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Describing the Risk Associated with a Given Quota when the Stock Assessment is Based on Sequential Population Analysis

by

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Abstract: In Restrepo et al. (1990) we presented a method for quantifying the degree of uncertainty associated with the outputs from stock assessment models. We repeatedly simulated the measured and/or perceived uncertainty in the inputs and, for each set of simulated inputs, we computed the results obtained from the assessment model. This method was demonstrated using results from the ADAPT approach to sequential population analysis as applied to the assessment of cod in NAFO Divisions 2J+3KL. In this paper we illustrate approaches for expressing the uncertainty in terms of the risks and opportunity costs associated with various management options.

Résumé: Dans Restrepo et al. (1990), nous avons présenté une méthode permettant de quantifier le degré d'incertitude des extrants produits par les modèles d'évaluation des stocks. Nous avons à plusieurs reprises simulé l'incertitude mesurée ou perçue dans les intrants et, pour chaque série d'intrants simulée, avons compilé les résultats produits par le modèle d'évaluation. La démonstration de cette méthode était fondée sur les résultats obtenus avec la méthode d'analyse de population séquentielle ADAPT, telle qu'elle est appliquée à l'évaluation des stocks de morue des divisions 2J+3KL de l'OPANO. Dans le présent texte, nous illustrons les manières d'exprimer l'incertitude d'après les risques et les coûts d'opportunité associés aux diverses options de gestion.

The effect of uncertainty in the inputs to a sequential population analysis can be translated into uncertainty about the outputs by Monte Carlo methods; the uncertainties can then be fed into other analyses to obtain pictures of the uncertainty associated with the projected catch level that will achieve a given objective. Restrepo et al. (1990) demonstrated this approach by quantifying uncertainties in the assessment of northern cod. For example, they described the perceived probability of maintaining the status quo fishing mortality as a function of the choice of the total allowable catch (TAC) (Figure 1). This paper extends their work by illustrating how the simulation results can be cast as a risk analysis. It should be noted that in the original paper the descriptions of the uncertainties in the inputs to our simulations were ad hoc. Consequently, the results in this paper are intended for illustrative purposes only.

Fishery managers are likely to be dissatisfied with the histogram in Figure 1 because it does not provide certain key information: 1) what are the consequences of not meeting the objective (target fishing mortality), and 2) how likely are these consequences. For example, the histogram shows that the most likely value for the catch that achieves $F_{status\ quo}$ is around 210,000 mt, i.e., in the middle of the histogram. If the TAC is set at 210,000 mt then there appears to be roughly a 50% chance of the fishing mortality increasing and a 50% chance of it decreasing. Is this a bad (reckless) risk? Suppose one is risk averse and chooses a TAC of 195,000 mt instead. What would be the risk, or probability, of exceeding the target F under this quota? What yield are we giving up in order to obtain this degree of protection?

The risk of exceeding the target fishing mortality ($F_{status\ quo}$) is given by the area under the histogram to the left of the TAC chosen (Figure 2). Thus,

$$\text{Prob}(F_{achieved} > F_{target}) = \sum_{i=1}^{t} p(i) \qquad (1)$$

where p(i) is the probability mass (relative frequency of outcomes) associated with the ith bar of the histogram and t is the number of bars to the left of the chosen TAC. This probability can be computed for any value of the TAC. In practice, the risk would be computed by sorting in ascending order the 1000 catch values obtained from the simulation, and then plotting the cumulative count of outcomes less than any value of the TAC versus that value of the TAC (Figure 3). One can also derive a family of risk curves. For example, one curve could be generated for the risk of exceeding $F_{status\ quo}$ by each of several amounts. For each of the 1000 simulation runs, one computes the value of $F_{status\ quo}$ and the catch that causes current F to exceed the status quo by the specified amount. The resulting histogram of catches is summed, as in equation (1), to obtain the risk curve.

