An Analysis of Errors in Catch Projections for Canadian Atlantic Fish Stocks

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Two techniques were used to identify and evaluate the components of error inherent in the catch projection method used in the assessment of Canadian Atlantic fish stocks. Firstly, a retrospective analysis was used to evaluate, for the projections made in 1979 and 1981, the impact of the actual error made in input variables such as catch-at-age, mean weight-at-age, recruitment, and stock size. Secondly, the variance of projections was estimated from the variance of input variables. From the retrospective analysis, the principal causes of error in catch projections were identified as the estimation of stock size, as well as the estimation and forecast of fishing mortalities for the projection years. The difference between actual catch and assumed catch for the first year of a 2-yr projection did not appear to be a major source of bias for catch projections. The coefficients of variation of the catch projected at $F_{0.1}$ were estimated as follows: 15–20% for the projections of Atlantic cod (*Gadus morhua*) catches; 25–50% for those of haddock (*Melanogrammus aeglefinus*); 28% for those of pollock (*Pollachius virens*); 16% for those of redfish (*Sebastes* sp.); and 35–42% for those of herring (*Clupea harengus*). The uncertainties associated with abundance estimates for prerecruited age-groups and estimates of stock size emerged as key factors in the projections. Also important was the effect of uncertainties associated with the forecast of reference fishing mortalities (partial recruitment coefficients × $F_{0.1}$) for the projection period, e.g. uncertainties resulting from changes in fish catchability, in fleet behavior, and in fishing patterns.

Deux techniques ont servi à identifier et à évaluer les composantes de l'erreur associée à la méthode de projection des captures commerciales utilisée lors de l'évaluation des stocks de poisson dans l'Atlantique canadien. En premier lieu, une étude rétrospective a permis d'évaluer, pour les projections faites en 1979 et en 1981, l'impact d'erreurs faites sur les variables d'entrée, telles la prise et le poids moyen par groupe d'âge, le recrutement et l'abondance du stock. En second lieu, la variance des prises prévues fut estimée à partir de la variance des variables d'entrée. A partir de l'étude rétrospective, l'estimation de l'abondance du stock, ainsi que l'estimation et la prédiction des taux de mortalité par pêche pour les années de projection, ont été identifiées comme les principales causes d'erreur dans les projections. La différence entre la prise actuelle et la prise utilisée pour la première année de la période de projection (qui est de 2 années) n'est pas apparue comme une cause majeure de biais pour les projections. La coefficient de variation des prises projetées à $F_{0.1}$ s'est établi comme suit : 15–20 % pour les projections de captures de morue franche (*Gadus morhua*); 25–50 % pour celles d'aiglefin (*Melanogrammus aeglefinus*); 28 % pour celles de goberge (*Pollachius virens*); 16 % pour celles de sébaste (*Sebastes* sp.); et 35–42 % pour celles de hareng (*Clupea harengus*). Les incertitudes associées à l'estimation de l'abondance des groupes d'âge pré-recrutés et à l'estimation de l'abondance du stock sont apparues comme des facteurs importants pour ces projections. Egalement important fut l'effet des incertitudes associées à la prévision des mortalités par pêche de référence (coefficients de recrutement partiel × $F_{0.1}$) pour la période couverte par les projections, e.g. les incertitudes résultant de changements de la capturabilité du poisson, du comportement de la flotte de pêche et des patrons de pêche.

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On the Canadian Atlantic coast, the management of many marine fish stocks is based on a quota system. Quotas are generally established from the determination of the total allowable catch (TAC) on a given stock. The estimation of a TAC generally involves the reconstruction of historical population levels from a virtual population analysis (Gulland 1965; Pope 1972) and a projection of future catches. For such projections, the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC) and the Northwest Atlantic Fisheries Organization (NAFO) use a reference fishing mortality level called $F_{0.1}$ (i.e. the rate of fishing mortality at which the slope of the yield-per-recruit curve is 1/10 the value at zero fishing mortality). This fishing mortality level, which is lower than the fishing mortalities which were imposed on many fish stocks of the Northwest Atlantic in the early 1970s, yields in the long term certain economic benefits. As the biomass goes up due to reduced fishing effort, so do the catch rates, and as a result of this, the cost of catching fish goes down. Also, as more fish have a chance to grow to older ages, bigger, more valuable fish are produced on the average. With a lower fishing mortality, the fisheries become less dependent on the strength of single year-classes. As the dependency on incoming year-classes is reduced at low fishing mortality levels

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such as those generated by the $F_{0.1}$ strategy, our ability to predict future commercial catches should, at least in theory, be improved.

In this paper, we focus on the accuracy of catch projections. The basic scientific data for the assessment of fish stocks include catch and weight information, biomass estimates from research surveys, and information on commercial catch rates. Analytical models are used for integrating the information originating from these various sources. In a study of the performance of assessments carried out on eight groundfish stocks of the Northwest Atlantic, Rivard (1981) observed a maximum difference of more than 33% (on average) among estimates of stock size produced in three consecutive assessments. A relative error of 15% was calculated for Atlantic cod in NAFO Divisions 4T-Vn, and for that stock, more than 60% of the variance was due to the uncertainties associated with the estimates of mean weights-at-age. Subsequently, Rivard (1983) analyzed, using Monte Carlo simulations, the impact of systematic, analytical, and sampling errors in catch-at-age, mean weight-at-age, and the stock size index on the results of an assessment. In the case studied — the simulated stock had the biological characteristics of a cod stock of the Northwest Atlantic — the author concluded that the variance of the projected catch was principally due to errors associated with the mean weights-at-age and with the independent index of stock size used to calibrate the sequential population analysis.

In their simulation of three North Sea fish stocks, Pope and Gray (1983) investigated the relationship between the precision of the input data and the precision of the TACs for three different methods, namely (1) the estimation of status quo TACs, i.e. a TAC established under the assumption that the fishing mortality in the projection year is the same as the fishing mortality achieved in the current year, (2) the determination of TACs from projections at a reference fishing mortality level, F_{MAX}, and (3) the determination of TACs from projections at a fixed arbitrary fishing mortality level. Their estimate of the coefficients of variation for TAC estimates was 12–25% for North Sea plaice, 27–33% for North Sea cod, and 39–53% for North Sea sprat.

In his evaluation of the level of accuracy/precision for various groundfish stocks evaluated by the International Council for the Exploration of the Sea (ICES), Brander (1985) concluded "Whatever the merits of TACs and quotas as a means of allocating shares in a stock to the different countries or fishing interests participating, it must be recognized that the present level of variability in assessments carried out in the previous year makes them an imprecise tool for achieving desired levels of fishing mortality." In view of the uncertainties about recruitment, fishing mortality, and catch composition in the intermediate year, Brander recommended that forecasts be carried out for the current year only. This statement was made in the context of fish stocks which experience much higher fishing mortalities than those encountered by most Canadian groundfish and pelagic stocks in the Northwest Atlantic. Brander (1985) does not provide insight into the impact of such uncertainties when much lower fishing mortality rates are prevalent.

The past performance of catch projections is evaluated below in a retrospective analysis of the assessments for a number of groundfish and pelagic stocks of the Northwest Atlantic. Variances of stock size, mean weight-at-age, catch-at-age, and recruitment estimates used in catch projections are also estimated and their impact on catch projections are evaluated. Our purpose is to identify the parameters of importance for catch projections and to develop recommendations for improving their accuracy.

Methods

For many of the groundfish and pelagic stocks of the Northwest Atlantic, the TAC is based on the results of a projection model which uses the most recent information on growth, partial recruitment, and stock size (population abundance) and on estimates of recruitment for the projection period. In a typical assessment, a 2-yr projection is carried out. In general, the following assumptions are made for the calculation of TACs from input parameters (i.e. stock size, $N_{i,t}$; catch-at-age, $C_{i,t}$; mean weight, $W_{i,t}$; recruitment R_{t+1} and R_{t+2}, where i refers to age and t to year): yield is projected for year $t + 2$, assuming that the TAC for year $t + 1$ will be taken; the mean weights, $W_{i,t}$, used in the projection $t + 1$ and $t + 2$, are those estimated for year t; and the recruitments, R_{t+1} and R_{t+2}, are estimated from a long-term average calculated from virtual population analysis (VPA). The projection algorithm used in a typical assessment is described in detail in Rivard (1982).

