundland
D. Power	Newfoundland
K. Brander	Scotia Fundy, Dartmouth
R. O'Boyle (Leader Group 1)	Scotia Fundy, Dartmouth
R. Mohn	Scotia Fundy, Halifax
G. Chouinard	Gulf
D. Rivard (Leader Group 2)	Headquarters
S. Gavaris (Leader Group 4)	Scotia Fundy, St. Andrews
D. Gascon	Quebec
E. Laberge	Quebec
A. Fréchet	Quebec
G. Nielsen	Gulf
D. Clay	Gulf

Annex II: Population estimates from retrospective analyses of seven Atlantic Canadian groundfish stocks. Population year refers to the year of the population estimated while Assessment year refers to the last year in the assessment time series. The age groups are stock specific, and these are given in Table 1 of the report. Population numbers for 2J3KL cod are expressed as 10^{5} and for other stocks as 10^{-3}.

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
2J3KL	78	83	2946	3131	99
2J3KL	78	84	2750	3013	98
2J3KL	78	85	2829	3050	99
2J3KL	78	86	2821	3049	96
2J3KL	78	87	2750	3013	95
2J3KL	78	88	2736	3013	96
2J3KL	79	83	2547	4145	85
2J3KL	79	84	2591	3886	84
2J3KL	79	85	2598	3981	86
2J3KL	79	86	2591	3974	85
2J3KL	79	87	2516	3887	82
2J3KL	79	88	2463	3877	83
2J3KL	80	83	1167	4590	83
2J3KL	80	84	1228	4417	81
2J3KL	80	85	1267	4500	83
2J3KL	80	86	1349	4488	81
2J3KL	80	87	1258	4355	78
2J3KL	80	88	1250	4304	77
2J3KL	81	83	1411	3758	154
2J3KL	81	84	1386	3668	149
2J3KL	81	85	1315	3766	154
2J3KL	81	86	1389	3822	154
2J3KL	81	87	1316	3644	149
2J3KL	81	88	1298	3594	147
2J3KL	82	83	3456	3138	463
2J3KL	82	84	3467	3093	410
2J3KL	82	85	4326	3102	427
2J3KL	82	86	3317	3209	424
2J3KL	82	87	3058	3015	409
2J3KL	82	88	3095	2961	409
2J3KL	83	83	3509	4093	574
2J3KL	83	84	3686	4137	460
2J3KL	83	85	3310	4818	502
2J3KL	83	86	3173	4084	498
2J3KL	83	87	2910	3738	460
2J3KL	83	88	2766	3729	455
2J3KL	84	84	4523	5195	512
2J3KL	84	85	4893	5440	550
2J3KL	84	86	5330	4730	546
2J3KL	84	87	3576	4259	486
2J3KL	84	88	3087	4154	462
2J3KL	85	85	5183	7401	411
2J3KL	85	86	6728	7147	438
2J3KL	85	87	5016	5358	355
2J3KL	85	88	4419	4875	333
2J3KL	86	86	6071	10152	346
2J3KL	86	87	4569	7314	253
2J3KL	86	88	4016	6436	228
2J3KL	87	87	2466	8202	323
2J3KL	87	88	2017	7017	317
2J3KL	88	88	2069	5912	399
3Pn4RS	74	78	535	1227	228
3Pn4RS	74	79	563	1256	232
3Pn4RS	74	80	547	1249	230
3Pn4RS	74	81	553	1254	231
3Pn4RS	74	82	558	1265	232
3Pn4RS	74	83	554	1262	232
3Pn4RS	74	84	556	1265	232
3Pn4RS	74	85	557	1266	232
3Pn4RS	74	86	557	1267	233
3Pn4RS	74	87	927	1029	296
3Pn4RS	75	78	908	971	280
