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Some Examples of Probabilistic Catch Projections Using ADAPT Output.

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Abstract

An approach for communicating the uncertainty of short term catch projections to decision makers is described. Case studies for Georges Bank haddock and southern Gulf of St. Lawrence cod were used to illustrate the method. It was assumed that the management strategy was to fish at a fixed fishing mortality of $F_{0.1}$ and TAC's were used as the main management tactic. The uncertainties about two state variables, F in the projection year and the surviving biomass, were calculated in relation to total catch in the projection year. The uncertainty was expressed as the probability that a given TAC would result in an F in excess of the target and of the surviving adult biomass being less than a given level. These calculations use standard output from analytical stock assessments.

Résumé

L'article décrit une façon de faire connaître aux décideurs le niveau d'incertitude lié aux prévisions des captures à court terme. La méthode utilisée est décrite à l'aide d'études de cas portant sur l'aiglefin du banc Georges et la morue du sud du golfe du Saint-Laurent. Il est supposé que la stratégie de gestion reposait sur une mortalité par pêche fixe de niveau $F_{0,1}$ et que l'imposition de TAC était le principal outil de gestion. L'incertitude liée à deux variables d'état, F au cours de l'année de la prévision et la biomasse des survivants, était calculée en fonction des captures totales de l'année de prévision. L'incertitude était exprimée sous forme de la probabilité qu'un TAC donné se traduise par un F supérieur au F cible et une biomasse de survivants adultes inférieure à une certaine valeur. Les résultats habituels des évaluations analytiques des stocks sont utilisés pour les calculs.

Introduction

In this paper, we examine ways of conveying uncertainties in stock assessment projections to decision makers. Information on uncertainty of current year-class abundance estimates is readily available from the outputs of current assessment techniques. We use two stocks as case studies, haddock on Georges Bank (5Zjm) and cod in the southern Gulf of St. Lawrence (4TVn (N-A)) and compare the results from two different computation methods for translating the uncertainty in year-class estimates to uncertainty in projected results. Knowledge about this uncertainty may be as important to decision makers as traditional point estimates of stock status. Managers and the fishing industry are now asking "what are the chances" that specific management goals will be met as a result of specific management actions.

Three issues to consider in communicating these uncertainties are, a) what quantities should be examined, b) how to report the results and c) how to compute the results.

Quantities to examine

Two factors are important here, choosing the relevant management action (treatment), and choosing the relevant population state variables (response). The choice depends on the strategies and tactics of the management system.

The management strategy for groundfish fisheries in Atlantic Canada is to maintain fishing mortality (F) constant at a target level defined by yield per recruit considerations, i.e. the $F_{0.1}$ target. The fisheries are managed with a variety of measures, which we will call tactics, including seasons, mesh size, and limited entry. However, the principle management tactic is to control F indirectly by controlling yield with total allowable catches (TAC). As a result, we have computed the probability distributions of important population state parameters in relation to a TAC. If the tactic was to control F by limiting the number of fishing days, then it would be more appropriate to provide information on population state in relation to numbers of fishing days.

We have focused on 2 population state variables which summarize most, but not all, of the concerns of managers and industry: fishing mortality and adult (some specified age group) biomass. Fishing mortality is relevant since this is the *de facto* basis of the management strategy. A question may be; "What are the chances that a TAC of "x" will result in a fishing mortality consistent with the target?" Biomass is also of concern given that many groundfish fisheries are either closed or considered to be in danger because of low biomass. A possible question may be; "Is the biomass likely to increase as a result of a given TAC?"

Ways to report uncertainty

We express uncertainty in the population estimates in a risk analysis. By risk we mean the probability of something undesirable happening as a result of a given TAC. For F, we calculated the probability that a given TAC will produce an F in excess of $F_{0.1}$. For adult biomass we calculated two probabilities. The first is simply the probability that the adult biomass will decrease for a given TAC. The second is the probability that the adult biomass will be below a specific threshold for a given TAC. Biomass thresholds have been defined for some stocks. The Fisheries Resource Conservation Council (FRCC) has recently published a discussion paper on criteria for reopening fisheries. Spawning biomass was one criterion. The southern Gulf of St. Lawrence cod stock (4TVn (N-A)) has been under moratorium since 1993. Following the suggested FRCC guidelines, the reopening threshold for 4TVn cod is 115,000 t. The 5Zjm haddock fishery is not under moratorium, and no biomass thresholds have been defined. Therefore, we did not calculate any biomass threshold probabilities for this stock.