Retrospective Analysis

Our analysis of the performance of past projections is based on the study of 18 fish stocks of commercial importance in the Northwest Atlantic. Among groundfish species, our study covers six stocks of Atlantic cod (*Gadus morhua*), two stocks of haddock (*Melanogrammus aeglefinus*), and one stock each for redfish (*Sebastes* sp.), yellowtail flounder (*Limanda ferruginea*), American plaice (*Hippoglossoides platessoides*), and pollock (*Pollachius virens*). Among pelagic species, it covers five stocks of herring (*Clupea harengus*) and one stock of Atlantic mackerel (*Scomber scombrus*).

In order to assess the performance of past projections, we compared the 1980 TACs calculated in 1979 (using 1978 data) and the 1982 TACs calculated in 1981 (using 1980 data) with the catch projected at $F_{0.1}$ using the most recent information on stock size, mean weight, and partial recruitment coefficients (for simplicity, the most recent estimates are referred to as the "true" quantities). In order to maintain some objectivity in this comparison, the following procedure was adopted. A 1-yr (or within year) projection was made, using as input (1) the stock size estimate at the beginning of the assessment year (1979 and 1981), as estimated in the most recent assessment (usually, the 1985 assessment), and (2) the mean weights-at-age for the assessment year, as presented in the most recent information. The partial recruitment coefficients were derived from the matrix of fishing mortality calculated in the most recent assessment. In most cases, to prevent small errors at older ages from systematically lowering all partial recruitment coefficients, fishing mortalities were smoothed by using medians of 3, repeated until convergence (i.e. the A3R method of McNeil 1977); the smoothed fishing mortalities were then standardized to unity to give the partial recruitment coefficients. For the projection, the $F_{0.1}$ value corresponding to the true partial recruitment vector and the true mean weights-at-age was calculated.

Natural mortality was fixed arbitrarily at the same level currently adopted by CAFSAC for the various species. The results of this calculation of the $F_{0.1}$ catch were compared with the 2-yr projections made by CAFSAC. As more than one option is often explored in calculating reference catch levels,

TABLE 1. Source references and methods used in calculating variances of input parameters used in catch projections. Abbreviations: NAFO = Northwest Atlantic Fisheries Organization; CV = coefficient of variation; VPA = virtual population analysis.

Stock		Input parameter			
Species	NAFO area	Catch-at-age	Weight-at-age	Recruitment	Initial stock size
Cod	3Pn-4RS	Calculated using CVs estimated for 1982 catch given in Gavaris and Gavaris (1983) and Gascon (1983)	Calculated from Table 12b in Gascon (1984) for 1977–83.	Calculated from VPA of Gascon (1984) for 1974–83.	CV of 9–13% estimated in VPA tuning regression of Gascon (1984). CV of 11% used in our analysis
Cod	4T-Vn	CVs assumed to be equal to average of CVs estimated for cod stocks	Calculated from table 9 of Lever and Waite (1984) for 1971–83	Calculated from VPA of Lever and Waite (1984) for 1971–83	CVs of 15–18% for ages 6–9; 20–25% for others were estimated in survivor analysis of Lever and Waite (1984)
Cod	4VsW	CVs used were those estimated for the 1984 catch by Sinclair and Gavaris (1985)	Calculated from historical mean weights for 1965–83 given in Gagné et al. (1984)	Calculated from VPA of Gagné et al. (1984) for 1958–83	CV of 11% was used as was suggested by the VPA tuning regression of Gagné et al. (1984)
Haddock	4VW	CVs assumed equal to averages estimated for cod stocks	Calculated from table 15 of Mahon et al. (1984) for 1970–83	Calculated from VPA of Mahon et al. (1984) for 1971–83	CV of 35% used given poor tuning of VPA reported by Mahon et al. (1984)
Haddock	4X	CVs assumed to be equal to averages estimated for stocks	Calculated from table 7 of O'Boyle et al (1984) for 1970–83	Calculated from VPA of O'Boyle et al. (1984) for 1962–82 for age 1	CVs of 50–55% as estimated in survivor analysis of O'Boyle et al. (1984) were used
Pollock	4VWX + SA5	CVs assumed to be equal to averages estimated for cod stocks	Calculated from table 9 of McGlade et al. (1984) for 1974–83 for ages 2–11	Calculated from VPA of McGlade et al. (1984) for 1974–82 for age 2	CV of 20% was estimated from VPA tuning regressions of McGlade et al. (1984)
Redfish	4RST	Calculated using CVs estimated for 1982 catch given in Maguire et al. (1983)	Calculated from table 7 of Rubec et al. (1984) for 1980–83 for ages 5–29	Calculated from VPA of Maguire et al. (1983) for 1972–80 for age 5	CV of 18% estimated from VPA tuning regression of Rubec et al. (1984)
Herring	4T	CV assumed to be 10%	Average of relative error of spring and fall spawners, calculated from tables 7 and 8 of Ahrens (1985) for 1971–76 for ages 2–11+	Average of relative error of spring and fall spawners, calculated from VPA of Ahrens (1985) for 1971–83 for age 2	CV of 26% for fall spawners estimated from VPA tuning regressions of Ahrens (1985)
Herring	4R	CV assumed to be 10% for each age group	Average of relative error of spring and fall spawners, calculated from table 12 of Cleary and McQuinn (1984)	Average of relative error of spring and fall spawners (130%), calculated from VPA of Cleary and McQuinn (1984)	CV of 22% estimated from VPA tuning regression for fall spawners

we have (except where otherwise indicated) used the projection which assumed that the catch in the first year of the projection was equal to (or closest to) the TAC adopted for that year. The reader should note that because the TAC initially set from the 2-yr projection is often revised in a subsequent assessment, the projected catches reported herein may deviate from the final TAC advised.

A measure of the relative contribution of each source of error was obtained in the following manner. A TAC, say TAC_x, was computed with the "true" values for each variable, except for variable x which was assigned the value originally used in the assessment. Then a measure of the impact of variable x on the observed difference in TAC was calculated as

$$\frac{TAC_x - TAC_{true}}{TAC_{true}} \times 100.$$

In order to attain an overall impression of the contribution of each input variable to overall error, a global impression scale was developed for the stocks studied. A contribution index (CI)

TABLE 2. Estimates of the 1980 and 1982 catch at $F_{0.1}$ for some commercial stocks of the Northwest Atlantic, as initially projected and as back-calculated from the results of the 1985 assessments.

Species	Stock	1980 Projected	1980 Back-calculated	1980 Relative difference (%)	1982 Projected	1982 Back-calculated	1982 Relative difference (%)
Cod	2J-3KL	212 000	144 350	46.9	270 000	207 410	30.2
	3NO	16 500	22 760	−27.5	20 000	23 857	−16.2
	3Ps	28 000	18 834	48.7	33 000	17 814	85.2
	3Pn-4RS	59 000	58 310	1.2	105 000	75 540	39.0
	4TVn[a]	63 000	20 699	204.4	65 000	32 945	97.3
	4VsW	45 000	31 338	43.6	53 000	23 613	124.5
Haddock	4VW	15 000	8 461	77.3	24 000	7 127	236.7
	4X[b]	28 000	17 436	60.6	32 000	12 655	152.9
Redfish	4RST[c]	18 000	59 094	−69.5	31 000	76 571	−59.5
Yellowtail flounder	3LNO	18 000	8 509	111.5	23 000	5 413	324.9
American plaice	3LNO	43 400	41 419	4.8	45 000	15 581	188.8
Pollock	4VWX-5	41 750	47 403	−11.9	55 000	32 589	68.8
Herring	4WX[d]	83 000	68 514	21.1	92 000	74 344	23.7
	4T, spring[e]	50 102	8 992	457.2	20 000	31 831	−37.2
	4T, fall[e]	39 271	11 332	246.5	—	—	—
	4R, spring[f]	13 160	23 497	−44.0	8 202	11 547	−29.0
	4R, fall[f]	4 911	5 841	−15.9	4 542	4 058	11.9
Mackerel	2-6[g]	197 000	176 710	11.5	118 000	97 700	20.8
Overall		975 094	773 499	26.1	998 744	750 595	33.1

[a]The TAC was revised to 54 000 t for 1980 and to 60 000 t for 1982.
[b]A 1-yr projection was done for 1980.
[c]The projections for 1979 were considered to be indications only because of the unreliability of the data.
[d]The 1980 projection was revised to 65 000 t.
[e]The $F_{0.1}$ projections were not the recommended options for 1980; instead, a strategy to reduce the decline of the stock was recommended.
[f]A 1-yr projection was done for both 1980 and 1982.
[g]The value of 118 000 t for 1982 corresponds to one of many options explored.

was first assigned to each variable from its contribution to overall error:

CI	Contribution to error in % (range)
0	0−15
1	16−30
2	31−60
3	61−90
4	>90

A global contribution index for variable x (GCI_x) was calculated as the summation of the CIs for all stocks.