Of course, if we choose a conservative value for the TAC then we are probably passing up some of the yield we could have had while still meeting our obective. We can calculate the expected value of the potential yield forgone, assuming there is some yield to forego, as the weighted average of the yields to the right of the chosen TAC in Figure 2. Thus,

$$E(\text{potential yield foregone} \mid \text{potential yield} \geq \text{TAC selected}) = \frac{\sum_{i=t+1}^{\infty} p(i)\, y(i)}{\sum_{i=t+1}^{\infty} p(i)} - TAC_t$$

where E(·) denotes the expectation operator, the summation is over all intervals of the histogram to the right of the TAC selected (TAC_t), and y(i) is the yield associated with the ith interval of the histogram. The expected potential yield foregone can be plotted against the corresponding TAC. In practice, the expected yield foregone would be computed by sorting in ascending order the 1000 catch values obtained from the simulation, and then plotting the mean of the values greater than an observation minus the observation versus the observation, as in Figure 3. Of course, the expected value of the potential yield foregone is only one of many possible ways to describe what is given up when a conservative TAC is selected. Another possibility would be to consider the median potential yield foregone.

The manager can now choose how to trade off potential yield and risk. For example, consider the option of a TAC of 195,000 mt. The perceived risk of the fishing mortality exceeding the target mortality is about 9%. The expected value of the potential yield foregone, given that the TAC that achieves the target fishing mortality is greater than the selected TAC of 195,000, is approximately 16,000 mt. If, instead, a TAC of 200,000 mt is selected, the risk of exceeding the target fishing mortality becomes 20% and the average value of the potential yield foregone becomes 12,000 mt. Thus, an increase in the TAC of 5,000 mt would more than double the risk of increasing the fishing mortality and would reduce the expected potential yield foregone by 25%.

It remains to find a suitable event, or set of events, whose risk we wish to quantify. In the preceding, we measured the risk of increasing the fishing mortality by choosing an inappropriate TAC. This is appropriate if there is some biological or other basis for wishing to avoid an increase in fishing mortality. In general, however, it is more intuitive to quantify explicitly the risk of particular unfavorable biological or economic events. These risks will, of course, depend on the management goal that is being sought (e.g. $F_{status\ quo}$, a target spawning biomass, etc.)

Another way to present the results of the ADAPT simulations is to plot percentiles of output distributions versus the TAC selected. For example, for each ADAPT run on simulated data, one can take the estimated population size and iteratively seek the fishing mortality that will result in each of several TACs. Then, for any value of TAC one can compute the median and 2.5th and 97.5th percentiles (Figure 6).

Thus, we have two approaches which we can summarize as follows. The first approach is to select a goal or objective (such as $F_{0.1}$) and then quantify the chances of achieving that goal as a function of the TAC or effort restriction selected. The second is to quantify the consequences of choosing different quotas or effort restrictions. These approaches appear to match the thought processes of managers well. That is, a manager is likely to first ask how a specific management objective like $F_{0.1}$ can be met. A graph like Figure 5 makes it clear that there are few absolutes and that risks and costs must be balanced or traded off. The manager is also likely to want to know the consequences of picking particular quotas or effort restrictions. For example, for economic or political reasons, it may be difficult to stick with a management policy if a large quota reduction is called for. In this case, the consequences to the stock of maintaining the status quo or reducing the quota by various intermediate amounts may be of interest. A graph like Figure 6 may be helpful for this.

Biological Reference Points and Risk

Various biological reference points have been proposed. For example, in a number of fora, the concept of spawning potential ratio (ratio of current egg production to virgin egg production) is becoming incorporated in working definitions of recruitment over-fishing (Brown 1990; Goodyear 1990). A general rule that has been proposed is that the ratio should not fall below 20% otherwise the risk of stock collapse is too great.

Regardless of which biological reference point or points is (are) selected, there are three aspects to the uncertainty that must be dealt with. The first is what level of the indicator is "unsafe" (e.g. a spawning potential ratio < 20%). The second is the time frame over which the risk is postulated. For example, one might specify that spawning potential ratio should not be below 20% ever, or for two years in a row, or for more than two years out of five. The third aspect is the uncertainty inherent in the current estimate of the spawning potential ratio for the stock. For example, we believe the value of the ratio in January, 1990, was most likely between 17 and 26% with approximately uniform probability (Figure 7). Although the stock probably has a spawning potential ratio above 20%, the number of observations below 20% is not negligible.

Discussion

Managers and industry have a strong interest in maintaining stability in a fishery. Conflicts can easily arise when annual assessments give rise to point estimates of the quota required to achieve a specified goal. This is because random error in the estimates implies that annual adjustments in the quota will be proscribed even when no changes are in fact necessary.