The risk that F will exceed $F_{0.1}$, that adult biomass will decrease, or that the adult biomass will be below a threshold will all increase as the TAC increases.

How to compute

This study involves short term (1 - 3 year) projections of a specific management tactic and we recognize that these are inappropriate for evaluating strategies that satisfy broader objectives. We assume that some evaluation of strategies has been conducted previously and that the accepted strategy is to maintain fishing mortality constant at F0.1.

The results from the recent 5Zjm haddock (Gavaris and Van Eeckhaute 1995) and 4TVn cod (Sinclair et al. 1995) assessments were used as test cases. Projections began with the population at the beginning of 1995. The 1995 catch was assumed to have been determined in advance, 3000 t for 5Zjm haddock and 1300 t for 4TVn cod. The probability distributions of 1996 F and beginning of year 1997 adult biomass (ages 3+ for 5Zjm haddock and 5+ for 4TVn cod) were calculated for a range of 1996 TACs. Weights at age, partial recruitment, and natural mortality were assumed known and constant. Additional work on the sensitivity of the probability distributions to variation in these parameters is warranted.

We used two methods for translating the uncertainty in current year-class abundance estimates, obtained using the analytical approximation results from ADAPT (Gavaris 1988), to precision of yield projections. Both methods provide results which are conditional on the models used in the estimation of stock status, additionally, they both make distribution assumptions about errors. Additional work could be carried out to compare these results with those from a model conditioned bootstrap experiment where distribution assumptions are considerably more relaxed.

Method 1: ADAPT

We use the ADAPT results and apply the formulas for computing variance and bias for functions of the estimated parameters (Gavaris 1993). To do this, we used accepted yield projection relationships to define the functions which link year-class estimates to forecast fishing mortality and biomass for specified yield options (Rivard 1982). Using the obtained variance for F and biomass, a normal distribution was assumed to derive the probability that estimated mean forecast F would exceed the reference and that the estimated mean forecast biomass was below the threshold or the present biomass. This approach accounts for covariance between parameters

Bias Adjustment in ADAPT

It has been recognized that fisheries model relationships are intrinsically non-linear with respect to parameters of interest such as projected yield, biomass and fishing mortality. This non-linearity translates into biased point estimates of the mean. Two ways to account for this bias in the projected parameters are :

A) adjust the terminal population abundance estimates for their bias and then project (this is the common approach used in most assessments)
B) project with the unadjusted population abundance estimates and then compute the bias on the projected parameters using linear approximations

Results of these two adjustments were compared for 4TVn (N-A) cod.

Method 2: Monte Carlo

The ADAPT estimates of terminal year abundance and standard error were used to conduct Monte Carlo experiments for projected F and biomass in the second method. The terminal year abundance estimates were assumed to be independent and lognormally distributed with a mean corresponding to the bias adjusted mean from ADAPT and a standard error corresponding to the analytical approximation results from ADAPT. Trials of 100 and 300 replicates were generated for each TAC option and the frequency distributions of F and biomass were used to quantify the probability that the reference F was exceeded, that the threshold biomass was not reached, and that the adult biomass decreased.

The calculations were done in a Microsoft Excel (v. 5.0) spreadsheet using the Crystal Ball add-in (Decisioneering Inc., Denver Colorado) to control the Monte Carlo simulations. The catch projections were calculated using the method of Rivard (1982) and included the period from the beginning of 1995 to the beginning of 1997. The 1995 TAC was fixed for all replicates and the effects of a range of 1996 TACs on F and biomass was investigated. For each 1996 TAC, either 100 or 300 replicates were performed. We examined the variability in results among simulations with different numbers of replicates. The first step was to generate the 1995 beginning of year population numbers at age from the estimated means and standard deviations (see flow chart in Figure 1). The F required to catch first the 1995 and then the 1996 TAC's was calculated using the Goal-Seek function in Excel. The surviving adult biomass was calculated using these Fs. The resulting 1996 F, and beginning of year adult biomass in 1996 and 1997 were saved. When the required number of replicates were finished, the probabilities (risks) that the biomass and F criteria failed were calculated.