Calculation of Variances

While the variances of input quantities are not presented in every assessment, it is often possible to estimate them from the assessment data. The study of variances covered three cod stocks, two stocks of haddock, one of pollock, one of redfish, and two of herring. Specific stocks are listed in Table 1, together with data sources and assumptions used in estimating variances. Variances have been estimated in the following manner for catch-at-age, mean weight, recruitment, and stock size.

Variance of catch-at-age

Variances for catch-at-age were calculated using the method of Gavaris and Gavaris (1983), which assumes that the proportion at length is a multinomial variate. It should be noted, however, that recent developments suggest that the above method for calculating the variance of catch-at-age generally gives estimated coefficients of variation which may be somewhat lower than the actual values (S. Gavaris, Department of Fisheries and Oceans, Fisheries Research Branch, St. Andrews Biological Station, St. Andrews, N.B., pers. comm.). The variance of catch-at-age is thus likely to have been underestimated by the method used.

Variance of mean weight-at-age

The variance of mean weight-at-age appears as a result of both stochastic errors and sampling errors. Stochastic error is present because we do not have a reliable equation to describe changes in growth over time. The variance of the mean weights was estimated from the relative error observed in historical data. As the current practice is to use the weights in year t to project catches in year $t + 2$, the average relative error for a given age i has been defined as

$$\bar{e}_i^2 = (1/k)\ \mathrm{SUM}\ [(W_{i,t} - W_{i,t+2})^2/(W_{i,t+2})^2]$$

where the summation is over t (time) and where k is the number of elements in the summation (Rivard 1981). Then, the average relative errors were used to estimate the variance of mean weight for each age-group in the projection, i.e.

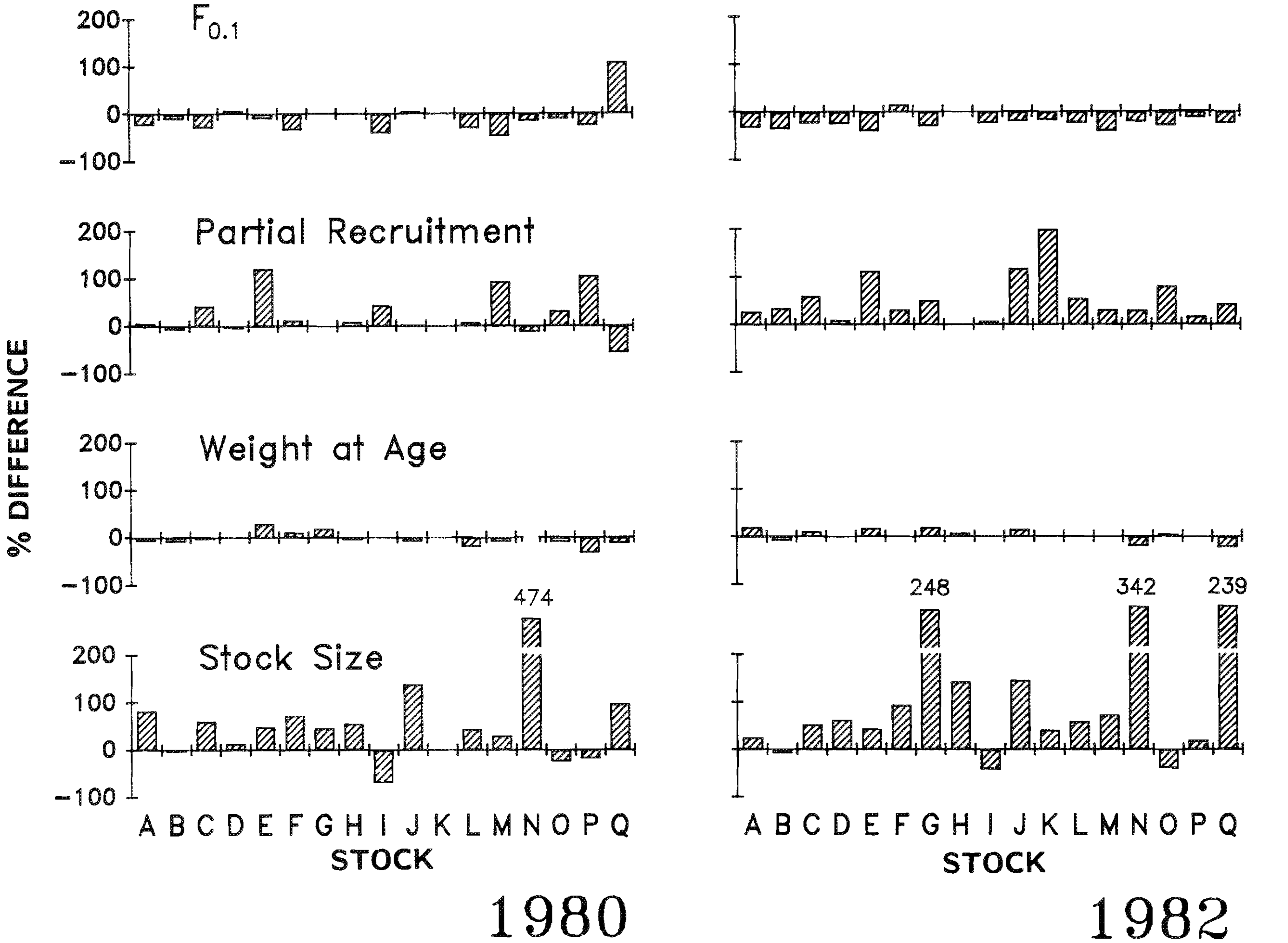

FIG. 1. Anatomy of relative differences between the projections provided in previous assessments and the $F_{0.1}$ catch calculated from the results of the 1985 assessments. The stocks are cod (A–F), haddock (G–H), redfish (I), flatfish (J–K), pollock (L), herring (M–P), and mackerel (Q).

$$\mathrm{VAR}\,[W_i] = (W_i \times \bar{e}_i)^2$$

for each age i.

Variance of recruitment

The relative error on recruitment prediction was estimated from the ratio of the standard deviation of recruitment to mean recruitment. Estimates of recruitment were obtained from the results of virtual population analyses (Table 1). The number of observations included in the calculation of the relative error in recruitment varied between 9 and 26. As the years covered by these observations are representative only of the recent history of these stocks, the estimates of relative error in recruitment prediction must be seen only as a measure of recruitment variability in recent times.

Variance of stock size-at-age

Estimates of stock size for the first year of the projection period are the result of a complex procedure (see Rivard 1983). As regression analyses are used for the *calibration* of virtual population analysis, we have assumed, for estimating variances of initial stock size, that the confidence intervals of the stock size predicted by the regressions provide an appreciation of the precision of the stock size estimates. This assumes that the independent variable of the calibration regression is known without error, or has a measurement error which is much smaller than the measurement error in the dependent variable. Such an assumption is implicit in most assessments. In addition, a measure of the precision (variance) of stock size estimates has been obtained from the SURVIVOR method (Doubleday 1981) for certain stocks. Finally, when more than one method is used for estimating the initial stock size, the range of values obtained from these different methods has been used to calculate the relative error.

Variance of catch projections

We have used the approach of Rivard (1981) for calculating the variance of catch projections from the variance of input parameters. The variance of the yield projected for year $t + 2$, say Y_{t+2}, has been calculated as:

$$\begin{aligned}\mathrm{VAR}[Y_{t+2}] = {} & \mathrm{SUM}\ \mathrm{VAR}[N_{i,t}](\partial Y_{t+2}/\partial N_{i,t})^2 \\ & + \mathrm{SUM}\ \mathrm{VAR}[C_{i,t}](\partial Y_{t+2}/\partial C_{i,t})^2 \\ & + \mathrm{VAR}[R_{t+1}](\partial Y_{t+2}/\partial R_{t+1})^2 \\ & + \mathrm{VAR}[R_{t+2}](\partial Y_{t+2}/\partial R_{t+2})^2 \\ & + \mathrm{SUM}\ \mathrm{VAR}[W_{i,t}](\partial Y_{t+2}/\partial W_{i,t})^2\end{aligned}$$

where all summations are over i. This equation assumes that there is no significant covariance between input parameters and that the partial recruitment coefficients are known exactly for the projection years $t + 1$ and $t + 2$.