3Pn4RS	75	79	902	1014	288
3Pn4RS	75	80	856	996	284
3Pn4RS	75	81	866	1004	285
3Pn4RS	75	82	887	1016	289
3Pn4RS	75	83	881	1011	288
3Pn4RS	75	84	884	1014	289
3Pn4RS	75	85	885	1015	289
3Pn4RS	75	86	887	1016	289

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
3Pn4RS	75	87	824	1303	264
3Pn4RS	76	78	982	1243	246
3Pn4RS	76	79	1040	1270	258
3Pn4RS	76	80	1123	1219	254
3Pn4RS	76	81	1137	1233	256
3Pn4RS	76	82	1197	1259	261
3Pn4RS	76	83	1192	1250	259
3Pn4RS	76	84	1213	1256	260
3Pn4RS	76	85	1218	1258	261
3Pn4RS	76	86	1224	1260	261
3Pn4RS	76	87	503	1342	213
3Pn4RS	77	78	599	1435	188
3Pn4RS	77	79	751	1504	199
3Pn4RS	77	80	883	1534	191
3Pn4RS	77	81	992	1556	194
3Pn4RS	77	82	1062	1624	199
3Pn4RS	77	83	980	1614	197
3Pn4RS	77	84	1001	1634	198
3Pn4RS	77	85	1012	1640	198
3Pn4RS	77	86	1019	1647	199
3Pn4RS	77	87	1210	1155	173
3Pn4RS	78	78	389	1313	141
3Pn4RS	78	79	647	1485	156
3Pn4RS	78	80	917	1617	148
3Pn4RS	78	81	1213	1723	152
3Pn4RS	78	82	1379	1835	159
3Pn4RS	78	83	1384	1759	157
3Pn4RS	78	84	1402	1793	159
3Pn4RS	78	85	1406	1806	159
3Pn4RS	78	86	1423	1817	160
3Pn4RS	78	87	1210	984	90
3Pn4RS	79	79	593	1326	118
3Pn4RS	79	80	795	1660	110
3Pn4RS	79	81	1359	1988	115
3Pn4RS	79	82	1457	2213	123
3Pn4RS	79	83	1424	2156	120
3Pn4RS	79	84	1528	2197	123
3Pn4RS	79	85	1557	2212	123
3Pn4RS	79	86	1576	2234	124
3Pn4RS	79	87	1210	1077	131
3Pn4RS	80	80	342	1533	102
3Pn4RS	80	81	778	2259	111
3Pn4RS	80	82	953	2517	125
3Pn4RS	80	83	1009	2445	120
3Pn4RS	80	84	1087	2563	123
3Pn4RS	80	85	1147	2598	124
3Pn4RS	80	86	1184	2631	126
3Pn4RS	80	87	0	916	149
3Pn4RS	81	81	3389	1863	163
3Pn4RS	81	82	3012	2195	202
3Pn4RS	81	83	2220	2184	195
3Pn4RS	81	84	2133	2337	206
3Pn4RS	81	85	2119	2412	209
3Pn4RS	81	86	2205	2468	213
3Pn4RS	81	87	0	3714	218
3Pn4RS	82	82	1530	3651	289
3Pn4RS	82	83	1480	3024	253
3Pn4RS	82	84	1350	3071	275
3Pn4RS	82	85	1321	3117	283
3Pn4RS	82	86	1344	3230	289
3Pn4RS	82	87	0	3602	314
3Pn4RS	83	83	1527	3046	262
3Pn4RS	83	84	981	2971	288
3Pn4RS	83	85	1116	2984	298
3Pn4RS	83	86	1275	3089	310
3Pn4RS	83	87	0	3103	349
3Pn4RS	84	84	886	2556	408
3Pn4RS	84	85	1426	2666	426
3Pn4RS	84	86	1625	2876	446
3Pn4RS	84	87	0	2228	406
3Pn4RS	85	85	1530	2738	450
3Pn4RS	85	86	1426	3059	482
3Pn4RS	85	87	0	2709	617
3Pn4RS	86	86	1600	2854	682
3Pn4RS	86	87	0	3076	797
3Pn4RS	87	87	1369	935	38
4TVn	71	78	1316	905	37
4TVn	71	79	1275	900	37

Stock	Year: Population	Year: Assessment	Age Group: Recruitment	Age Group: Partially Recruited	Age Group: Fully Recruited