Results

The following tables compares results of the two bias adjustment approaches for cod in 4TVn (N-A).

Conditioned on a TAC of 15000 for 1996

	Method A		Method B	
	Mean	Mean	Bias	Adjusted Mean
F_{96}	0.194	0.190	0.008	0.182
5+ $Biom_{97}$	93829	96559	2738	93821

Conditioned on a Fishing Mortality of 0.19 for 1996

	Method A	Method B		
	Mean	Mean	Bias	Adjusted Mean
TAC_{96}	14683	14992	307	14685
5+ $Biom_{97}$	94132	96567	2738	93829

It is apparent that either approach gives comparable results for biomass or yield but that the direction of the calculated bias for F from method B is counter-intuitive, the sign of the bias is the same on both F and biomass. One would expect the signs to be opposite. This behavior may be related to the skewness in the distributions and warrants further investigation. For this paper, the generated probability distributions were centered around the mean F obtained with Method A.

Number of Replicates in Monte Carlo Simulations

The results of three simulations of the 5Zjm haddock data, using 100 replicates each, shows relatively minor variation in the probability distributions (Figure 2). There tended to be higher variation between simulations at the higher TACs for both the biomass and F criteria. The range of estimated percentages increased with the TAC. When 300 replicates were used the range declined. In general, it would be desirable to do higher numbers of replicates, subject to time constraints and improved precision. We elected to use 300 replicates in all further calculations.

ADAPT vs. Monte Carlo

In this section we compare uncertainty estimates from the two methods used. They differ mainly in how parameter covariance is treated. In the ADAPT approach, covariance is included while in the Monte Carlo simulations it is not. If the covariance among population at age estimates is large, the estimated standard errors for the individual means will be underestimated.

Results from the ADAPT and Monte Carlo projections for the two stocks are compared in Figures 3 and 4. The estimates of the probability that F exceeds 0.25 were very similar for both stocks, suggesting that covariance had little effect on this criterion. There were larger differences in the probability distributions of the biomass criteria between methods. In the case of 5Zjm haddock, the Monte Carlo curve was steeper than the ADAPT curve, and the difference between the two was fairly large at the low catches. This indicates that the Monte Carlo approach, underestimated the variance in biomass relative to the ADAPT approach.

In both stocks, the probability distributions were steeper for the F goals than the biomass goals (Figures 3 and 4). This is because the 1997 biomass is largely dependent on the initial biomass, and fishing takes only a small fraction of it. The surviving biomass is relatively insensitive to these low levels of fishing over a one year period. On the other hand, catch and F are closely related and the probability distributions of F are steeper.

Discussion

We present one approach for communicating information on the uncertainty of projection results to decision makers. Obviously there are many ways to do this and many population state variables of interest. What is suggested here is particular to a management strategy based on fixed fishing mortality of $F_{0.1}$ where the main management tactic is a TAC. We chose two state variables, F and surviving adult biomass. The choice of F is obvious since the strategy is to achieve a target F. Biomass was chosen because there is often a desire to increase or improve the stock biomass. In the case of 4TVn cod, the fishery was closed because of critically low biomass and threshold biomass criteria have been proposed to reopen the fishery.

It is relatively straightforward to use current assessment tools to calculate the required probability distributions. Similar results were obtained from two different approaches: 1) an integrated assessment formulation of ADAPT where the projected population state parameters and their variances/covariances were estimated analytically, and 2) Monte Carlo simulations based on ADAPT estimates of population abundance at the beginning of the projection period. The choice between methods may depend on the degree of covariance among population estimates. In the two cases used here, there was very little difference whether or not covariance was included.

We favor a presentation of probability vs. catch because catch (i.e. TAC) is the principle tactic used to implement the constant F strategy. The TAC is allocated among user groups and catches are monitored against their quotas throughout the year. Probability vs. F is not very useful since F is controlled indirectly through catch.