In this study, the *prerecruited* age-groups were defined as those age-groups for which the partial recruitment coefficient was less than 0.3. This value was chosen because stock size is difficult to estimate for age-groups showing a partial recruitment coefficient smaller than 0.3. Such a definition is necessary to allow comparisons of variances between species or species groups.

Results

Retrospective Analysis

The results of the retrospective analysis (Table 2) indicate considerable differences between projected catch levels and the actual $F_{0.1}$ catches for the two years studied. The deviations from the $F_{0.1}$ catch are often large and there is a general tendency to be optimistic, i.e. to overestimate the $F_{0.1}$ catch. The overall error level for all stocks tested is +26.1% for 1980 and +33.1% for 1982. Most frequently, advised TACs resulted in a much higher fishing mortality rate than $F_{0.1}$. It is somewhat surprising to see that the relative difference between the projected and the true TACs is small for a stock like 3NO cod for which the quality of assessment data is currently questioned. The fact that the retrospective analysis did not identify major differences between the projected and the *true* TACs for some stocks does not necessarily imply that a high accuracy is achieved for these stocks. The differences may be small in certain cases because the basic data are limited and thus less likely to lead to divergent interpretations.

The major sources of error which contributed to the differences between the advised TAC and the true catch at $F_{0.1}$ were examined. The errors can be attributed to differences in partial recruitment coefficients, mean weight-at-age, stock size estimates for year 2 of the projections, and the $F_{0.1}$ value utilized (Fig. 1). The origin or causes of error in the projections which we examined were, in order of importance, as follows. (1) The estimation of stock size for the last year of the projection period. This can be influenced by several sources of error: (i) the estimation of population abundance from the virtual population analysis; (ii) difference between the TAC in the first year of the 2-yr projection and the actual catch in that year; (iii) difference between the catch composition in the first year of projection and the actual catch composition in that year; and (iv) differences in estimations of recruiting cohorts during the projection period. (2) The changes or variations in partial recruitment coefficients. These may be due to (i) estimation errors or (ii) external changes in fleet behavior, gear types, seasonality of the fishery, etc. (3) The estimation of $F_{0.1}$ for the projection years.

Errors in estimation of mean weights-at-age appeared to contribute little to overall error in the catch projections. The errors in the coefficients of partial recruitment and in $F_{0.1}$ were often compensatory or of opposite sign. This results from the fact that $F_{0.1}$ is itself estimated from the estimates of partial recruitment and that $F_{0.1}$ appears as a multiplier to the partial recruitment in the projection algorithm. Thus, in a particular assessment, it is the combined effect of $F_{0.1}$ and partial recruitment that is important.

The overall contribution of each variable to error in catch projections, as measured by the GCI, is illustrated for each species in Fig. 2 and for the two common groupings, groundfish and pelagic fish, in Fig. 3. Note that errors attributable to the estimation of $F_{0.1}$ and partial recruitment have been combined to illustrate the overall error in reference fishing mortality (i.e. $F_{0.1}$ × partial recruitment).

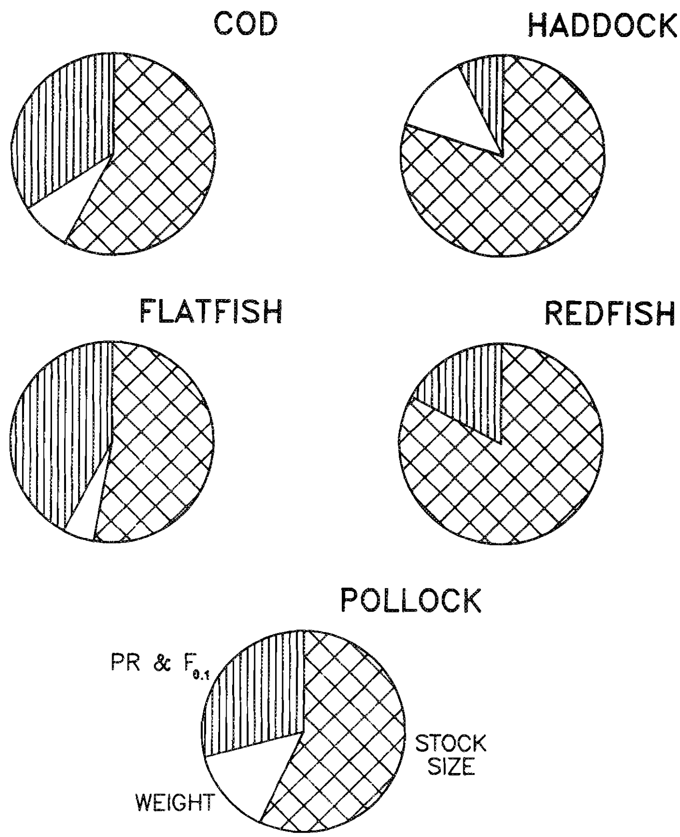

FIG. 2. Relative contribution of each input variable to error in catch projections for cod, haddock, flatfish, redfish, and pollock, based on the global contribution indices (GCIs).

Sources of error tend to vary considerably between stocks (Fig. 1) and between species (Fig. 2). Inaccuracies in the catch projections of cod are largely attributable to errors in estimation of stock size and reference fishing mortalities (partial recruitment × $F_{0.1}$) for the projection period. Similarly, pollock and flatfish projection inaccuracies can be related to changes in stock size and reference fishing mortalities. Errors in haddock and redfish projections result largely from changes in stock size. Errors in estimating age-specific mean weights appear to contribute relatively little to the total error.

Variance of Input Parameters

The overall precision of projected catches is affected by both *sampling errors* and *stochastic errors*. Because the quantities serving as input to catch projections cannot be enumerated exhaustively, we must rely on a sampling scheme to estimate them. Consequently, sampling errors are a function of the intensity of catch sampling programs and of the coverage of research surveys. In general, when sampling is carried out according to a predetermined design (such as a random stratified design), sampling errors can be evaluated from sampling theory. The other type of error, stochastic error, is the result of "natural" variability and is independent of sampling programs.

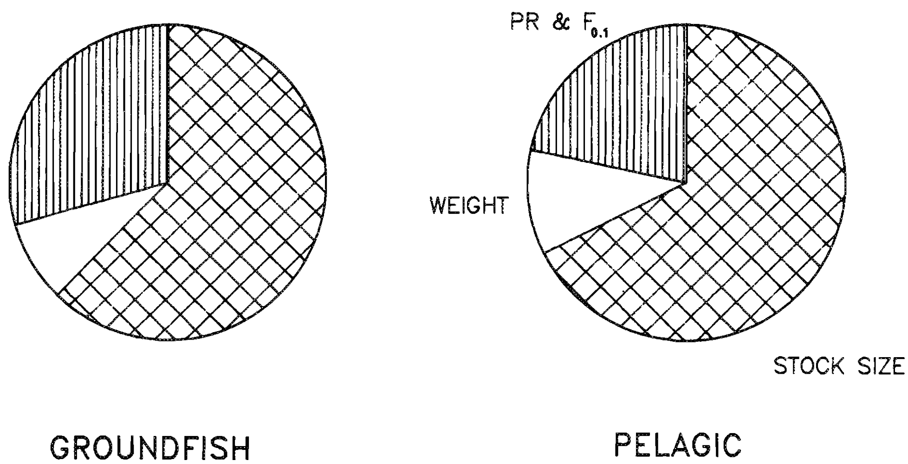

FIG. 3. Relative contribution of each input variable to error in catch projections for groundfish and pelagic fish of the Northwest Atlantic, based on the global contribution indices (GCIs).

TABLE 3. Coefficient of variation (%) for catch-at-age estimates for 10 Atlantic Canada fish stocks. Data sources: Gavaris and Gavaris (1983); Gavaris and Bishop (1983); Bishop and Gavaris (1983); Gascon (1983); Brodie and Pitt (1983a, 1983b, 1983c); Maguire et al. (1983); Atkinson (1983a, 1983b); Sinclair and Gavaris (1985).