Instead of letting the quota "float" from year to year, one can stabilize the quota and let the risks float from year to year. Thus, as long as the risks remain within certain limits, there is no need to adjust the quota. (Here, the risks can include stock collapse as well as foregone potential yield.)

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Restrepo, V.R., J.W. Baird, C.A. Bishop and J.M. Hoenig. 1990. Quantifying uncertainty in ADAPT (VPA) outputs using simulation - an example based on the assessment of cod in Divisions 2J+3KL. Presented at NAFO Special Session on Uncertainty, Halifax, 5-7 September, 1990. NAFO SCR Doc. 90/103, Ser. No. N1838.

Figure 1. Frequency distribution for estimates of total allowable catch necessary to achieve $F_{status\ quo}$ (no change in F over last year) in 1990 for 1000 simulated data sets analyzed by the ADAPT approach. Note that the current quota of 197,000 mt is well to the left of the median value suggesting strongly that we probably did not increase the fishing mortality over last year and may well have reduced it.

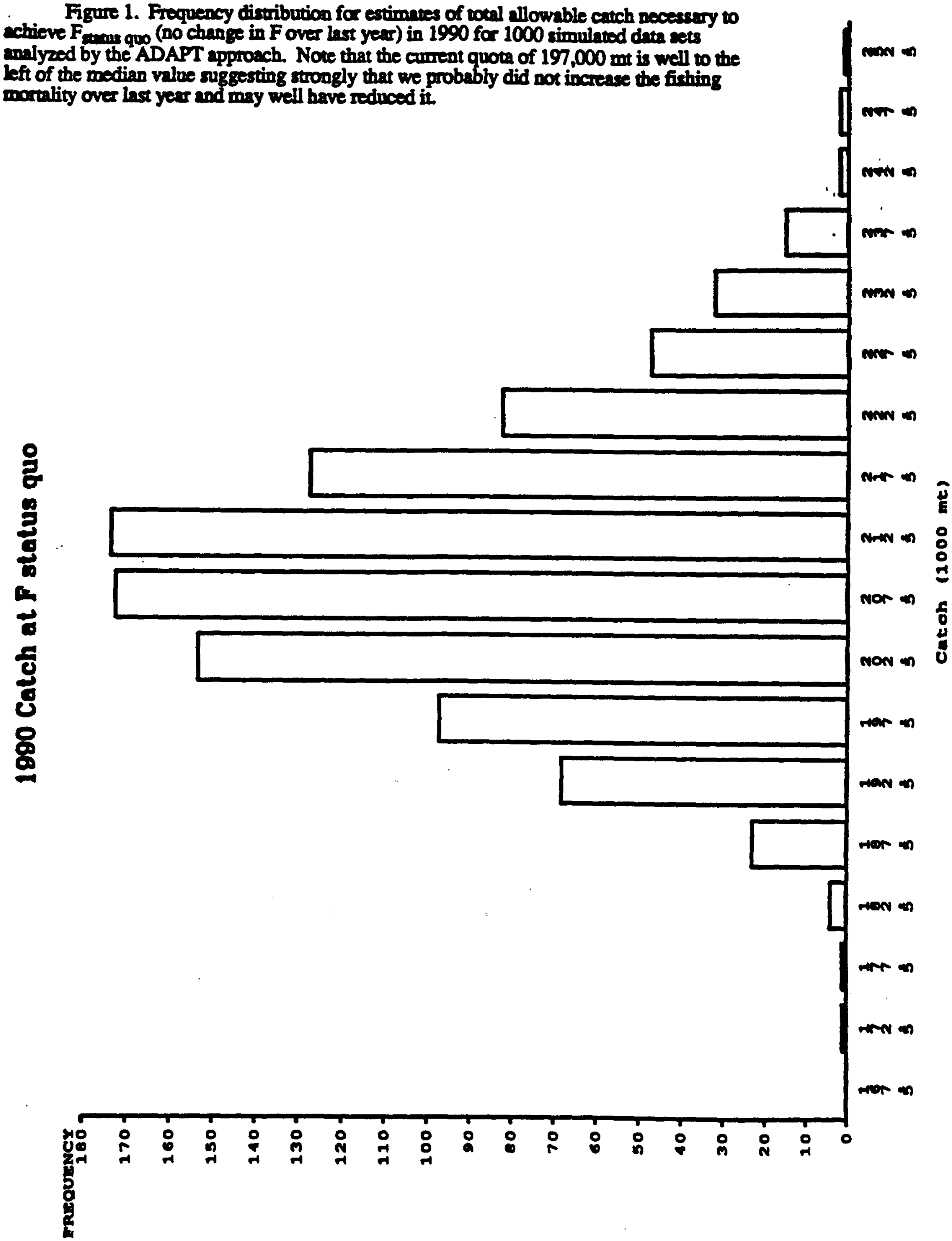


Figure 2. Same figure as Figure 1 except that ordinate is expressed as probability mass (frequency ÷ 1000). If a TAC of 195,000 mt is selected (arrow), the probability that the fishing mortality will exceed the status quo is estimated by the sum of the histogram bar heights to the left of 195,000 (i.e. the shaded portion).