Risk is often thought of as the probability of something undesirable happening. Thus, we calculated the probabilities of either the fishing mortality exceeding the target, the biomass declining, or the biomass being less than the reopening threshold. Risk curves were made from the cumulative probability distributions of these criteria

The steepness of the risk curve indicates the precision of the estimate. Consider two hypothetical probability distributions of F exceeding a target in relation to catch (Figure 5). Both are centered on the same median value and the point estimates of F necessary to catch 1000t are the same. However, the precision of one (solid line) is higher than the other (dashed line). This is reflected by the interval of catches covered by the center 90% of the distribution, 850t - 1150t in the more precise case and 500t - 1500t in the less precise case.

The choice of any particular catch level will reflect the risk tolerance of the decision maker. Again using Figure 5 as an example, a risk neutral decision maker would choose the median as the best strategy, there would be a 50% chance that the fishing mortality would be greater than the target. A risk averse decision maker would favor catches lower than the median, wishing to have a lower probability of the target being exceeded. A risk prone decision maker would favor the opposite approach. A risk neutral individual would take the same decision regardless of the precision of the projected F and they would not be interested in probabilistic catch projections.

The probability distributions from these short term catch projections indicate a higher degree of certainty associated with statements about an F criterion in relation to catch than about a biomass criterion in relation to catch. The probability distributions of F are steeper and provide a relatively discrete range of catch to choose from. The probability distributions of biomass are shallower and cover a much larger range of catches. This is because F is much more sensitive to variations in catch than is stock biomass, especially in low F, short term projections. One could anticipate much longer discussions of management actions among risk prone and risk averse decision makers if biomass was the main concern than if F was the main concern.

References

Gavaris, S. 1988. An adaptive framework for the estimation of population size. CAFSAC Res. Doc. 88/29: 12 p.

Gavaris, S. 1993. Analytical estimates of reliability for the projected yield from commercial fisheries. p. 185-191 *In* S.J. Smith, J.J. Hunt, D. Rivard [ed] Risk evaluation and biological reference points for fisheries management. Can. Spec. Pub. Fish. Aquat. Sci. 120.

Gavaris, S., and L. Van Eeckhaute. 1995. Assessment of haddock on eastern Georges Bank. DFO Atl. Fish. Res. Doc. 95/6: 25 p.

Rivard, D. 1982. APL programs for stock assessment (revised). Can. Tech. Rept. Fish. Aqua. Sci. 1091: 146 p.

Sinclair, A. F., G. Chouinard, D. Swain, G. Nielsen, M. Hanson, L. Currie, T. Hurlbut, and R. Hébert. 1995. Assessment of the southern Gulf of St. Lawrence cod stock, March 1995. DFO Atl. Fish. Res. Doc. 95/39: 84 p.

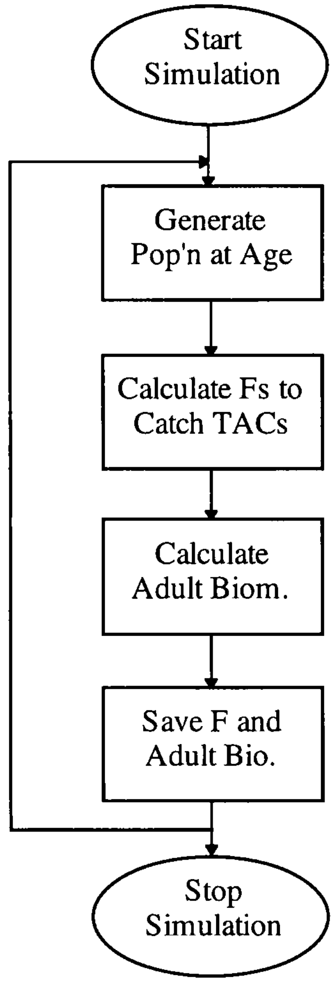

Figure 1: Flow chart of Monte Carlo simulations of catch projections.