	Cod					American plaice			Redfish		
Age	4RS-3Pn (1981)	4RS-3Pn (1982)	2GH (1982)	3Ps (1982)	4VsW (1984)	3LNO (1982)	2J-3K (1982)	3Ps (1982)	4RST (1982)	3P (1982)	2 + 3K (1982)
2	52	—	—	61	81	—	—	—	—	—	—
3	20	20	7	27	13	—	—	—	—	—	—
4	4	10	8	4	4	—	—	—	—	—	—
5	5	4	10	6	3	33	—	—	—	—	—
6	3	6	11	8	4	22	71	66	—	—	—
7	4	5	4	5	4	12	32	23	17	46	21
8	6	6	6	4	6	7	19	18	15	21	12
9	8	9	3	9	9	4	13	12	11	12	10
10	12	11	14	12	12	4	10	7	14	16	10
11	15	13	33	23	10	4	9	5	10	14	10
12	15	19	47	19	12	4	11	9	12	12	10
13	16	26	27	29	16	5	11	11	13	11	10
14	22	28	38	33	19	6	14	11	14	10	11
15	31	40	43	39	49	7	19	18	15	11	10
16	—	—	—	—	19	9	29	19	18	12	10
17	—	—	—	—	—	15	55	22	22	15	10
18	—	—	—	—	—	18	63	21	30	18	11
19	—	—	—	—	—	72	—	—	32	18	12
20	—	—	—	—	—	—	—	—	28	25	14
21	—	—	—	—	—	—	—	—	27	20	13
22	—	—	—	—	—	—	—	—	22	19	18
23	—	—	—	—	—	—	—	—	18	21	17
24	—	—	—	—	—	—	—	—	12	16	16
25	—	—	—	—	—	—	—	—	18	15	19
26	—	—	—	—	—	—	—	—	14	13	18
27	—	—	—	—	—	—	—	—	19	16	19
28	—	—	—	—	—	—	—	—	20	16	21
29	—	—	—	—	—	—	—	—	27	18	21
30	—	—	—	—	—	—	—	—	—	10	9

The coefficients of variation for catch-at-age estimates have been produced for a number of stocks in Atlantic Canada (Table 3). Typically, the coefficients of variation for the dominant ages in the catch are in the order of 3−6% for cod stocks, 4−10% for American plaice stocks, and 10−15% for redfish stocks. The coefficients of variation are larger for very young ages and for older age-groups.

The error made in mean weight-at-age is related to the fact that the weights calculated for year t are used to forecast the mean weights for years $t + 1$ and $t + 2$. This error has two components: a sampling component, due to the fact that the weights in year t are estimated from sampling data, and a stochastic component, due to *external* factors affecting mean weight in a given year (fishery being prosecuted in different

TABLE 4. Relative error (%) in weight-at-age estimates for 10 stocks of the Northwest Atlantic. Data sources: see Table 1, and Simon and Campana (1984) for 4Vn herring.

	Cod			Haddock		Pollock	Redfish	Herring				
Age	4RS-3Pn	4T-Vn	4VsW	4VW	4X	4VWX	4RST	4T, spring	4T, fall	4Vn	4R, spring	4R, fall
2	—	—	35	47	20	33	—	13	19	—	—	—
3	—	33	20	19	13	33	—	16	31	13	18	21
4	25	14	14	12	11	30	—	2	10	16	11	18
5	16	16	13	11	13	12	15	3	11	7	10	13
6	8	19	14	12	13	11	15	5	24	8	11	10
7	4	28	15	12	14	10	15	6	9	8	13	14
8	7	36	18	17	14	13	12	4	12	7	12	12
9	13	37	16	8	13	10	12	7	11	7	11	11
10	19	45	16	13	11	11	11	5	10	7	11	16
11	25	42	18	18	12	11	8	8	9	—	11	12
12	49	29	19	—	19	—	5	—	—	—	—	—
13	22	31	20	—	16	—	3	—	—	—	—	—
14	34	42	18	—	—	—	3	—	—	—	—	—
15	35	114	19	—	—	—	5	—	—	—	—	—
16	—	—	19	—	—	—	1	—	—	—	—	—
17	—	—	—	—	—	—	7	—	—	—	—	—
18	—	—	—	—	—	—	4	—	—	—	—	—
19	—	—	—	—	—	—	18	—	—	—	—	—
20	—	—	—	—	—	—	21	—	—	—	—	—
21	—	—	—	—	—	—	20	—	—	—	—	—
22	—	—	—	—	—	—	24	—	—	—	—	—
23	—	—	—	—	—	—	21	—	—	—	—	—
24	—	—	—	—	—	—	18	—	—	—	—	—
25	—	—	—	—	—	—	15	—	—	—	—	—
26	—	—	—	—	—	—	16	—	—	—	—	—
27	—	—	—	—	—	—	8	—	—	—	—	—
28	—	—	—	—	—	—	10	—	—	—	—	—
29	—	—	—	—	—	—	5	—	—	—	—	—
30	—	—	—	—	—	—	—	—	—	—	—	—

time of year, differences in growth, effects of density dependence, etc.). The error made in mean weight can be important (Table 4). For dominant age-groups in the catch, it varies from 4 to 20% for the cod stocks examined, from 10 to 15% for the haddock stocks, from 1 to 7% for redfish, and from 2 to 14% for herring.

The ratio *standard deviation/mean recruitment* was in the order of 0.3–0.7 for cod stocks, 1.0 for haddock, 0.5 for redfish, 0.7 for pollock, and 0.6–1.3 for herring. In other words, herring and haddock stocks showed the largest recruitment variability. These results are not surprising, since the fisheries on these stocks often depend on a single or a few strong year-classes.

Uncertainties in stock size estimates originate from the application of VPA, which combines information from research surveys, commercial catch sampling, and logbooks. The coefficients of variation for stock size estimates are presented for some stocks of the Northwest Atlantic in Table 1.

Variance of Catch Projections

The variance of catch projections, expressed in terms of coefficient of variation, for the major commercial fish stocks of the Northwest Atlantic is illustrated in Fig. 4. The coefficients of variation of the catch projected at $F_{0.1}$ were as follows: 15–20% for cod stocks; 25–50% for haddock; 28% for pollock; 16% for redfish; and 35–42% for herring. These coefficients provide an indication of the precision of the projected catches (assuming no biases are present) when the assessment procedure described above is applied. These coefficients are likely to be underestimated, since the variance of catch-at-age is likely to have been underestimated (see below).

The contribution of each of the input parameters to the total variance of catch projections is also illustrated in Fig. 4. For two of the cod stocks studied, the variance in initial stock size was the main contributor to total variance of projected catches. For the third cod stock, the variance in mean weight-at-age and the variance in prerecruit estimates were the main components of total variance. The precision of catch projections for the two haddock stocks showed a strong dependence on the variance in prerecruit estimates. This is consistent with the observation that these haddock stocks were fished at fishing mortality rates approaching F_{MAX} during a period of rapid recovery at the end of the 1970s. For one of the haddock stocks, the variance in stock size also made a large contribution to the variance of the projections. For pollock and redfish, the major component of variance was that of stock size estimates; recruitment estimates and stock size estimates for prerecruited age-groups had little impact on the precision of catch projections. Similarly, the variance of mean weight-at-age contributed little to the overall variance of catch projections for these two species. The variance of catch projections for herring had two major components: the variance of stock size estimates and the variance of recruitment and prerecruit estimates. From these observations, it appears that for any given stock only a few input parameters

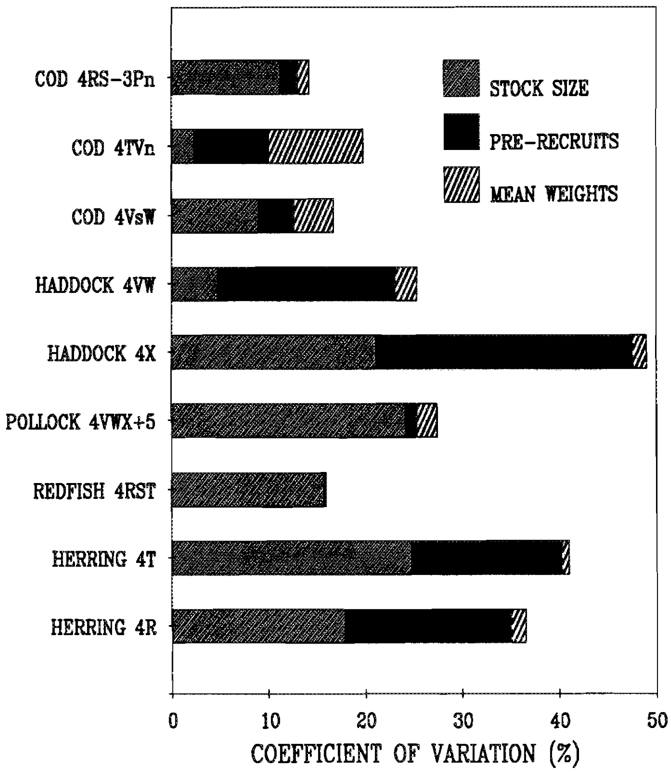

FIG. 4. Components of variance for catch projections of various Atlantic Canada fish stocks. The variance components are expressed in terms of their contribution to the coefficient of variation. The coefficient of variation for catch-at-age was less than 1% for all stocks and is not illustrated. See Table 1 for data sources.

contribute significantly to the variance of catch projections and that these vary among stocks. Consequently, there is no unique approach/solution for improving the overall precision of catch projections.