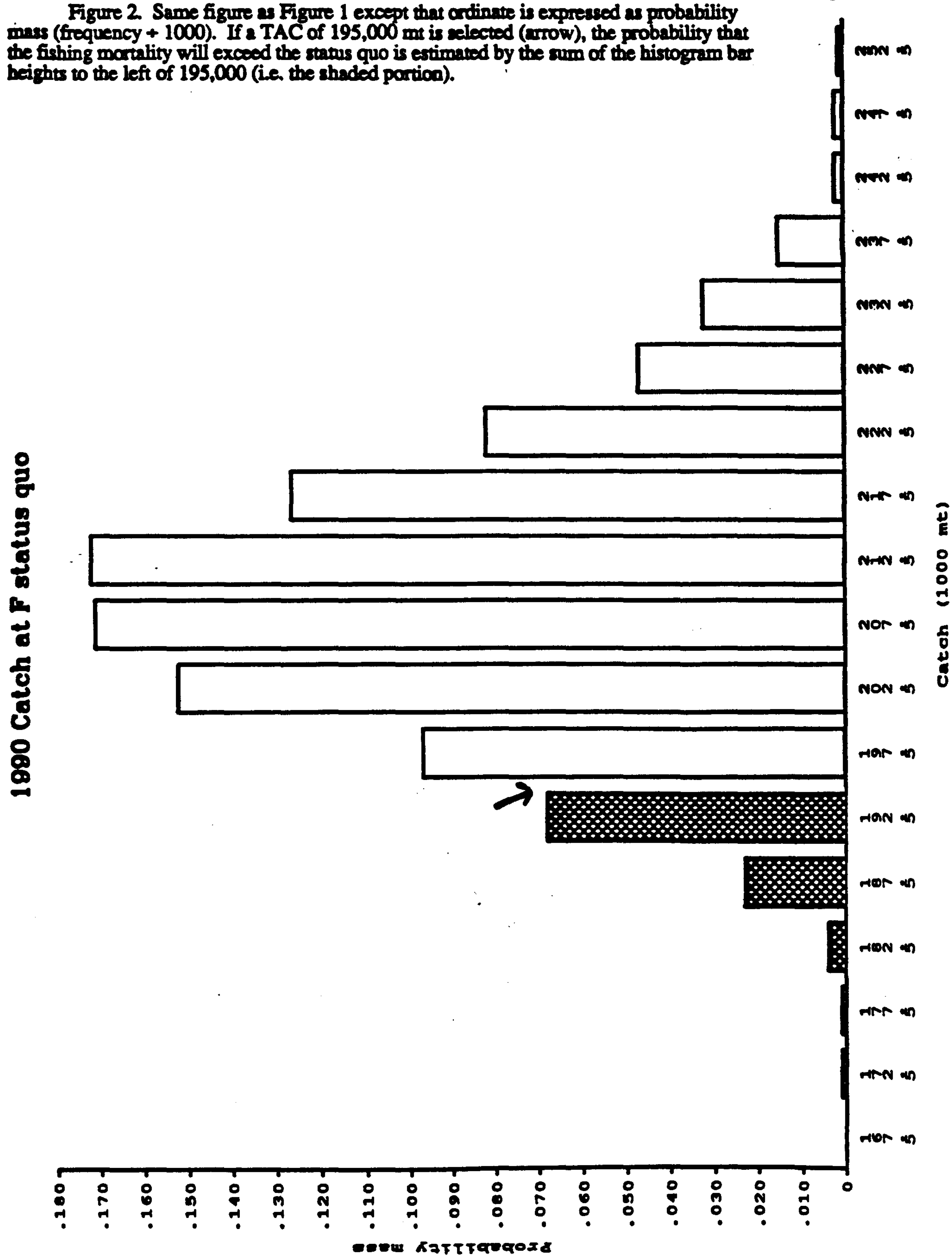


Figure 3. Probability of exceeding the status quo fishing mortality as a function of the TAC selected.

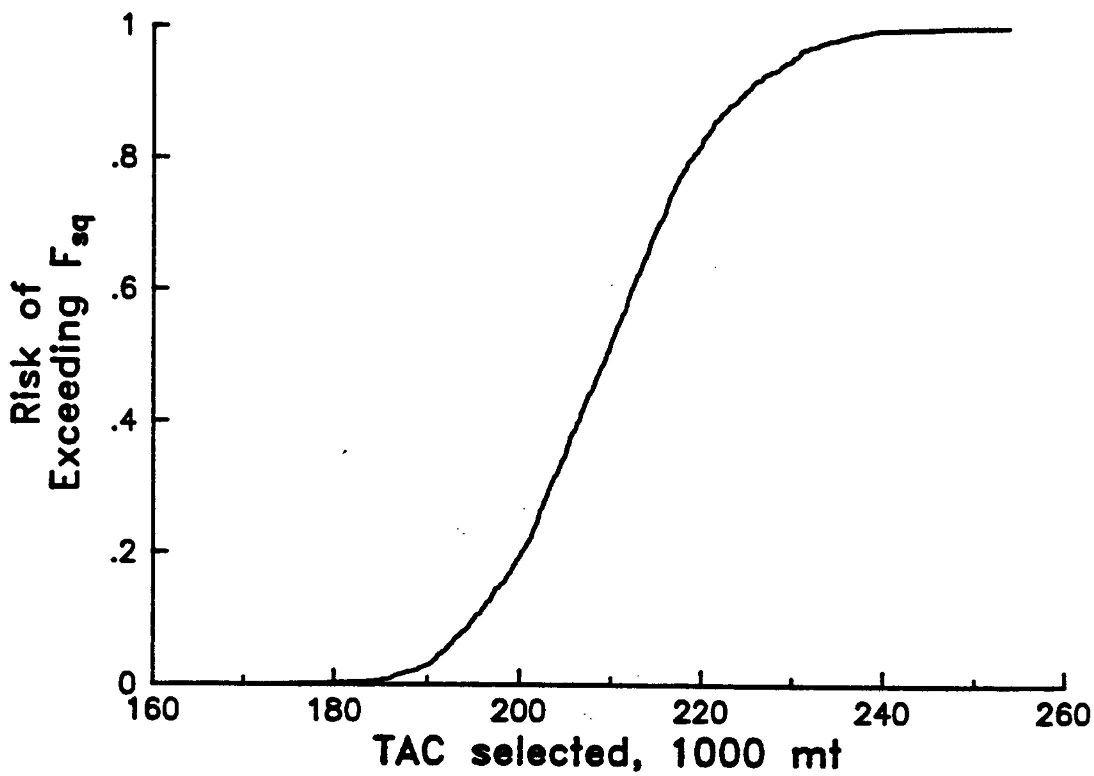


Figure 4. Same figure as Figure 1. If a TAC of 195,000 mt is selected (arrow), the expected value of the potential yield foregone is the mean of the TACs to the right of 195,000 (i.e., mean of the shaded portion).