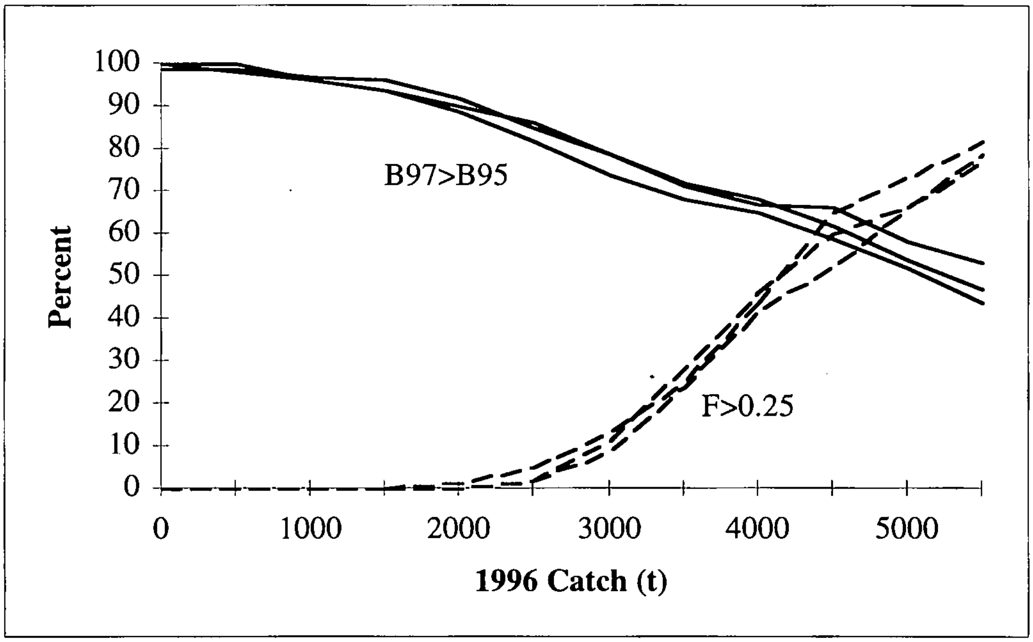

Figure 2: Comparison of probabilities that the 1997 biomass exceeds the 1995 biomass, and that the 1996 F > 0.25 for three Monte Carlo simulations of 100 replicates using different random number seeds, 5Zjm Haddock.

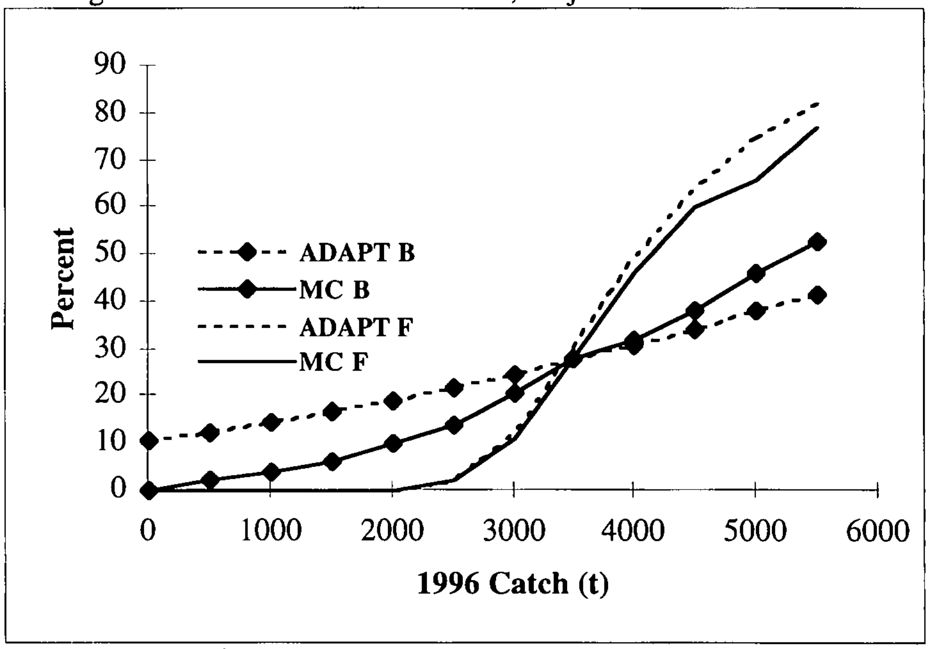

Figure 3: Comparison of ADAPT and Monte Carlo (MC) estimates of two probability distributions for 5Z haddock catch projections: the probability that the 1997 biomass is less than the 1995 biomass, and the probability that the 1996 F exceeds 0.25.