4TVn	71	80	1300	905	37
4TVn	71	81	1276	904	37
4TVn	71	82	1275	897	37
4TVn	71	83	1275	898	37
4TVn	71	84	1274	897	37
4TVn	71	85	1274	897	37
4TVn	71	86	1274	897	37
4TVn	71	87	1155	848	35
4TVn	72	78	1121	805	34
4TVn	72	79	1083	796	33
4TVn	72	80	1103	798	33
4TVn	72	81	1071	797	33
4TVn	72	82	1069	792	33
4TVn	72	83	1069	793	33
4TVn	72	84	1068	792	33
4TVn	72	85	1067	791	33
4TVn	72	86	1067	791	33
4TVn	72	87	803	838	35
4TVn	73	78	809	783	33
4TVn	73	79	764	754	32
4TVn	73	80	763	774	32
4TVn	73	81	755	758	31
4TVn	73	82	718	753	31
4TVn	73	83	717	753	31
4TVn	73	84	719	752	31
4TVn	73	85	717	752	31
4TVn	73	86	716	752	31
4TVn	73	87	1041	579	43
4TVn	74	78	1022	527	43
4TVn	74	79	1006	497	41
4TVn	74	80	988	511	42
4TVn	74	81	980	490	41
4TVn	74	82	899	485	41
4TVn	74	83	910	486	41
4TVn	74	84	899	485	41
4TVn	74	85	896	484	41
4TVn	74	86	895	484	41
4TVn	74	87	1015	561	40
4TVn	75	78	993	534	34
4TVn	75	79	986	483	34
4TVn	75	80	1000	496	34
4TVn	75	81	998	480	33
4TVn	75	82	827	453	32
4TVn	75	83	868	453	32
4TVn	75	84	827	453	32
4TVn	75	85	823	452	32
4TVn	75	86	829	451	32
4TVn	75	87	1461	631	32
4TVn	76	78	1565	594	20
4TVn	76	79	1524	564	19
4TVn	76	80	1640	560	20
4TVn	76	81	1685	540	20
4TVn	76	82	1788	485	17
4TVn	76	83	1664	492	18
4TVn	76	84	1584	485	17
4TVn	76	85	1516	482	17
4TVn	76	86	1535	481	17
4TVn	76	87	2618	643	35
4TVn	77	78	3001	621	19
4TVn	77	79	2910	586	16
4TVn	77	80	3162	603	16
4TVn	77	81	2928	591	16
4TVn	77	82	3188	459	14
4TVn	77	83	3111	486	14
4TVn	77	84	2877	460	14
4TVn	77	85	2779	457	14
4TVn	77	86	2662	460	14
4TVn	77	87	4142	1084	49
4TVn	78	78	4748	1142	28
4TVn	78	79	4588	1105	17
4TVn	78	80	5033	1174	24
4TVn	78	81	4422	1196	18
4TVn	78	82	3623	1228	16
4TVn	78	83	3663	1150	16
4TVn	78	84	3589	1092	16
4TVn	78	85	3277	1044	16
4TVn	78	86	3097	1057	16
4TVn	78	87	5108	2042	32
4TVn	79	79	4381	1967	20

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
4TVn	79	80	4893	2142	26
4TVn	79	81	3818	1985	18
4TVn	79	82	3089	2072	16
4TVn	79	83	3099	2038	16
4TVn	79	84	3152	1864	15
4TVn	79	85	2917	1796	15
4TVn	79	86	2691	1720	15
4TVn	79	87	5160	3235	27
4TVn	80	80	5746	3580	32
4TVn	80	81	1930	3187	26
4TVn	80	82	2562	2682	15
4TVn	80	83	2413	2657	15
4TVn	80	84	2369	2568	15
4TVn	80	85	2365	2327	15
4TVn	80	86	2412	2215	15
4TVn	80	87	5451	4013	46
4TVn	81	81	2245	3190	38
4TVn	81	82	2274	2779	17
4TVn	81	83	2116	2761	20
4TVn	81	84	2041	2682	17
4TVn	81	85	2141	2480	16
4TVn	81	86	2311	2278	16
4TVn	81	87	3062	2602	66