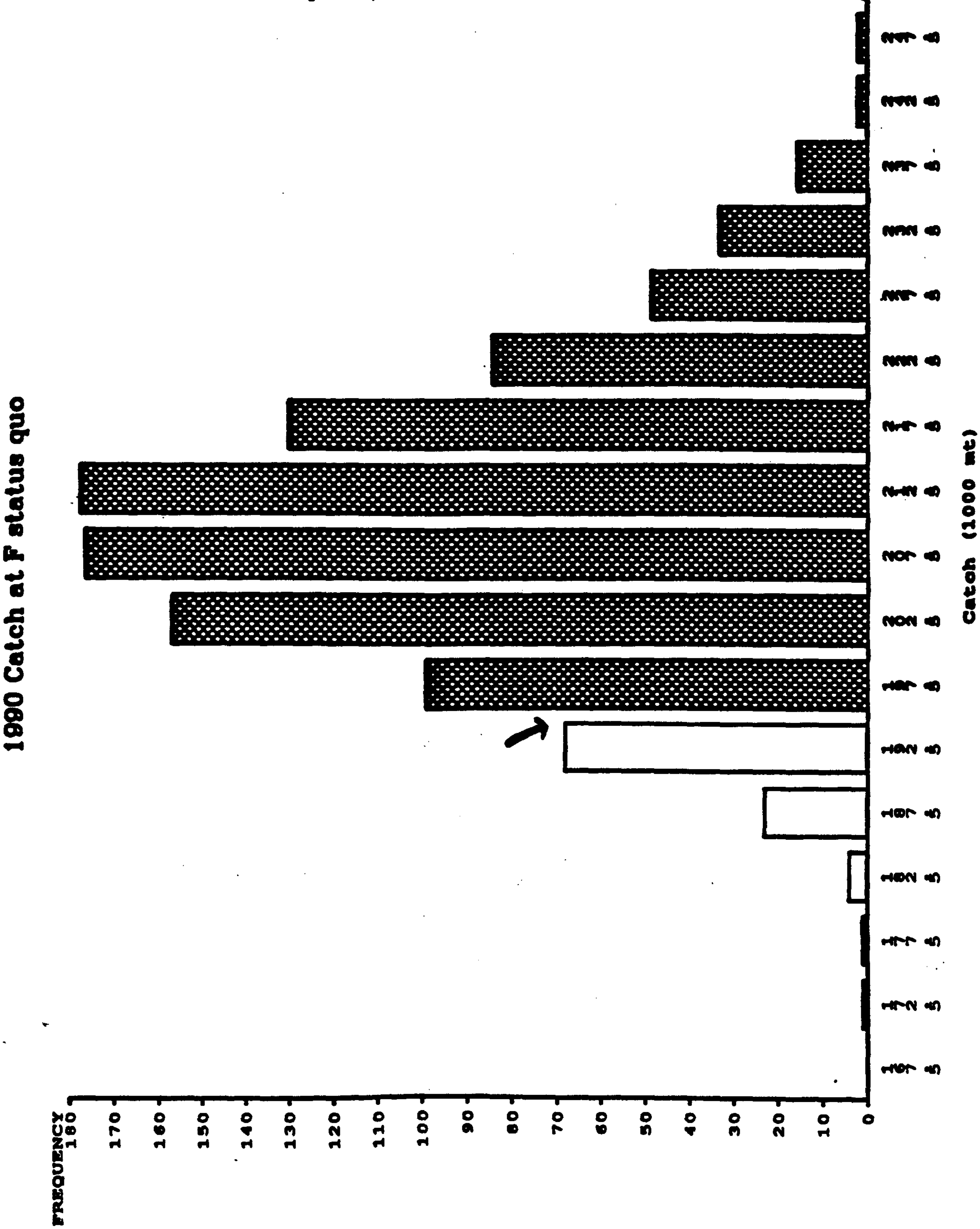