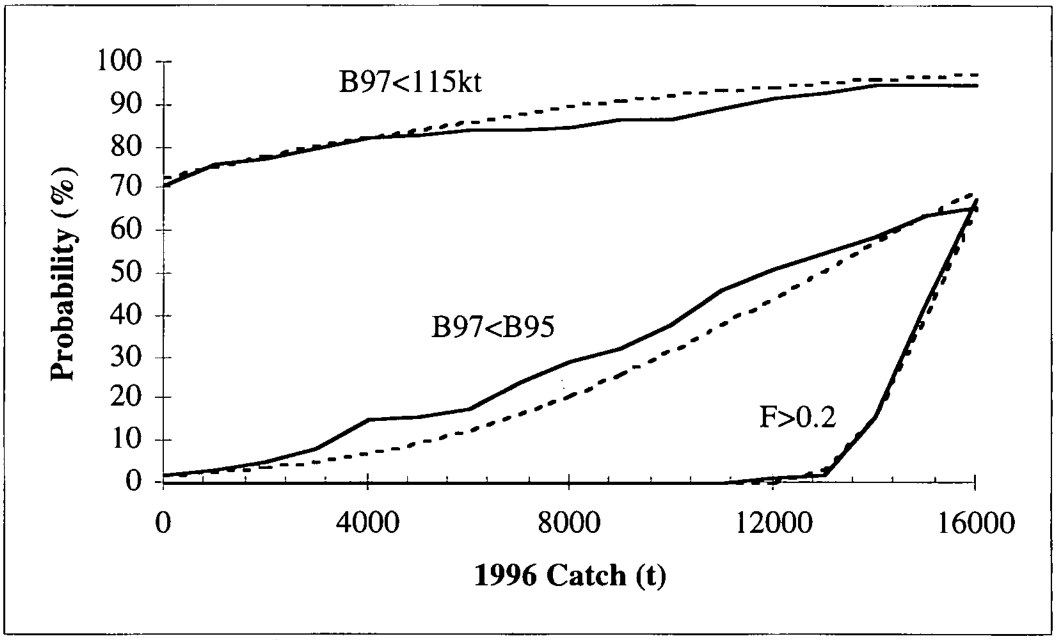

Figure 4: Comparison of ADAPT and Monte Carlo estimates of three probability distributions for 4TVn cod catch projections: the probability that the 1997 biomass is less than the 1995 biomass, the probability that the 1997 biomass is less than 115,000 t, and the probability that the 1996 F exceeds 0.2. Two estimation methods were used, ADAPT (dashed) and Monte Carlo (solid).

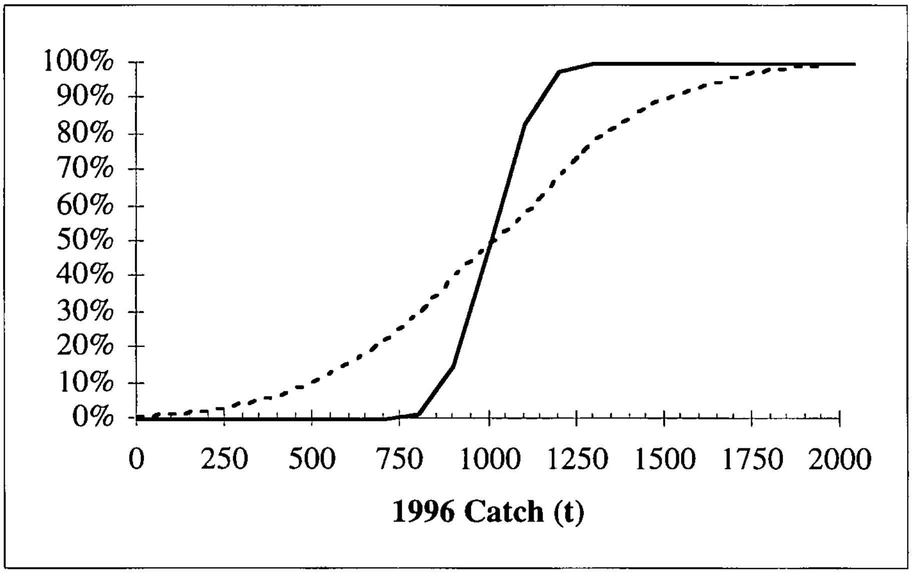

Figure 5: Two hypothetical probability distributions of F exceeding a target for a range of 1996 catches. The steeper line (solid) indicates a more precise estimate of F than the shallow line (dashed).