4TVn	82	82	3054	2730	17
4TVn	82	83	2177	2603	27
4TVn	82	84	1976	2524	17
4TVn	82	85	2316	2361	16
4TVn	82	86	2832	2315	17
4TVn	82	87	6092	2498	137
4TVn	83	83	3676	2411	109
4TVn	83	84	3538	2327	87
4TVn	83	85	3799	2276	70
4TVn	83	86	4182	2249	74
4TVn	83	87	3663	2266	227
4TVn	84	84	3722	2136	163
4TVn	84	85	3815	2279	138
4TVn	84	86	3778	2623	110
4TVn	84	87	4505	3063	260
4TVn	85	85	4522	3280	172
4TVn	85	86	2931	3564	130
4TVn	85	87	6342	3228	227
4TVn	86	86	2430	3490	153
4TVn	86	87	2810	3408	188
4TVn	87	87	65	1072	392
4VsW	86	86	281	1194	316
4VsW	86	87	86	1592	531
4VsW	85	85	351	1399	333
4VsW	85	86	534	1399	267
4VsW	85	87	296	2207	371
4VsW	84	84	614	1906	390
4VsW	84	85	442	1690	300
4VsW	84	86	581	1456	243
4VsW	84	87	1586	1953	210
4VsW	83	83	1283	1942	241
4VsW	83	84	1067	1796	258
4VsW	83	85	1188	1354	205
4VsW	83	86	969	1251	171
4VsW	83	87	1311	1927	317
4VsW	82	82	1149	1607	201
4VsW	82	83	1209	1578	196
4VsW	82	84	1122	1490	213
4VsW	82	85	879	1157	184
4VsW	82	86	831	1061	160
4VsW	82	87	1538	1104	294
4VsW	81	81	1680	1152	248
4VsW	81	82	1133	1232	183
4VsW	81	83	1118	1210	178
4VsW	81	84	997	1226	196
4VsW	81	85	718	1092	166
4VsW	81	86	678	998	155
4VsW	81	87	1492	877	213
4VsW	80	80	810	985	188
4VsW	80	81	737	1050	198
4VsW	80	82	996	857	150
4VsW	80	83	906	914	150
4VsW	80	84	916	933	163
4VsW	80	85	814	854	144
4VsW	80	86	747	801	136
4VsW	80	87	1680	987	103

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
4VsW	79	79	292	1181	117
4VsW	79	80	408	1192	91
4VsW	79	81	562	1100	122
4VsW	79	82	478	917	95
4VsW	79	83	558	910	91
4VsW	79	84	565	937	95
4VsW	79	85	499	893	86
4VsW	79	86	466	851	86
4VsW	79	87	411	1020	45
4VsW	78	79	558	1112	59
4VsW	78	80	656	1001	54
4VsW	78	81	664	891	81
4VsW	78	82	527	793	59
4VsW	78	83	524	784	59
4VsW	78	84	527	818	59
4VsW	78	85	517	764	58
4VsW	78	86	487	745	56
4VsW	78	87	684	644	27
4VsW	77	79	826	622	36
4VsW	77	80	730	574	38
4VsW	77	81	611	572	59
4VsW	77	82	552	501	43
4VsW	77	83	540	502	42
4VsW	77	84	559	524	43
4VsW	77	85	525	492	41
4VsW	77	86	515	478	40
4VsW	77	87	563	401	42
4VsW	76	79	523	420	49
4VsW	76	80	514	371	50
4VsW	76	81	479	409	69
4VsW	76	82	423	373	55
4VsW	76	83	430	369	53
4VsW	76	84	451	376	53
4VsW	76	85	426	360	52
4VsW	76	86	408	360	52
4VsW	76	87	403	347	76
4VsW	75	79	409	368	79
4VsW	75	80	361	357	81
4VsW	75	81	379	394	95
4VsW	75	82	359	363	84
4VsW	75	83	351	364	85
4VsW	75	84	360	363	85
4VsW	75	85	341	363	84
4VsW	75	86	344	360	83
4VsW	75	87	370	467	76