In general, catch-at-age contributed little to total variance. It must be noted, however, that uncertainties in catch-at-age appear explicitly in the projection model only for the first year of the projection period and that part of the variance calculated for stock size estimates is due to uncertainties in catch-at-age, as catch-at-age enters the calculation of stock size through VPA. In effect, the *variance of stock size* is the result of sampling errors from research surveys, logbook information, and commercial catch sampling programs.

Sources of Bias in Catch Projections

The variance of projected catches was calculated under the assumption that the driving variables were known exactly for the projection period. The driving variables are (1) the catch level for the first year of projection, (2) the age composition for the first year of the projection period (implied from the partial recruitment coefficients), and (3) the fishing mortalities (partial recruitment coefficients $\times$ $F_{0.1}$) for the second year of the projection period. These variables are rarely known exactly. In general, the errors they contain are not random but systematic. Consequently, these errors translate as biases into catch projections.

Catch in the first year of projection

In general, a 2-yr projection assumes that the catch level for the first year is equal to the TAC advised for that year. Often, the real catch level is quite different from the TAC advised, as indicated in Table 5. There are two reasons for these differences: firstly, the advised TAC in the first year may have been updated in a subsequent projection, and secondly, the actual catch from the stock may have been higher or lower than the advised TAC. We investigated the effect of such factors upon the projections carried out in 1979 and 1981 for the 1980 and 1982 fishing seasons, respectively. For those years, the catch projections were made under the assumption that the catch level for the first year of the projection period was equal to the nominal catch reported. Results (Table 6) indicate that the error made in the catch level for the first year of the projections is not a major source of error for a 2-yr projection. The only stock in which a major error was introduced because of this factor was mackerel in SA 2–6. For this stock, the projection assumed catch levels of 259 000 and 151 000 t for 1979 and 1981, respectively, while the actual catch in those years was approximately 30 000 t.

Catch composition for the first year of the projection period

In a 2-yr projection, the catch composition for the first year of the projection period is implied from the values of the partial recruitment coefficients (see Rivard 1982). The assumed and the actual catch compositions for year 1 of the projection are known to be different in many cases. Figure 5 illustrates two particular cases.

For stocks that showed a large difference between the assumed and the actual partial recruitment pattern, we evaluated the impact of changes in age composition on the TAC calculations (Table 7). Errors in catch composition for the first year of the projection period did not have, in general, a significant impact on catch projections. The impact on reference catch estimates is small because, under current fishing strategies, the catch represents a small fraction of the total stock biomass, and consequently, any variation in the age composition of the catch changes only slightly the age composition of the stock itself.

Fishing mortalities for the second year of the projection period

From the retrospective analysis (Fig. 1), partial recruitment coefficients appear to be a major source of bias in 2-yr projections. Problems in the estimation of partial recruitment can be further described as follows. The current practice, in making catch projections, is to use the partial recruitment estimated for the latest year or an average based on recent data. As partial recruitment is based on historical data, a lag is introduced between the occurrence of an event in the fishery (such as the arrival of a strong year-class) and its representation in the estimates of partial recruitment. Partial recruitment estimates are not forecasts; they are back-calculations from recent data.

These problems are illustrated in Fig. 6, which uses data for cod in NAFO Divisions 4VsW. For the projection of the 1979 catch level, an almost asymptotic partial recruitment pattern was used but a marked dome appears in the back-calculated partial recruitment. For the projection of the 1980 catch level, the same pattern emerges with the exception that the dome formed by the back-calculated coefficients moves to the right by one age-group. For the projection of the 1981 catch level, a dome-shaped partial recruitment pattern was used, but as this pattern was estimated from historical data in which the peak occurred at younger ages, it does not match the pattern described by the back-calculated values. For the projection of the 1982 catch level, the partial recruitment pattern used was dome shaped; however, the back-calculated values form a flat-top curve, suggesting a change in the strategy followed by the fleet.

TABLE 5. Nominal catch (t) vs. the catch level (t) assumed for the first year of projection in assessments done in 1979 and 1981 for several stocks.

Species	Stock	1979 Used in projection	1979 Nominal catch	1981 Used in projection	1981 Nominal catch
Cod	2J-3KL	170 000	167 000	200 000	171 000
	3NO	25 000	28 000	15 000	24 000
	3Ps	25 000	33 000	30 000	39 000
	3Pn-4RS	75 000	83 000	75 000	98 000
	4TVn	36 000	56 000	53 000	65 000
	4VsW	30 000	40 000	50 000	54 000
Haddock	4VW	3 000	3 000	23 000	20 000
	4X[a]	25 000	25 000	28 000	31 000
Redfish	4RST	16 000	15 000	20 000	21 000
Yellowtail flounder	3LNO	18 000	18 000	21 000	15 000
American plaice	3LNO	47 000	49 000	48 000	50 000
Pollock	4VWX-5	40 000	47 000	54 000	59 000
Herring	4WX	99 000	96 200	112 000	87 700
	4T, spring	52 000	18 000	16 000	22 000
	4T, fall	52 000	30 000	—	—
Mackerel	2-6	259 000	31 000	168 000	32 000
All groundfish		510 000	564 000	617 000	647 000
All pelagic species		462 000	175 200	296 000	141 700
Overall		972 000	739 200	913 000	788 700

[a]For 4X haddock, a 1-yr projection was done in 1979; the 1979 catch was known at the time of the assessment.

TABLE 6. Estimates of the 1980 and 1982 catch (t) at $F_{0.1}$ as initially projected and as back-calculated under the assumption that the catch in the first year of projection was known.

Species	Stock	1980 Initial projection with TAC in 1979	1980 Back-calculated with nominal catch in 1979	1980 Relative error (%)	1982 Initial projection with TAC in 1981	1982 Back-calculated with nominal catch in 1981	1982 Relative error (%)
Cod	2J-3KL	210 000	211 000	−0.5	267 000	272 000	−1.8
	3NO	16 500	16 000	3.1	20 000	18 000	11.1
	3Ps	28 000	27 000	3.7	33 000	31 000	6.5
	3Pn-4RS	59 000	57 000	3.5	105 000	101 000	4.0
	4TVn	63 000	59 000	6.8	65 000	62 000	4.8
	4VsW	45 000	43 000	4.7	53 000	52 000	1.9
Haddock	4VW	15 000	15 000	0.0	24 000	24 700	−2.8
	4X	—	—	—	32 000	31 000	3.2
Redfish	4RST	—	—	—	31 000	30 000	3.3
Yellowtail flounder	3LNO	20 000	20 000	0.0	23 000	25 000	−8.0
American plaice	3LNO	—	—	—	48 000	48 000	0.0
Pollock	4VWX-5	42 000	40 000	5.0	55 000	53 000	3.8
Herring	4WX	82 000	83 000	−1.2	92 000	98 000	−6.1
	4T, spring	50 000	58 000	−13.8	20 000	22 000	−9.1
	4T, fall	39 000	44 000	−11.4	—	—	—
Mackerel	2-6	197 000	277 000	−28.9	118 000	158 000	−25.3
All groundfish		498 500	488 000	2.2	756 000	747 700	1.1
All pelagic species		368 000	462 000	−20.3	230 000	278 000	−17.3
Overall		866 500	950 000	−8.8	986 000	1 025 700	−3.9

Discussion and Conclusions

Three objectives were pursued in this review of catch projections: the documentation of historical performance; the identification of sources of error; and the development of recommendations for future actions.