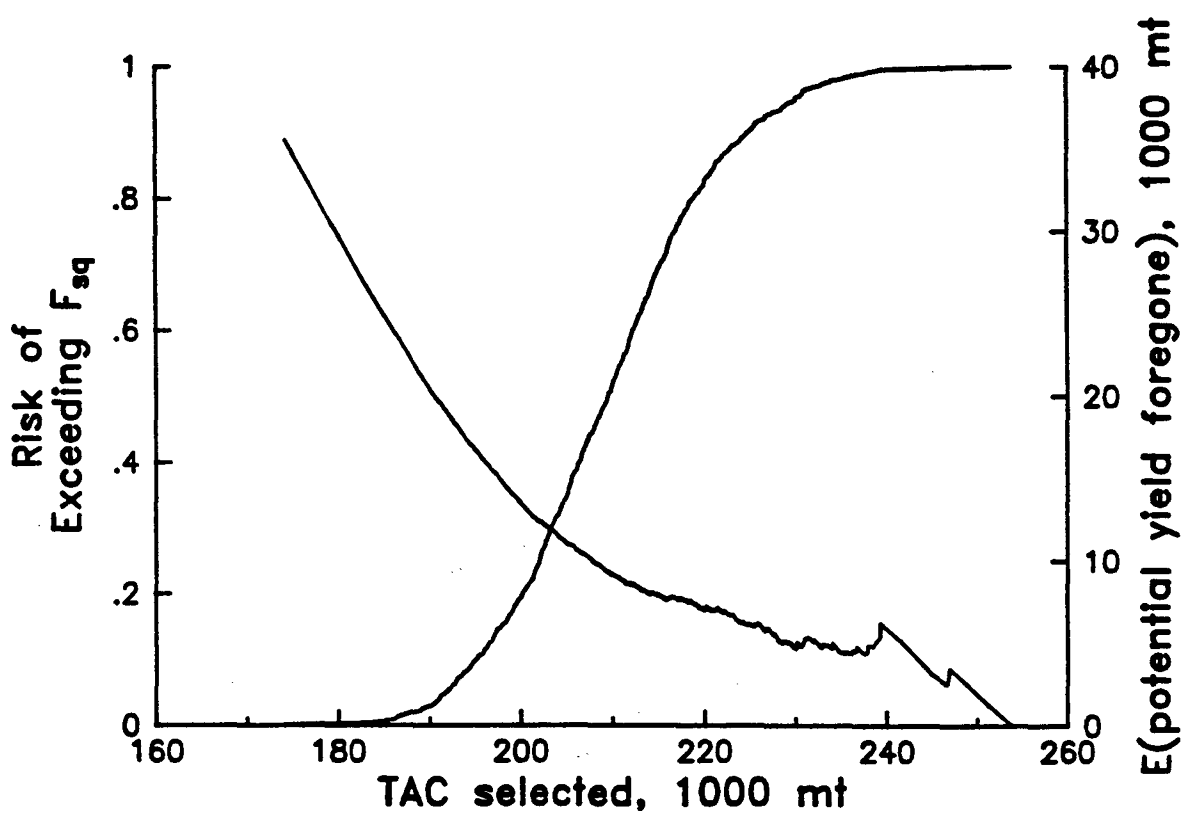