4VsW	74	79	383	483	76
4VsW	74	80	367	486	77
4VsW	74	81	392	518	82
4VsW	74	82	372	491	80
4VsW	74	83	374	489	80
4VsW	74	84	371	491	81
4VsW	74	85	374	488	80
4VsW	74	86	371	487	79
4VsW	74	87	454	543	157
4VsW	73	79	462	554	158
4VsW	73	80	464	556	159
4VsW	73	81	476	590	159
4VsW	73	82	465	565	158
4VsW	73	83	467	561	158
4VsW	73	84	470	562	158
4VsW	73	85	466	560	158
4VsW	73	86	465	559	158
4VsW	73	87	479	769	184
4VsW	72	79	487	774	185
4VsW	72	80	488	777	185
4VsW	72	81	505	802	185
4VsW	72	82	493	784	184
4VsW	72	83	488	784	184
4VsW	72	84	487	785	184
4VsW	72	85	487	783	184
4VsW	72	86	487	782	184
4VsW	72	87	630	897	177
4VsW	71	79	636	898	177
4VsW	71	80	638	900	177
4VsW	71	81	659	909	177
4VsW	71	82	640	905	177
4VsW	71	83	640	906	177
4VsW	71	84	640	906	177

Stock	Year Population	Year Assessment	Age Group Recruitment	Age Group Partially Recruited	Age Group Fully Recruited
4VsW	71	85	639	905	177
4VsW	71	86	639	904	177
4VsW	71	87	208	151	46
4VW	70	87	208	151	46
4VW	70	86	208	151	46
4VW	70	85	208	151	46
4VW	70	84	208	151	46
4VW	70	83	209	151	46
4VW	70	82	211	151	46
4VW	70	81	211	151	46
4VW	70	80	152	121	36
4VW	71	87	152	121	36
4VW	71	86	152	121	36
4VW	71	85	152	121	36
4VW	71	84	152	121	36
4VW	71	83	154	121	36
4VW	71	82	156	121	36
4VW	71	81	155	121	36
4VW	71	80	161	65	14
4VW	72	87	161	65	14
4VW	72	86	161	65	14
4VW	72	85	161	65	14
4VW	72	84	161	65	14
4VW	72	83	163	65	14
4VW	72	82	169	66	14
4VW	72	81	170	66	14
4VW	72	80	165	58	10
4VW	73	87	165	58	10
4VW	73	86	166	59	10
4VW	73	85	166	59	10
4VW	73	84	166	59	10
4VW	73	83	170	59	10
4VW	73	82	185	60	10
4VW	73	81	185	60	10
4VW	73	80	145	33	4
4VW	74	87	145	33	4
4VW	74	86	146	33	4
4VW	74	85	147	33	4
4VW	74	84	146	33	4
4VW	74	83	155	34	4
4VW	74	82	176	35	5
4VW	74	81	189	35	5
4VW	74	80	282	41	4
4VW	75	87	282	41	4
4VW	75	86	283	41	4
4VW	75	85	284	41	4
4VW	75	84	283	41	4
4VW	75	83	315	42	4
4VW	75	82	428	46	4
4VW	75	81	471	46	4
4VW	75	80	462	52	5
4VW	76	87	463	52	5
4VW	76	86	463	52	5
4VW	76	85	467	52	5
4VW	76	84	469	52	5
4VW	76	83	604	54	6
4VW	76	82	800	63	6
4VW	76	81	791	63	6
4VW	76	80	656	56	5
4VW	77	87	655	56	5
4VW	77	86	659	56	5
4VW	77	85	667	56	5
4VW	77	84	669	56	5
4VW	77	83	913	61	6
4VW	77	82	1231	72	7
4VW	77	81	1201	79	7
4VW	77	80	789	125	6
4VW	78	87	788	125	6
4VW	78	86	800	126	6
4VW	78	85	833	126	6
4VW	78	84	818	126	6
4VW	78	83	1317	143	7
4VW	78	82	1370	205	9
4VW	78	81	1395	229	9
4VW	78	80	601	201	9
4VW	79	87	602	201	9
4VW	79	86	647	202	9
4VW	79	85	686	204	9