Error levels in 2-yr projections are significant: the $F_{0.1}$ reference catch levels were overestimated systematically in the two assessment years studied. There is also a certain tendency for reference catch levels to change abruptly. Sudden changes oc-

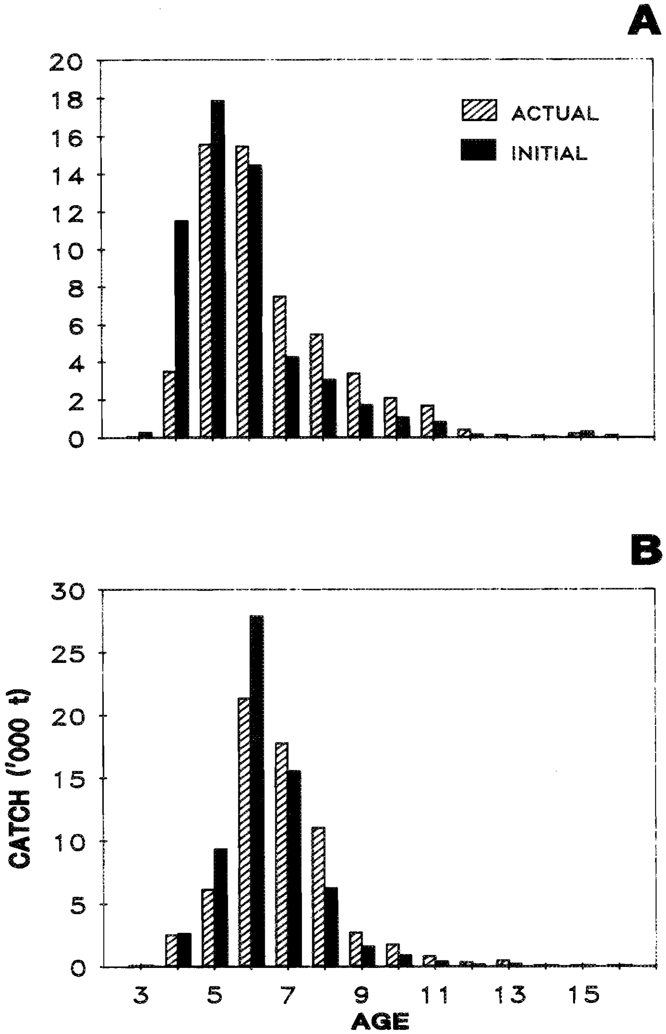

FIG. 5. Comparison of the assumed catch composition for year 1 of the projection period with the actual catch composition for that year. Data are for 4TVn cod in (A) 1979 and (B) 1981.

cur because the variability inherent in assessment data reduces our ability to detect small changes in stock levels. However, accumulated scientific evidence or new information eventually leads to a new interpretation of data, to a revision of stock status, and to a revision of potential catch levels. Sudden changes are more likely to occur when the error content of input variables increases.

The review of historical performance concentrated on "annual errors" and no attempt has been made to measure the accuracy achieved in the long term with 2-yr projections. It is clear, however, that fishing mortality rates have been maintained, in general, below or around F_{MAX} for these Northwest Atlantic stocks, an improvement over the fishing mortalities exerted in the early 1970s. While a relative error of 50 or 60% appears to be a large error for any given year, it may be relatively small if viewed in relation to the catch history of a given stock. For instance, the error of 30–47% for 2J-3KL cod in 1980 and 1982 corresponds to a difference of about 70 000 t between the $F_{0.1}$ catch and the initial projection. This difference is small with respect to catches that could result from the application of excessive fishing mortalities. It is also small with respect to the catches of 500 000 to 700 000 t which took place in the 1960s when the international fleet was competing for fish. In other words, a projected catch level of 270 000 t, despite its inherent error content, still exerts a significant control on fishing effort for this stock.

From our historical review and from our analysis of precision and bias, the following factors emerged as key issues for the projections: dependent on abundance estimates for prerecruited age groups; dependence on stock size estimates for partially recruited and fully recruited age-groups; and dependence on partial recruitment and $F_{0.1}$ estimates for the projection period.

The following did not appear to be major factors for most stocks: the difference between actual catch and assumed catch for the first year of a two year projection; differences in the age composition of the actual and assumed catch for the first year of the projection period; and mean weight-at-age estimates for the projection period.

The impact of each of these sources of error is illustrated in Fig. 7 for all groundfish combined and for herring. While these proportions vary among species (e.g. for haddock, there is higher dependence on the estimation of prerecruited age-groups and recruitment), this illustration conveys a general impression of the relative contribution of each source of error to catch projections.

The retrospective analysis of catch projections is based on the assumption that the VPA has converged to the true stock size. While this assumption is likely to be valid for the cod and haddock stocks studied, it does not necessarily hold for other species (Rivard 1979). For these species, the results of the comparisons made must be interpreted as an indication of the consistency of the projections made in subsequent years.

We have evaluated separately the component of variance due to the abundance estimates of fully recruited age-groups and the component of variance due to the estimation of prerecruited age-groups. It is important to separate these components, as their variance originates from completely different sources. The estimation of abundance for fully recruited age-groups is made through the calibration of VPA. The estimation of prerecruits is made using a wide variety of techniques and is not necessarily linked to VPA. The high dependence of projections for haddock stocks on the abundance estimates of prerecruited age-groups suggests that improving the stock size estimate from the VPA is unlikely to improve the precision of catch projections for this species. It must be noted, however, that the high dependence on prerecruits may be only a transient state for certain stocks. For example, a move towards lower fishing mortalities could reduce the dependence on estimates of prerecruits.

The results of assessments were evaluated here solely on their ability to produce an estimate of the reference catch level. It must be recognized, however, that the value of scientific advice for fisheries management is not limited to the provision of a TAC. In general, scientific assessments also provide information on the performance of the fishery and past history of a stock. In addition, advice generated from the assessment with respect to possible management measures such as gear restrictions, direct effort limitations, or time restrictions (e.g. seasons) is less dependent on the type of quantitative information required for the establishment of a TAC regulation.

Recommendations

The objective of recommendations to improve catch projections should be to reduce errors which contribute significantly

TABLE 7. Relative errors in catch projections due to errors in the catch composition for the first year of the projection period.

		1980			1982		
		Reference catch (t)			Reference catch (t)		
Species	Stock	Back-calculated	With initial catch composition	Relative error (%)	Back-calculated	With initial catch composition	Relative error (%)
Cod	2J-3KL	144 350	145 110	−0.5	207 410	208 288	−0.4
	3NO	22 760	23 026	−1.2	23 857	23 943	−0.4
	3Ps	18 830	19 240	−2.1	17 810	18 160	−1.9
	3Pn-4RS	75 540	75 468	0.1	58 310	58 527	−0.4
	4TVn	20 700	21 608	−4.2	32 940	33 818	−2.6
	4VsW	31 340	31 730	−1.2	23 610	24 125	−2.1
Pollock	4VWX-5	47 400	47 270	0.3	32 590	32 644	−0.2