Figure 5. Probability of exceeding the status quo fishing mortality and expected value of the potential yield foregone as functions of the TAC selected.



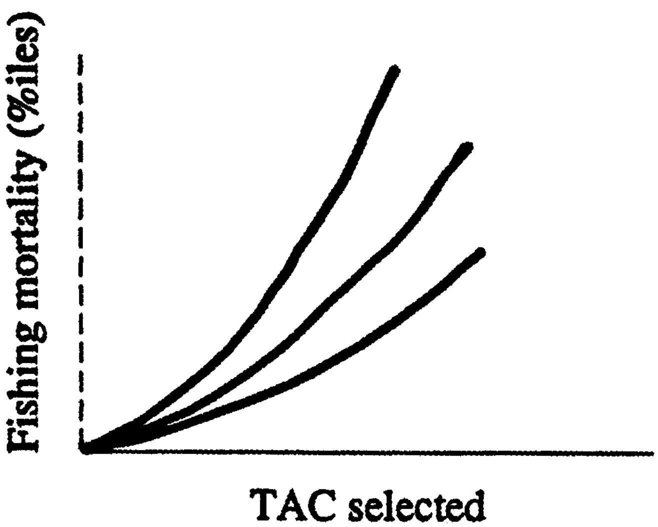


Figure 6. Hypothetical distribution of fishing mortality as a function of the TAC selected. Middle line gives the median simulated value of F; top and bottom lines give 97.5th and 2.5th percentiles, respectively (i.e., a 95% personal confidence interval).

Figure 7. Frequency distribution for estimates of spawning potential ratio (SPR) in January of 1990 for 500 simulated data sets analyzed by the ADAPT approach. It has been suggested that most stocks which have collapsed due to recruitment overfishing have had SPR values less that 0.2. The bulk of the estimates are above 0.2 suggesting that SPR is probably well above 20%; however, it is worth noting that a fair proportion of the estimates are below 20%.