4VW	79	84	623	205	9

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
4VW	79	83	912	279	10
4VW	79	82	875	387	15
4VW	79	81	905	382	15
4VW	79	80	509	304	11
4VW	80	87	528	304	11
4VW	80	86	660	305	11
4VW	80	85	676	310	12
4VW	80	84	846	311	11
4VW	80	83	1051	445	14
4VW	80	82	921	620	21
4VW	80	81	2247	603	25
4VW	80	80	471	318	22
4VW	81	87	604	317	22
4VW	81	86	1028	324	22
4VW	81	85	1351	342	22
4VW	81	84	1449	334	22
4VW	81	83	1327	608	32
4VW	81	82	2064	637	67
4VW	81	81	798	179	22
4VW	82	87	1581	180	22
4VW	82	86	1499	204	22
4VW	82	85	1690	225	23
4VW	82	84	1830	191	24
4VW	82	83	1783	350	65
4VW	82	82	1280	147	12
4VW	83	87	1798	157	12
4VW	83	86	1523	230	13
4VW	83	85	1769	239	15
4VW	83	84	1608	332	16
4VW	83	83	1108	172	7
4VW	84	87	1394	246	7
4VW	84	86	918	478	11
4VW	84	85	918	655	21
4VW	84	84	773	316	4
4VW	85	87	625	746	5
4VW	85	86	947	701	18
4VW	85	85	313	532	3
4VW	86	87	242	816	8
4VW	86	86	522	382	5
4VW	87	87	426	131	240
4X	70	87	358	100	157
4X	71	87	690	105	92
4X	72	87	874	147	63
4X	73	87	889	112	42
4X	74	87	970	256	28
4X	75	87	1117	325	30
4X	76	87	1090	281	21
4X	77	87	1064	362	31
4X	78	87	871	435	46
4X	79	87	922	388	40
4X	80	87	886	406	43
4X	81	87	866	315	60
4X	82	87	1081	321	49
4X	83	87	976	304	52
4X	84	87	813	301	46
4X	85	87	382	446	49
4X	86	87	151	406	55
4X	87	87	426	131	240
4X	70	86	358	100	157
4X	71	86	690	105	92
4X	72	86	874	147	63
4X	73	86	889	112	42
4X	74	86	975	256	28
4X	75	86	1124	325	30
4X	76	86	1095	281	21
4X	77	86	1067	365	31
4X	78	86	873	438	46
4X	79	86	924	391	40
4X	80	86	1050	408	44
4X	81	86	1115	416	62
4X	82	86	1550	323	51
4X	83	86	1284	393	54
4X	84	86	1004	438	48
4X	85	86	365	703	51
4X	86	86	426	131	240
4X	70	85	359	100	157
4X	71	85	690	105	92
4X	72	85	874	147	63
4X	73	85	900	112	42
4X	74	85	984	256	28

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
4X	75	85	1134	325	30
4X	76	85	1099	287	21
4X	77	85	1071	370	31
4X	78	85	875	444	46
4X	79	85	1008	392	43
4X	80	85	1349	410	47
4X	81	85	1360	317	65
4X	82	85	1808	369	54
4X	83	85	1197	558	57
4X	84	85	735	572	50
4X	85	85	426	131	240
4X	70	84	359	100	157
4X	71	84	691	105	92
4X	72	84	900	147	63
4X	73	84	923	112	42
4X	74	84	1005	257	28
4X	75	84	1142	339	30
4X	76	84	1105	299	21
4X	77	84	1078	381	31
4X	78	84	891	448	54
4X	79	84	1076	396	50
4X	80	84	1476	413	53
4X	81	84	1316	326	71
4X	82	84	1282	406	59
4X	83	84	628	627	62
4X	84	84	427	132	240
4X	70	83	359	101	157
4X	71	83	755	105	93
4X	72	83	963	148	63
4X	73	83	980	112	42