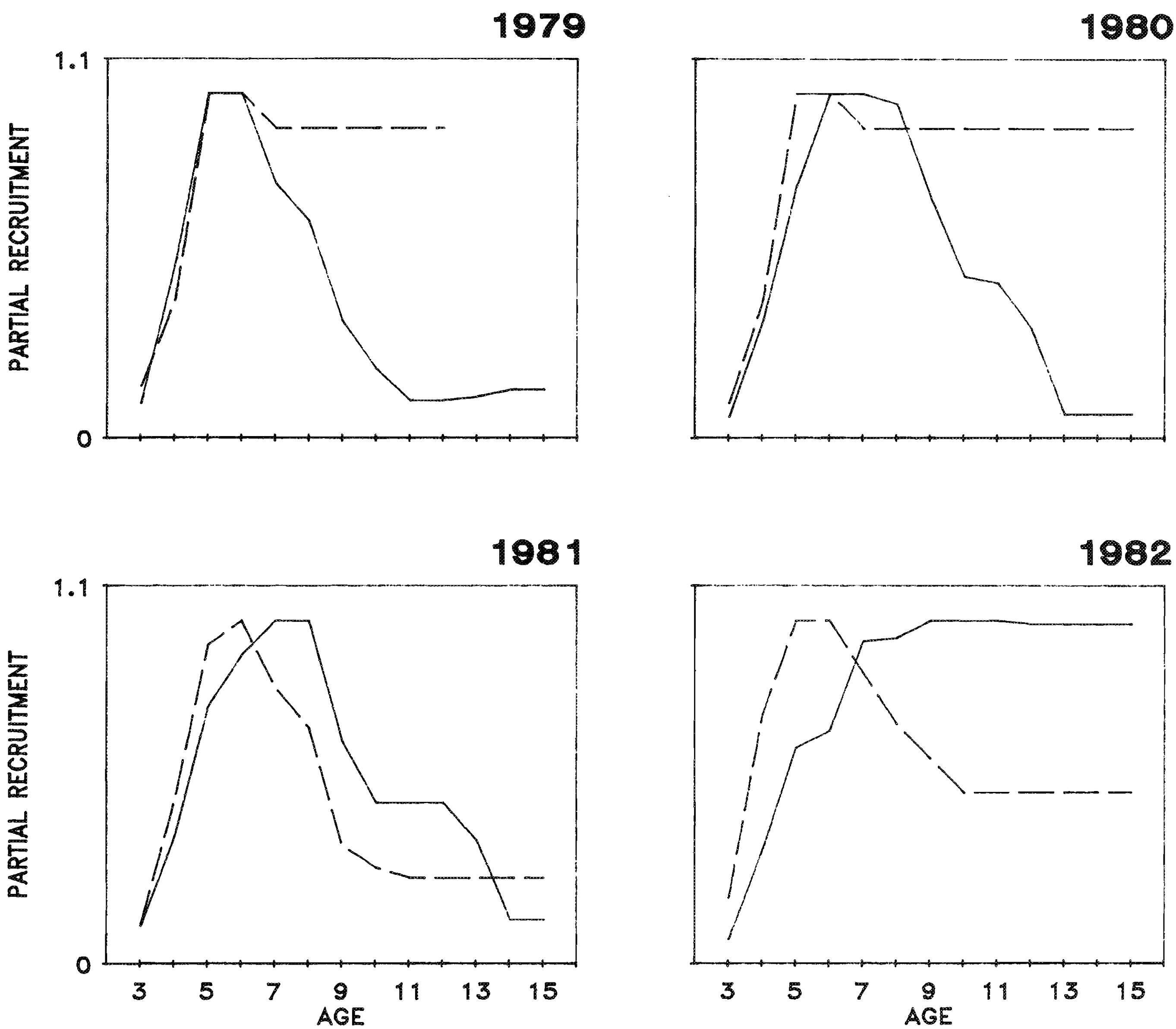

FIG. 6. Comparison of the partial recruitment values initially used (broken line) for catch projections with the values calculated (solid line) from the most recent information. Data are for 4VsW cod.

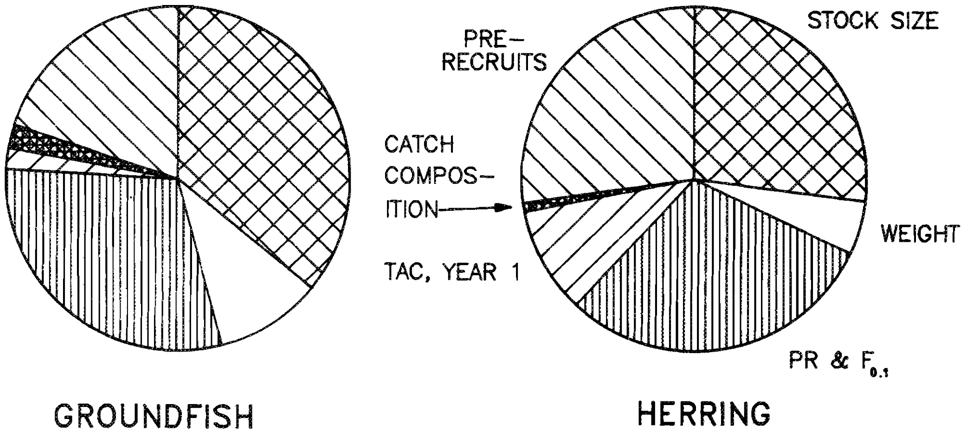

FIG. 7. This composite graph combines the results of the retrospective analysis and those of the study of uncertainties (bias and variance) to illustrate the relative contribution of input parameters to errors in catch projections for groundfish and herring. Note that the category "prerecruits" refers to the abundance of those age-groups for which the partial recruitment coefficients were smaller than 0.3, while the category "stock size" refers to the abundance of the remaining age-groups, i.e. those for which the coefficients were equal to, or higher than, 0.3.

TABLE 8. Recommendations for improving catch projections.

Factor	Recommendation	Program activity or function affected
Estimates of stock size	Improve estimation of stock size obtained from virtual population analysis. Here, there is a wide variety of actions possible:	
	(A) Improve independent measure of stock size (catch rate indices, research survey estimates); related questions are how to combine independent measures when more than one is available and how to resolve conflicting trends in time series	Research surveys; logbook analysis; observer program
	(B) Improve catch composition estimates	Sampling
	(C) Improve methodology: calibration process; need way to cope with variability in survey data; more objective approach	Analysis
Estimates of prerecruited age-groups and of recruitment	Improve estimation of prerecruited age-groups and forecasts of recruitment:	
	(A) Obtain independent measure of abundance	Research surveys
	(B) Better forecasts of recruitment from independent index	Analysis
	(C) Reduce dependence of projections on recruitment by reducing forecast horizon	Scheduling of advice
	(D) Develop stock recruitment relationships	Analysis
	(E) Measure partial recruitment independently of virtual population analysis	Analysis; surveys
Forecasts of fishing mortalities for the projection period	Improve forecasts of partial recruitment coefficients for year 2 of the projection:	
	(A) Develop a model taking into consideration fleet behavior	Analysis
	(B) Do 1-yr projections	Scheduling of advice
	(C) Do multiyear projections which accommodate known levels of error	Analysis
	(D) Other methods/approaches	Analysis

to the accuracy/precision of projections. These sources of error originate from the accuracy/variance of estimates of input variables, such as stock size, partial recruitment, and size of recruiting cohorts, the stochastic nature of some input variables, such as natural mortality and mean weight-at-age, and external changes affecting input variables, such as changes in fishing patterns, in the gear type used, or in the time of year in which the fishery is prosecuted. Because there is no single source of error, there is no simple solution for improving catch projections. Specific ways for improving precision appear in Table 8.

The first source of error, i.e. the estimation of stock size, partial recruitment coefficients, and size of recruiting cohorts, depends on sampling and scientific surveys. Currently, most sampling programs on commercial catches and research surveys are based on norms which were established when Canadian fisheries jurisdiction was extended in 1977. While the norms of NAFO are widely accepted as minimum requirements (Beckett, 1983), sampling based on these norms is not necessarily related to appropriate statistical measures of precision and bias (see Doubleday and Rivard 1981, 1983). Sampling levels should be dictated by target precision levels.

Changes in fleet behavior and fishing pattern result in major changes in partial recruitment coefficients in some years. For instance, a common strategy for a fleet is to adjust their fishing pattern so as to target large cohorts as soon as they become available to the gear and to follow these cohorts in subsequent years; when these cohorts do not provide satisfactory returns, sudden shifts to other age-groups may occur. Similarly, a fleet might avoid an area of good recruitment for a short time and temporarily reduce partial recruitment on specific ages for that year. Changes in partial recruitment for a few age-groups may make a large difference to TAC calculations. While these external factors are generally not under the control of fishery managers, it might be possible, in some instances, to define a model governing the changes in partial recruitment. We presently have sufficient information on certain fisheries to permit a study of fleet behavior in response to changes in recruitment. Such study could serve to define better estimates for partial recruitment during the projection period.

The current approach for catch projections is to project 2 yr ahead. One-year projections (in fact, within-year projections) would reduce the components of error due to recruitment, the abundance of prerecruited age-groups, and to partial recruitment coefficients. One-year projections would be possible, however, only if the assessment could take place before the fishing season. Availability of data on the fishery performance and the lead time required for the establishment of fishing plans may limit the applicability of 1-yr projections for certain stocks. Alternatively, advice can be provided for more than 1 yr. For example, advice could be given for a period of 3–5 yr. From the current knowledge of uncertainties in input data (e.g. catch estimates, mean weights-at-age) and of the natural variability (stochasticity) of some input parameters, it is possible to advise a TAC which would provide a high probability of achieving $F_{0.1}$ despite measurement errors. Reference catch levels (or TACs) would then account for uncertainties and stochasticity in fisheries and biological data. The less that is known about a stock, the more conservative TACs would have to be. Because of this, such an approach may be difficult to implement in an industry which tends to focus on immediate opportunities.

Finally, it must be recognized that a significant proportion of the error in catch projections cannot be reduced by improvements in the model structure, in sampling programs, or in research surveys. For instance, there will always remain a certain amount of error due to the stochasticity of some input variables (e.g. natural mortality, fish availability) or due to unforeseen changes in control variables (e.g. fishing effort and selectivity).

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