4X	74	83	1022	292	28
4X	75	83	1163	374	31
4X	76	83	1124	330	21
4X	77	83	1108	391	51
4X	78	83	875	460	73
4X	79	83	1127	406	67
4X	80	83	1476	430	69
4X	81	83	1083	317	88
4X	82	83	573	434	74
4X	83	83	427	132	240
4X	70	82	360	101	157
4X	71	82	755	105	93
4X	72	82	961	148	63
4X	73	82	978	113	42
4X	74	82	1021	292	28
4X	75	82	1164	373	31
4X	76	82	1131	329	22
4X	77	82	1191	391	51
4X	78	82	944	460	72
4X	79	82	1403	410	67
4X	80	82	1387	476	69
4X	81	82	967	355	88
4X	82	82	428	132	240
4X	70	81	358	101	157
4X	71	81	754	105	93
4X	72	81	960	148	63
4X	73	81	979	112	42
4X	74	81	1021	291	28
4X	75	81	1187	372	31
4X	76	81	1146	330	21
4X	77	81	1225	391	50
4X	78	81	966	473	72
4X	79	81	1828	419	67
4X	80	81	1214	495	69
4X	81	81	424	131	240
4X	70	80	355	101	157
4X	71	80	749	105	92
4X	72	80	957	146	63
4X	73	80	975	110	42
4X	74	80	1032	289	28
4X	75	80	1349	370	30
4X	76	80	1327	328	20
4X	77	80	1432	396	49
4X	78	80	886	562	70
4X	79	80	878	518	65
4X	80	80	1052	128	64
5Z	76	88	1040	126	64
5Z	76	87	1037	126	64
5Z	76	86	1008	121	62

Stock	Year		Age Group		
	Population	Assessment	Recruitment	Partially Recruited	Fully Recruited
5Z	76	85	1071	129	65
5Z	76	84	973	115	61
5Z	76	83	934	111	59
5Z	76	82	144	909	89
5Z	77	88	138	899	88
5Z	77	87	137	896	87
5Z	77	86	125	870	84
5Z	77	85	127	926	89
5Z	77	84	117	838	81
5Z	77	83	93	806	77
5Z	77	82	61	644	95
5Z	78	88	58	632	94
5Z	78	87	55	629	94
5Z	78	86	49	600	89
5Z	78	85	61	644	96
5Z	78	84	39	570	84
5Z	78	83	37	524	80
5Z	78	82	797	139	365
5Z	79	88	785	133	357
5Z	79	87	790	130	355
5Z	79	86	753	117	336
5Z	79	85	822	129	376
5Z	79	84	701	103	312
5Z	79	83	1300	86	288
5Z	79	82	99	693	277
5Z	80	88	94	681	267
5Z	80	87	86	683	265
5Z	80	86	78	649	243
5Z	80	85	107	714	277
5Z	80	84	148	600	220
5Z	80	83	170	1089	187
5Z	80	82	74	335	179
5Z	81	88	67	322	170
5Z	81	87	66	319	166
5Z	81	86	54	288	145
5Z	81	85	261	358	179
5Z	81	84	274	310	120
5Z	81	83	518	730	93
5Z	81	82	25	112	226
5Z	82	88	23	103	212
5Z	82	87	19	97	212
5Z	82	86	78	81	175
5Z	82	85	22	270	240
5Z	82	84	19	308	127
5Z	82	83	34	523	435
5Z	82	82	28	56	160
5Z	83	88	22	50	146
5Z	83	87	18	46	142
5Z	83	86	100	87	108
5Z	83	85	34	179	176
5Z	83	84	80	185	108
5Z	83	83	225	38	99
5Z	84	88	96	33	86
5Z	84	87	105	27	83
5Z	84	86	95	133	54
5Z	84	85	388	41	210
5Z	84	84	9	202	57
5Z	85	88	42	93	46
5Z	85	87	28	98	42
5Z	85	86	7	144	53
5Z	85	85	293	137	40
5Z	86	88	52	78	29
5Z	86	87	433	73	24
5Z	86	86	4	245	98
5Z	87	88	3	70	21
5Z	87	87	153	180	63